History and Consequence of Keystone Mammal Eradication in the Desert Grasslands: The Arizona Black-tailed Prairie Dog (*Cynomys ludovicianus arizonensis*)

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Dedication

This work is dedicated to my father, Claude Burr Oakes,
and his grandchildren, Cloud, Jerome and Catlin.

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Don Thompson.

History and Consequence of Keystone Mammal Eradication in the Desert Grasslands: The Arizona Black-tailed Prairie Dog (*Cynomys ludovicianus arizonensis*)

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Abstract: This study examines the unintended ecological consequences of systematic prairie dog eradication practiced in the United States since 1914. The study area lies within the range of the Arizona black-tailed prairie dog in southwestern New Mexico and southeast Arizona, and northern Mexico. The study tests the hypothesis that succession is occurring on eradicated prairie dog towns, resulting in decreased grass cover and increased dominance by desert-scrub vegetation.

An historical reconstruction of the original distribution of Arizona black-tailed prairie dog colonies is presented as a series of tables and maps. Southern Arizona and New Mexico are shown to have supported more than six million acres of Arizona black-tailed prairie dogs in 1916. The extirpation of the sub-species in Arizona and New Mexico is chronicled using archival records.

Vegetation studies were conducted on living and extinct prairie dog colonies to test the hypothesis of succession. A total of 61 living and extinct dogtowns in the study area were visited and described. Comparative studies of vegetation structure were conducted on a sub-set of four living colonies, 17 extinct colonies and historical vegetation data from prairie dog towns mapped and for vegetation cover in 1917 on the USDA Jornada Experimental Range (JER).

Test 1 compared vegetation structure on living prairie dog colonies in the region today with vegetation on colonies sampled on the JER in 1917. The average vegetation structure of living prairie dog towns in the desert grassland today is shown to consist of 86% grasses, 10% forbs, and 4% woody shrubs. No difference was found between vegetation on 1917 colonies and modern, at a significance level of $p<0.01$, indicating that climate change, cattle grazing and wildfire suppression are not interfering with vegetation on active prairie dog colonies.

Long-term vegetation change was demonstrated for six sites poisoned in 1917 on the JER at $p<0.001$. Succession was confirmed in six other extinct colonies, with significance at $p<0.01$. Short-term succession was evaluated on five colonies eradicated between 23 and 35 years earlier, but no significant change was found at $p<0.001$. The combined ecological tests indicate that succession occurs on eradicated prairie dog colonies in the desert grasslands, but it is a slow process, taking more than 35 years.

Descriptive data show significant burrow erosion-and-decay and/or gulling on 23 of the 57 extinct prairie dog towns examined. These physical changes are suggested as mechanisms that produce a distinctive microterrain that may favor the increase of woody shrub vegetation on extinct colonies.

The study suggests that more than six million acres of former prairie dog towns may be undergoing succession which will ultimately transform desert grassland on former colonies to desert scrub vegetation. The statistical tests confirm long-term succession found by Weltzin *et al.* (1997a and b) in previous single-site studies. This study is limited by small sample size, limited time interval data and lack of precise dates of eradication for some sites.

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Chapter 1: Introduction

ENVIRONMENTAL-HISTORICAL GEOGRAPHY AND THE PRAIRIE DOG

James Russell Bartlett, one of the first Americans to explore the vast New Mexico Territory in 1852-53, describes a common scene along the border with Old Mexico:

> Our course today was nearly south, over a broad valley, from eight to ten miles across, hemmed in on both sides by high ranges of mountains. So level was this valley, and so luxuriant the grass that it resembled a vast meadow; yet all its rich verdure seemed wasted, for no animals appeared, except a few antelopes and several dogtowns...Here the soil was rich black loam, as it appeared where the little creatures had thrown it up, and the grass was nibbled down to its roots. (Bartlett, 1854:250-51)

Bartlett was only one of several 19th century American travelers who described the landscapes of the Southwest as having vast verdant grasslands and thick colonies of prairie dogs nibbling down all the best grasses. The landscape was paradoxical because it was a hot semi-desert receiving scant rainfall, yet the broad plains and valleys of the region grew exceptional grasslands usually associated with higher rainfall.

The juxtaposition of luxurious grass and prairie dogs was viewed as an economic opportunity being wasted on the undeserving rodents. In the opinion of American explorers, the area needed settlements and livestock to make it complete. Within 80 years Americans brought about a profound transformation of the regional zoogeography: the extensive introduction of cattle and other European livestock and the elimination of millions of acres of prairie dogs.

The Arizona black-tailed prairie dog offers a case study of the effects of an intentional zoogeographic alteration supported by utilitarian science. This small herbivore was purposefully extirpated from its range in the United States as part of federal and state mandated "range improvement" programs designed to increase beef production in the desert grasslands (Bailey, 1932; Bell, 1921). Scientific structure and agency was consistently applied to the perceived "prairie dog problem" for nearly a century, without consideration of the ecological role of prairie dogs in the desert grassland ecosystem.

The lessons of environmental history repeatedly demonstrate that altering ecological systems for human benefit can have unintended and devastating effects far beyond the knowledge of scientific experts (Simmons, 1989; Wilson, 1988; Moyle, 1986; Myers, 1984; Lovejoy, 1980, 1981; Leopold, 1949; Marsh, 1965). Environmental wisdom has been gained largely by hindsight after ecological disasters unfolded in the 20th century. There are numerous examples of the inadvertent consequences of the practice of utilitarian science, including Dust

Bowl phenomena that followed the plowing of mid-latitude grasslands in the United States and the Soviet Union, and fish-kills and wildlife loss following the introduction of potent pesticides, to mention just two (Simmons, 1989; Carson, 1962).

The indirect ecological effects of zoogeographic alterations can also have effects far beyond the intended purpose of species manipulations. For example, the introduction of predators and disease organisms into island ecosystems has resulted in significant population declines and species loss (Simmons, 1989; Wilson, 1988; Andrewartha and Birch, 1984). Drastic alteration of shoreline ecosystem dynamics and productivity occurred when sea otters and lobsters, both keystone marine carnivores, were over-harvested (Breen and Mann, 1976; Paine, 1974; Jones and Kain, 1967). Deer populations surged then crashed after predators were selectively eliminated from the Kaibab Plateau (Leopold, 1933). Reliable surface water sources and riparian habitats were lost in the American Southwest following over-harvest of beaver (Bahre, 1991; Rea, 1983).

Among the biological novelties explorers first described in Arizona and New Mexico during the Territorial Period (1849-1900) was the prairie dog. In less than a century the Arizona black-tailed prairie dog had been eliminated from grasslands in the American Southwest as an unwelcome pest (Doughty, 1986, 1983; Hoffmeister, 1986; Bailey, 1932). To scientists of the period, extermination of prairie dogs was as commendable as keeping one's house free of mice (Bailey, 1932; Jencks, 1929; Merriam, 1901).

Grasslands in the valleys and bottomlands of the Southwest proved to be fragile, however, in the face of the new conditions imposed by settlement and land use. Aldo Leopold (1924), A. L. Brown (1950), J. L. Gardner (1951) and other scientists began to note an unexpected trend beginning in the 1910s and accelerating with each decade: invasion of the grassland by undesirable brush and woody shrubs. Gardner (1951:400) decried, "...shrubs are now in possession of sites upon which Black grama grass hay was cut and baled within the memory of living residents." Range managers, cattle ranchers and farmers reported brush increases and severe gullying in numerous locations.

Today, the paradoxically verdant grasslands in the semi-desert have disappeared from many, but not all, areas, irreversibly replaced by the more characteristic desert vegetation of woody shrubs (Bahre and Shelton, 1993; Denevan, 1967; Harris, 1966; Hastings and Turner, 1965; Hastings, 1959; Branscomb, 1958; Leopold, 1924). Forgotten by residents and researchers is the earlier presence of immense colonies of Arizona black-tailed prairie dogs (Parmenter and Van Devender, 1995; Bahre, 1991; Hoffmeister, 1986; Hubbard and Schmitt, 1983). This study explores the hypothesis that vegetation change is an inadvertent consequence of the intentional elimination of this animal from the ecosystem.

Ecologists have only begun to understand that prairie dogs may be critically important to multiple interactive components of the grassland ecosystems they occupy (Weltzin *et al.*, 1997b; Archer, 1994, 1996; Parmenter and Van Devender, 1995; Whicker and Detling, 1988). Recent studies in Texas have demonstrated significant increases of woody shrub vegetation over a 25 year period after prairie dog eradication, suggesting that prairie dog eradication may either cause or contribute to vegetation change (Weltzin *et al.*, 1997a, 1997b; Weltzin, 1990).

While these studies are few in number and based on a small sample size, they are especially provocative since prairie dogs were formerly so widespread. Any pattern of vegetation change after prairie dog eradication would potentially affect large areas of the Southwest. New Mexico, for example formerly contained at least 15 million acres of prairie dog towns while today there may be less than 15,000 acres in the state (Knowles, 1998; Hubbard and Schmitt, 1983). If some or all of this area is undergoing succession from grassland to desert scrub, it would have profound ecological and economic implications. The patterns of environmental history suggest that zoogeographic tinkering of the magnitude of 20th century prairie dog eradication could have unintended ecological effects such as widespread vegetation change.

Understanding the ecological function of prairie dogs in grassland ecosystems is hampered by a paucity of historical data:

> Unfortunately, the dearth of information about pre-settlement vegetation constrains our ability to reconstruct effects of land-use activities on vegetation structure. This lack of historical perspective … can produce misleading conclusions about the causes of present-day patterns and processes (Weltzin *et al.*, 1997b:760).

This research gap occurs not only in the desert grasslands, but throughout the North American grassland biome where prairie dog populations have been reduced with little or no understanding of ecological consequences (Knowles, 1998; Miller and Ceballos, 1994; Hubbard and Schmitt, 1984). In other words, the "prairie dog problem" is one suited to historical as well as ecological study.

This study intends to fill this void by accomplishing four tasks. In this research, I use methods of historical geography to document the distribution and population of Arizona black-tailed prairie dogs in the study area in the late 19th and early 20th centuries. I then document the trajectory of local and regional prairie dog eradication. The study establishes a baseline of characteristic vegetation structure on living prairie dogtowns in the desert grasslands using historical and current ecological data. And this research presents ecological data from 61 extinct and living colonies, demonstrating that prairie dog eradication has been a significant causal factor in vegetation change in the desert grassland ecotone.

The subject of this research is not prairie dogs *per se*, but the loss of the unique ecological activity of this keystone organism. The study focuses on prairie dog towns as the biogeographic unit of study, and combines a cultural-historical with an ecological approach to explore the consequences of eradication. In this study I demonstrate that prairie dogs are keystone to the desert grassland ecosystem, and that their eradication has brought about grassland degradation, increases of woody shrub vegetation and desertification--the very antithesis of the effects envisioned by scientists only a few generations ago.

STUDY AREA

Lying within the Chihuahuan Biogeographic Province the study area encompasses approximately 94,000 square kilometers (36,293 square miles) of Arizona, New Mexico, Chihuahua and Sonora (Figure 1.1). It is bounded on the east by the Sacramento Mountains, on the north by the Gila River and the northern boundaries of Sierra and Grant counties, on the south by Nuevo Casas Grandes, and on the west by the Patagonia Mountains.

This area was selected for three reasons. First, there is a substantial historical record of early vegetation structure and long-term vegetation change due to the presence of two U.S. Department of Agriculture (USDA) experimental ranges devoted entirely to scientific research. The Santa Rita Experimental Range (SRER), with 20,000 hectares (49,420 acres) located 40 km (24.84 miles) south of Tucson, Arizona, was set aside by the federal government in 1903 as a range research facility (McClaran, 1995). The Jornada Experimental Range (JER) is a 78,000-hectare (192,738 acre) research range near Las Cruces, New Mexico, that was established in 1912 (Buffington and Herbel, 1965). These USDA ranges and other nearby large land holdings provided physical access to their properties, as well as archival research data (Figure 1.2).

In addition, this study area contains both living dogtowns and areas where the animals have been completely extirpated for many years—making comparative studies possible. Although systematic extermination programs in New Mexico and Arizona eliminated most black-tailed prairie dogs from the region north of the

Figure 1.1 Study Area

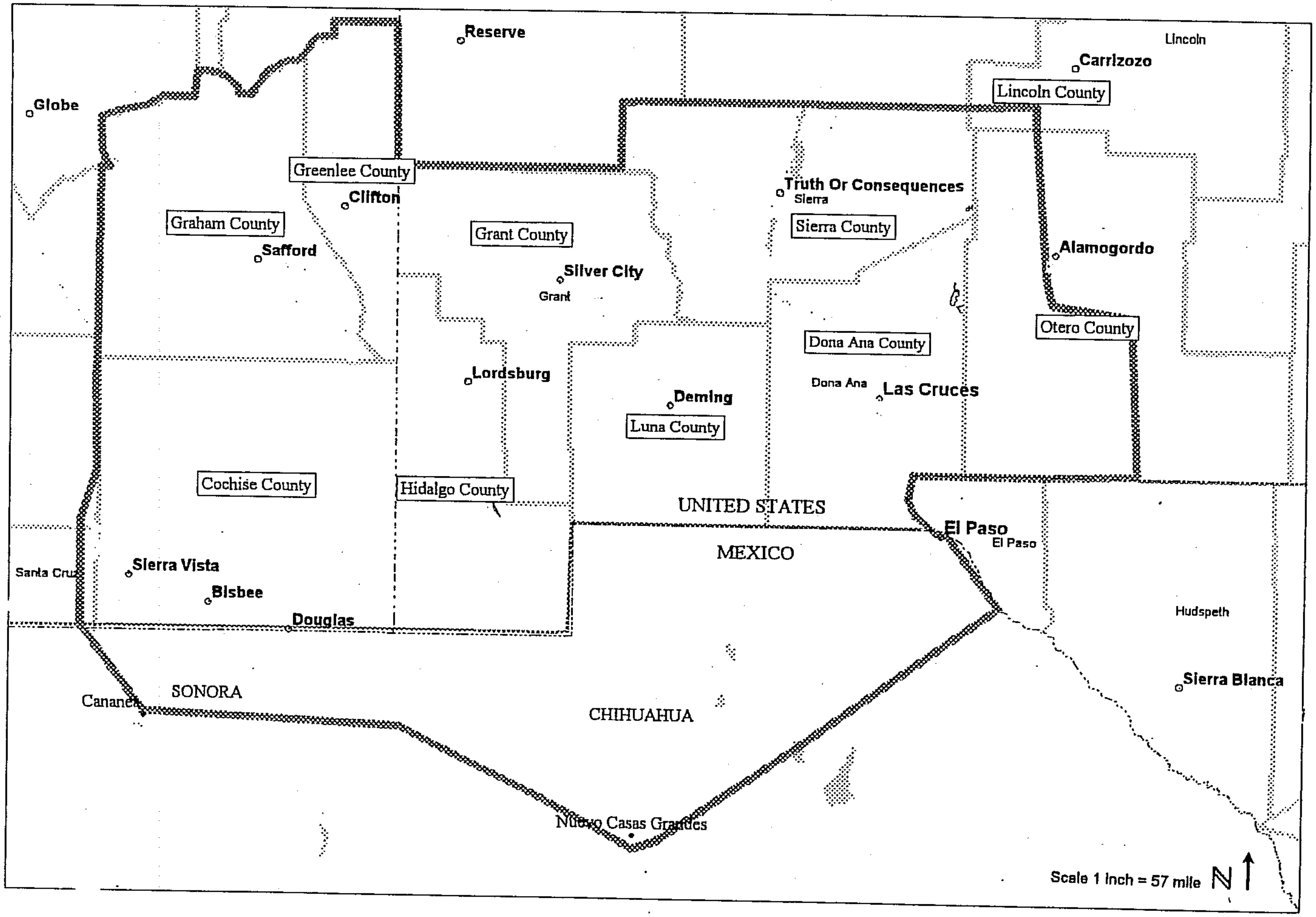
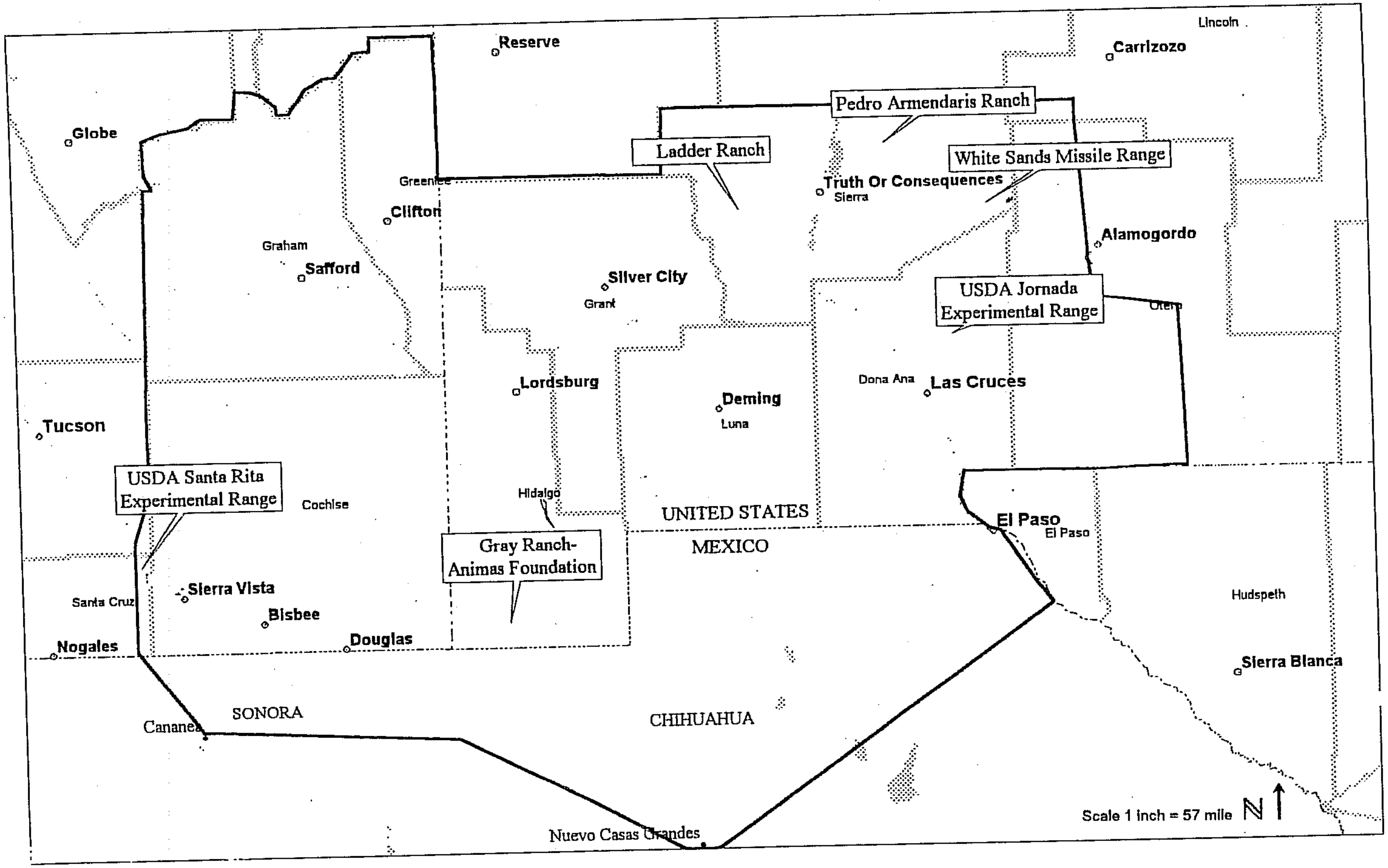


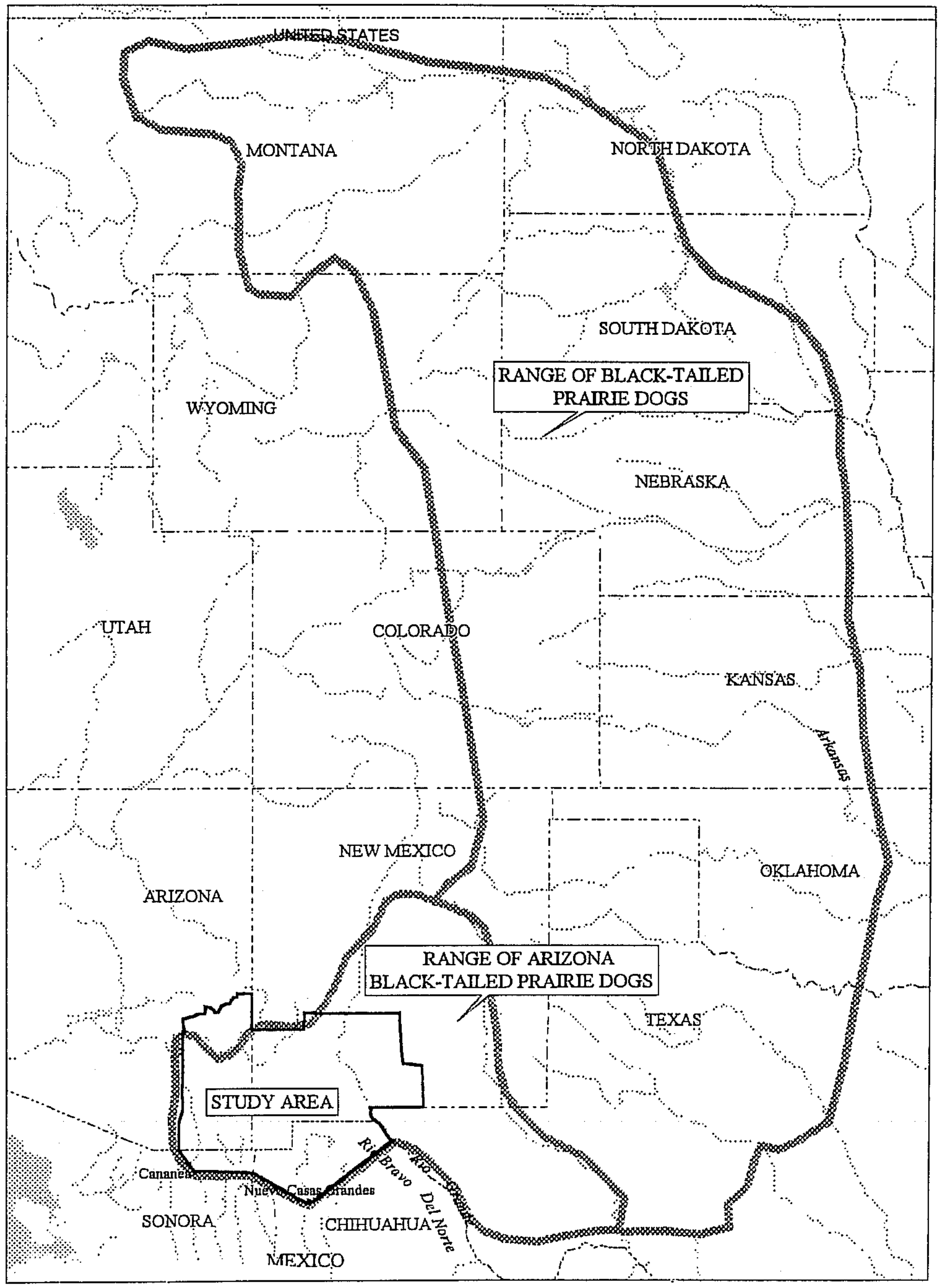
Figure 1.2. Locations of USDA Experimental Ranges and Other Large Land Holdings Used in the Study.



international border, efforts to poison prairie dogs in Mexico have not been as thorough, leaving several large colonies in nearby Chihuahua and, to a lesser extent, in Sonora, Mexico (Miller and Ceballos, 1994).

A final reason for selecting this area for study is that the presence of the Arizona black-tailed prairie dog as a taxonomic group distinct from other black-tailed prairie dogs generated considerable scientific interest between 1890 and the early 1930s. Mammalogists made a specific effort to visit the study area in order to collect specimens or otherwise study the unique animals, making historical records for this taxonomic group more comprehensive than other geographic areas (Hollister, 1916; Mearns, 1907). The study area lies in the southwestern half of the natural range of the Arizona black-tailed prairie dog, as shown in Figure 1.3.

Figure 1.3. Relationship of the study area to the original range of black-tailed prairie dogs and Arizona black-tailed prairie dogs (Source: Hollister, 1916).



ECOLOGICAL CONTEXT

The Chihuahuan Biogeographic Province

The Chihuahuan Biogeographic Province is defined on the basis of biotic structure and function (Brown, 1994; Bailey, 1978; Uvardy, 1975). Although specific descriptions and exact boundaries vary from one author to another, all agree that an important characteristic of the province is that it contains a complex mosaic of vegetation types: desertscrub, desert grasslands, plains grasslands, and evergreen woodlands (Brown, 1982).

The base elevation of the study area is 1,100 to 1,400 meters (3,609 to 4,593 feet) where desert grasslands and Chihuahuan desertscrub vegetation dominate. At elevations above 1,500 meters (4,922 feet), Madrean evergreen woodlands are interspersed with occasional stands of short-grass prairie. The landscape also includes high mountain peaks and riparian corridor habitats that add to the diversity of the physical environment (Brown, 1982).

At lower elevations, the desert grassland forms a complex contact zone, or ecotone, with Chihuahuan desertscrub. This ecotone is dynamic and complicated by two ecosystems which have considerable overlap in species composition but differ primarily in the dominance of grass versus woody plant species (McClaran, 1995; Dick-Peddie, 1993; Brown, 1994). In fact, it is this contact zone between desert grasslands and desertscrub that is undergoing dramatic vegetation change and desertification (Grover and Musick, 1990; Dick-Peddie, 1986; Humphrey, 1987).

Desert Grassland

The desert grassland is the focal plant community in this study because it has historically shown dramatic vegetation change and because black-tailed prairie dogs were formerly abundant there (Hubbard and Schmitt, 1983; Doughty, 1983; Buffington and Herbel, 1965). Desert grasslands are, however, poorly understood and subject to many different scientific interpretations. Accordingly, some background discussion is helpful.

The study area lies at the southwestern boundary of the shortgrass prairie, represented by a desert grassland community dominated by perennial bunch-grasses with minor components of annual herbaceous plants and woody scrub vegetation (Burgess, 1995; Brown, 1994; Schmutz *et al.*, 1991; York and Dick Peddie, 1969; Dick-Peddie, 1965; Buffington and Herbel, 1965). Also called semidesert or mesquite grasslands, these ecosystems are composed of a mixture of grasses including grama (*Bouteloua* spp.), tobosa (*Pleuraphis* spp.), three-awn (*Aristida* spp.), and bluestem (*Andropogon* spp.). The characteristic bunch grasses are interspersed with forbs and occasional woody shrubs at a relative density of less than 25% (McClaran, 1995; Brown, 1994; Dick-Peddie, 1993). Woody shrubs include snakeweed (*Gutierrezia* spp.), mesquite (*Prosopis glandulosa*), tarbush (*Flourensia cernua*), yucca (*Yucca* spp.), cholla (*Opuntia* spp.), creosote bush, four-winged salt bush (*Atriplex* spp.) and others. Velvet mesquite (*Prosopis velutina*) occurs only on the western fringe of the study area.

Although boundaries between biological communities are sometimes quite distinct, neighboring communities often exert great influence on one another, resulting in blurred transition zones called ecotones. Boundaries between grasslands and adjacent communities of desertscrub are frequently ecotonal. In fact, desert grasslands have only recently been recognized as a special biological community distinct from either of its component terms (Burgess, 1995; McClaran, 1995; Gross and Dick-Peddie, 1979; Buffington and Herbel, 1965).

Historically, North American biologists have had difficulty in formulating a conceptual framework for arid environments (Burgess, 1995). Early biological classification systems defined homogeneous vegetation formations in the American Southwest as either montane forest, grassland, or desert communities. The vegetation classification systems of the early 1900s emphasized two biomes with the greatest familiarity and economic importance: forests and grasslands (Burgess, 1995; Brown, 1993; Shreve, 1942; Clements, 1936). Classification systems were also biased by the idealistic concepts of succession and stable climax communities determined by climate (Schmidt, 1979; Carpenter, 1940; Clements and Clements, 1924). Woody shrubs, such as mesquite, yucca, and four-winged salt bush, which coexisted in a grassy matrix from southern Arizona east through Texas were explained away as a savanna (Clements and Clements, 1924:316).

Biologists routinely undervalue shrub components of the biological community, describing them as recent and undesirable invaders (Whitfield and Beutner, 1938; Harris, 1965), indicative of a depleted range condition in need of restoration (Buffington and Herbel, 1965; Whitfield and Beutner, 1938;), or an ecotone between true desertscrub and true grasslands (Clements, 1963; Shreve, 1942; Carpenter, 1940). There is ample evidence, however, that woody shrubs have always been a component of the desert grassland ecosystem (Burgess, 1995; Bahre and Shelton, 1993; Dick-Peddie, 1993; Schmutz *et al.*, 1991; Brown, 1982).

This study follows the premise of Burgess (1995) who asserts that desert grasslands are a unique and dynamic mixture of growth forms (grasses and shrubs) which respond to temporal fluctuations in climate and various topodeaphic factors and environmental disturbances. Desert grasslands exit in Arizona, New Mexico and Texas and over large areas of Mexico, east of the Continental Divide (McClaran, 1995; Brown, 1982).

Desert grasslands occur as disjunct patches within the basin-and-range topography, as opposed to the much more extensive short-grass and mixed grass prairies of the High Plains (Brown, 1982). Desert grasslands are only slightly wetter and cooler than deserts (Burgess, 1995; Schmutz *et al.*, 1991). They receive rainfall in both winter and summer, usually between 6 and 12 inches per year, and achieve the lowest total biomass production of any North American grassland (Burgess, 1995; Brown, 1994).

The woody component of the desert grassland consists of the same species represented in nearby desertscrub communities, but in lower density, usually less than 10%. Forbs and small perennials also coexist with grasses, and their relative abundance may vary temporally in response to cyclic rainfall patterns (Burgess, 1995). Topoedaphic factors, such as slope, aspect and soils, greatly influence the particular biological community. Communities may respond to human-induced factors such as grazing and mowing (Dick-Peddie, 1993; Buffington and Herbel, 1965).

Generally ecotones and transitional ecosystems have been ignored in scientific studies since they are neither homogeneous nor representative of a single community. The study of ecotones as separate and dynamic phenomena at a landscape scale or smaller scales is a relatively recent development (Risser, 1995; Grosz, 1992; Grover and Musick, 1990). Grosz describes a hierarchy of ecotones and their contributing factors. He defines "landscape" ecotones as a mosaic of vegetation types resulting from topoedaphic variations in the landscape, while "patch" ecotones are the result of localized soil characteristics, biological vectors, species interactions, microtopography and microclimatology (Grosz, 1992). In this study, I am interested in the possibility that prairie dog towns are themselves disturbance-related patch ecotones within the landscape ecotone of the desert grassland.

The Arizona Black-tailed Prairie Dog

Based on samples studied by Edgar Alexander Mearns in 1890, the Arizona black-tailed prairie dog (*Cynomys ludovicianus arizonensis*) was first identified as a sub-species of the black-tailed prairie dogs of the Great Plains (*Cynomys ludovicianus*). Mearns' investigation of the animals of southern Arizona and southern New Mexico led him to assign the separate systematic classification based on his observations that this was the largest of the black-tailed prairie dogs, with brighter fur color and broader frontal face bones than the prairie dogs of the Great Plains described earlier by Ord and Rafinesque in 1815-1817 (Mearns, 1907).

Hollister (1916) confirmed this opinion in his systematic account of prairie dogs based on 876 specimens, including 184 Arizona black-tailed prairie dog specimens. He described two species of black-tailed prairie dogs of the genus *Cynomys*: *C. ludovicianus* and *C. Mexicanus*, the Mexican black-tailed prairie dog. He further divided *Cynomys ludovicianus* into two sub-species: *C. l. ludovicianus*, the plains black-tailed prairie dog, and *C. l. arizonensis*, the Arizona black-tailed prairie dog (Hollister, 1916: 14-16).

This was the established taxonomy of the genus *Cynomys* during the entire period of systematic eradication (Hoffmeister, 1986). Taxonomic studies of the Arizona black-tailed prairie dog conducted in the 1970s and 1980s have cast some doubt on the validity of recognizing two sub-species of *Cynomys ludovicianus* (Pizzimenti, 1975; Chesser, 1983). These studies are limited by small sample sizes, skewed sex ratios, or lack of samples representative of populations west of the Rio Grande (Frey, 1997; Hubbard and Schmitt, 1983). A definitive genetic analysis of the species is sorely needed in light of regional extirpations and recent re-introduction initiatives (Frey, 1997:5; Hubbard and Schmitt, 1983). In this study I use the nomenclature developed by Hollister to make a particular point: scientists accepted the taxonomic uniqueness of the Arizona black-tailed prairie dog but failed to protect these animals in the United States.

The Prairie Dog as a Keystone Species

Black-tailed prairie dogs are important members of the vertebrate food-web within North American grassland ecosystems (Miller *et al.*, 1990; Sharps and Uresk, 1990; Whicker and Detling, 1988). As the number of ecological studies of prairie dogs has increased, a broader interpretation of their role in the grasslands has come about, and they have been suggested as a keystone species (Weltzin *et al.*, 1997b; Miller and Ceballos, 1994).

A keystone species is one whose effects on other organisms is disproportionately large and for which there is no alternative or redundancy within the ecosystem (Westman, 1990; Paine, 1974). Its ecological role is likened to an architectural keystone that holds a complex masonry arch together through balanced forces of nature. The critical role that a keystone organism plays in an ecosystem, like the architectural analogy, often goes unnoticed until it is removed and the support system collapses. Elimination of the keystone species produces a cascade of effects that reduce ecological diversity and productivity, leaving a degraded ecosystem (Power *et al.*, 1996:612; Mills, Soule and Doak., 1993; Paine, 1969).

Recently, ecologists have attempted to clarify the concept of keystone species (Power *et al.*, 1996; Mills, Soule and Doak., 1993). Some purported keystone interactions have proven to be weak and relatively unimportant in portions of the species range or under certain habitat conditions. Furthermore, there is a lack of precision in application of the term and it has come to mean different things to different researchers (Power *et al.*, 1996; Mills, Soule and Doak, 1993). A major theoretical revision, published by several authors in 1996, clarifies the concept and focuses on the strength of an organism's direct and indirect ecological interactions (Power *et al.*, 1996). This research proposes an index of "community importance" that measures the strength of the effect of a species on ecosystem characteristics.

This revised keystone concept emphasizes that "a community characteristic decreases after the species is deleted" (Power *et al.*, 1996:611). Two basic approaches are suggested to determine the community importance of a suspected keystone species: experimental removal of the potential keystone species, or comparison of habitats with varied densities of the species. Research into the keystone role of prairie dogs has used the former strategy (Weltzin *et al.*, 1997a, 1997b).

There are several classes of keystone species: predators (consumers), prey (resource species), mutualists (seed dispersal agents), and habitat modifiers (dam-building or burrowing animals) (Heske, Brown and Mistry, 1994; Mills, Soule and Doak, 1993; Chew and Whitford, 1992; Mielke, 1977). Most keystone interactions that have been studied are based on some aspect of consumption including predation, and herbivory. For example, pika (*Ochotona princeps*) and snowshoe hares (*Lepus americanus*) are considered keystone to tundra and alpine ecosystems because of their selective consumption of tree bark and subalpine vegetation that keeps certain plant populations in check (Huntly and Inouye, 1988; Huntly, and Inouye 1987; Huntly, 1987).

Another source of strong community interactions can occur from burrowing and other biophysical modifications that create conditions for a suite of disturbance-related processes (Power *et al.*, 1996). Pocket gophers (*Geomys bursarius* and *Thomomys bottae*) have been proposed as keystone species because of their ground disturbance as well as their consumption of underground plant tissue (Huntly and Inouye, 1988; Mielke, 1977). Seed consumption as well as burrowing and ground disturbance interactions of kangaroo rats (*Dipodomys* spp) increases their community importance (Brown and Heske, 1994; Chew and Whitford, 1992).

The evidence that prairie dogs are a keystone species for grassland ecosystems is threefold:

1) prairie dog colonies are different from nearby off-colony sites in important ecosystem functions such as nutrient cycling, soil moisture content and porosity, and below-ground energy and material flow (Stapp, 1998; Whicker and Detling, 1988; Archer *et al.*, 1986),
2) the presence of a prairie dog colony directly and indirectly affects the structure and abundance of floral and faunal functional groups (Davidson *et al.*, 1999; Agnew *et al.*, 1986; O'Melia *et al.*, 1982; Ingham and Detling, 1984), and
3) rapid and measurable ecosystem change has been documented on a grassland community after removal of prairie dogs (Weltzin *et al.*, 1997a, 1997b).

Important ecological functions are distinctly different on prairie dog colonies compared with off-colony sites. Prairie dog towns have higher soil moisture content despite heavy grazing (Archer and Detling, 1985). Prairie dogs mediate nutrient cycling between the soil and plants so that vegetation on colonies has a significantly higher above-ground nitrogen yield than that on uncolonized areas (Whicker and Detling, 1988; Archer *et al.*, 1987; Archer and Detling, 1986;

Cappock *et al.*, 1983b). Prairie dog grazing does not reduce above-ground net primary productivity, even under heavy grazing pressure, possibly due to greater water availability, and more rapid nutrient cycling (Whicker and Detling, 1988; Vitousek, 1985; Cappock *et al.*, 1983a).

Below-ground processes of energy and material flow were altered on prairie dog colonies, as well. One study shows a 40% decrease in annual net root production on a prairie dog colony (Ingham and Detling, 1984). The burrow system and entrance mounds represent tremendous soil mixing and the creation of distinctive microhabitats above and below ground (Stapp, 1998; Whicker and Detling, 1988; O'Meilia *et al.*, 1982; Sheets *et al.*, 1971).

Prairie dog towns also differ in vegetation structure, species composition and abundance compared with uncolonized prairie areas. The below-ground nematode density of prairie dog colonies on the mixed-grass prairie is higher than on surrounding areas resulting in increased root grazing (Cappock *et al.*, 1983a; Ingham and Detling, 1983; Detling and Painter, 1983). Prairie dog towns alter the vegetation composition of the mixed-grass and short-grass prairies (Whicker and Detling, 1988; Krueger, 1986; Agnew *et al.*, 1986; Cappock *et al.*, 1983a and 1983b; Bonham and Lerwick, 1976; Koford, 1958). Canopy height and standing biomass is lower and the percentage of forbs is higher on colonies (Bonham and Lerwick, 1976; Koford, 1958). Plant cover and nutritional content is also significantly higher (Krueger, 1986).

The rate of change in vegetation after colonization by prairie dogs is rapid and "dwarf" morphs of grass species increase under selective pressure from prairie dog grazing (Archer *et al.*, 1987; Detling and Painter, 1983). Research in the mixed-grass prairie of north Texas shows that prairie dogs destroy mesquite seeds and seedlings and suppress the growth of older mesquite plants by continuing to gnaw them to the ground (Weltzin *et al.*, 1997b). Further studies indicate that prairie dogs and their associated fauna substantially alter the relative distribution, abundance and composition of herbaceous vegetation (Weltzin *et al.*, 1997a).

In addition to flora, fauna is also greatly affected by the presence of prairie dog colonies. Bison (*Bison bison*), elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*) preferentially feed on prairie dog towns where nutrient flow is enhanced (Krueger, 1986; Wydeven and Dahlgren, 1985; Cappock *et al.*, 1983b). Rodent population densities are higher on dogtowns, but diversity is lower (Agnew *et al.*, 1986). Avian density and species richness were significantly greater on prairie dog towns than on uncolonized prairie (Agnew *et al.*, 1986). Arthropod biomass decreased on prairie dog towns in one study (O'Meilia *et al.*, 1982). Prairie dogs increase microhabitat heterogeneity with burrows and mounds, providing nesting opportunities for other species, such as burrowing owls (*Athena cunicularia*) and mountain plover (*Charadrius montana*) (Hoogland, 1995; Hubbard and Schmitt, 1983).

The role of the dogtown in attracting numerous ungulates and birds, also enhances them as sites frequented by various predators. Major predators known to frequent dogtowns include the American badger (*Taxidea taxus*), bobcat (*Felis rufus baileyi*), coyote (*Canis latrans*), long-tailed weasel (*Mustela frenata*), black-footed ferret (*Mustela nigripes*), foxes (*Vulpes* spp.), diamondback rattlesnakes

(*Crotalus* spp.), golden eagle (*Aquila chrysaetos*), peregrine falcon (*Falco peregrinus*), prairie falcon (*Falco mexicanus*), Cooper's hawk (*Accipiter cooperii*), and red-tailed hawk (*Buteo jamaicensis*) (Hoogland, 1995; Campbell *et al.*, 1987; Hubbard and Schmitt, 1983; Scheffer, 1945).

Thus, the living prairie dog colony is a "patch" of distinctive flora and fauna, microhabitats and ecological processes. The *active dogtown* is keystone to the ecosystem, not individual prairie dogs.

The third compelling aspect of prairie dog ecology is evidence for "post-eradication biogeographic change" that matches the criteria developed for identifying keystone species. Evidence that there is substantial post-keystone vegetation change on extinct prairie dog towns has been slowly growing ever since federal biologist Vernon Bailey complained that prairie dog towns became grown-over with worthless weeds after they are poisoned (Bailey, 1932). A 1949 study from the mixed-grass prairie of Oklahoma examined the vegetation on a prairie dog colony poisoned incrementally over several decades (Osborn and Allen, 1949). This study showed a pattern of succession in the form of concentric circles of vegetation consisting of mat forbs and prairie threeawn grass in the most recently abandoned zones, followed by an assemblage of threeawn with mixed forbs or threeawn with perennial grasses in the areas poisoned in 1926, and finally big bluestem and switch grass in the areas that had been empty the longest (Osborn and Allen, 1949). This was in a region without woody species, and thus no opportunity for colonization by shrubs.

In 1958, Koford found that prairie dog mounds, normally kept in a denuded state, were rapidly colonized by forbs after prairie dog removal (Koford, 1958). Although not very dramatic, the study indicates that change occurs when prairie dogs are removed and that succession may result. Koford's work is contradicted by a study in 1978 on one living and three extinct black-tailed prairie dog colonies on the short-grass prairie which shows that the absolute cover of annual forbs, perennial forbs and grasses all declined after prairie dogs were poisoned (Klatt and Hein, 1978). This was not good news to the proponents of prairie dog control who had been arguing for more than 50 years that extermination produced increased grass cover.

A recent study examined a prairie dog town poisoned in 1950 on the mixed-grass prairie of north-central Texas. Changes in canopy cover were measured using aerial photos 1950, 1963 and 1973 and compared with 1990 vegetation samples taken from the site (Weltzin *et al.*, 1997b). The results of the study showed that the original colony had 27% mesquite canopy at the time it was poisoned compared with 64% mesquite cover outside of the colony. Mesquite stands developed rapidly after prairie dogs were poisoned, showing a 61% density by 1973. The 1990 density of mesquite was higher on the former colony than the off-colony control site (Weltzin *et al.*, 1997b; Archer, 1993).

Weltzin *et al.*(1997b) conclude that prairie dogs act as keystone species in situations where woody shrubs would otherwise be competitive dominants over grasses. They also conclude that prairie dogs control woody shrubs on their colonies by an active process of clipping the shrub seedlings down. The results of their study, while provocative, are based on only a single eradicated colony. With such a small sample, these results merely suggest but cannot confirm a pattern of succession on eradicated prairie dog towns. The authors state that greater knowledge of historical prairie dog distributions will be required to further test their hypothesis.

Together, these studies indicate that prairie dog towns are patch ecotones with specialized patterns of nutrient cycling, water retention, soil microorganism composition, vegetation composition and invertebrate and vertebrate fauna of the prairie grasslands. Prairie dogs provide a cascade of effects which are felt at many trophic levels, and, by extension, there is a cascade of ecosystem effects on the prairie dog town when they are removed. Few studies have examined the ecological role of prairie dogs on the desert grassland ecotone, and to date, no studies have been conducted on the effects of their removal in a transitional ecotone where woody shrubs co-occur with grasses.

All of these characteristics combine to make desert grasslands dynamic in the face of environmental change and ideal for this study. It is clear from different descriptions of the desert grasslands that they may exhibit both landscape level ecotone characteristics, and patch ecotones of adjacent vegetation types within them. If there are ecological consequences to widespread prairie dog eradication, they can be expected to manifest themselves most clearly in the unstable co-occurrence of life-forms on the desert grassland.

Research at the southwestern edge of the prairie ecosystem is useful since ecotone boundaries are especially sensitive to ecological perturbation. Early extirpation of prairie dogs and their disturbance regime in the desert grassland may have resulted in directional changes in bio-physical processes and vegetation patch dynamics (Hubbard and Schmitt, 1983; Miller *et al.*, 1994).

The fundamental hypothesis of this study is that early extirpation of Arizona black-tailed prairie dogs and their disturbance regime from the desert grassland ecotone has altered below-ground and above-ground processes, ultimately leading to the increase in woody species and decrease in grass density. I predict that the greatest directional change will be observed on prairie dog colonies that have been eradicated for the longest time, and that living prairie dog towns will show the lowest density of woody shrubs.

PREVIOUS RESEARCH INTO THE CAUSES OF VEGETATION CHANGE IN THE DESERT GRASSLANDS

Evidence for Vegetation Change

Aldo Leopold (1924) first noted in 1924 that in the American Southwest, "brush is taking over the country". The issue became increasingly problematic for cattlemen whose productive range grasses were declining, and the subject began to dominate scientific publications as range managers, geographers and biologists investigated the causes of vegetation change in the desert grasslands (Bahre, 1991; Bahre and Bradbury, 1978; Cable and Martin, 1973; York and Dick-Peddie, 1969; Harris, 1966; Hastings and Turner, 1965; Buffington and Herbel, 1965; Bransconb, 1958; Leopold, 1951b; Brown, 1950).

Table 1.1 reviews the previous research on vegetation change in the desert grasslands of the Southwest. The substantial research into vegetation change shows that native grasses, so highly prized by cattle ranchers, have been greatly reduced while woody desertscrub species, such as mesquite (*Prosopis* spp.), creosote bush (*Larrea tridentata*), yucca (*Yucca* spp.) and others, have increasingly come to dominate the ecotone (Brown, 1994; Shelton and Bahre, 1994). As the number of studies of vegetation change have multiplied, the solution to the puzzle of vegetation change seems no closer to a solution, and there are recurring inconsistencies reported in many of the studies. Each of the major theories of vegetation change in the Southwest is reviewed in greater detail in order to place recent theories of keystone rodent interactions within the broader context of vegetation change research.

Table 1.1 Previous Research on Vegetation Change in the Desert Grasslands

Study	Location	Reported Cause of Vegetation Change	Reported Inconsistencies
Wooten, 1908	New Mexico	Livestock selective grazing, overgrazing	None reported
Thornber, 1910	Arizona	Overgrazing, erosion	None reported
Griffiths, 1910	Southern Arizona	Cattle grazing, fire suppression, erosion	Protection from grazing did not prevent woody shrub increases
Jardine and Forsling, 1922	Southwest	Drought combined with overgrazing	Ungrazed and heavily grazed areas both had increases in woody shrubs
Leopold, 1924	Arizona	Cattle grazing, erosion, fire suppression	None reported
Campbell, 1929	Southern New Mexico	Cattle grazing	None reported
Nelson, 1934	Southern New Mexico	Drought, overgrazing	None reported
Darrow, 1944	Arizona	Erosion, cattle grazing	None reported
Haskell, 1945	Southern Arizona	Cattle grazing, erosion	Uneven response of woody shrubs to grazing levels.
Brown, 1951	Southern Arizona	Combined cattle and rodent grazing	Protection from grazing did not prevent shrub invasion
Reynolds and Glendening, 1949	Southern Arizona	Kangaroo rat dispersal of mesquite seed	None reported
Leopold, 1951	Southwest	Erosion, overgrazing	None reported

Table 1.1 Previous Research on Vegetation Change in the Desert Grasslands (Cont'd.)

Study	Location	Reported Cause of Vegetation Change	Reported Inconsistencies
Gardner, 1951	S. New Mexico	Overgrazing	None reported
Branscomb, 1958	S. New Mexico	Wildfire suppression	Protection from grazing did not prevent shrub increases
Humphrey and Mehrhoff, 1958	S. Arizona	Fire suppression	Protection from grazing did not prevent shrub increases
Hastings, 1959	S. Arizona	Arroyo cutting, cattle overgrazing	Not reported
Wright, 1960	S. New Mexico	Cattle dispersal of mesquite	Protection from grazing did not prevent shrub increases
Humphrey, 1962	Southwest	Fire suppression	None reported
Lohmiller, 1963	Southwest	Drought	None reported
Rogers, 1965	S. Arizona	Human disturbances	None reported
Harris, 1965	Southwest	Cattle overgrazing, seed dispersal, fire suppression	None reported
Buffington and Herbel, 1965	JER	Cattle overgrazing, fire suppression, rodent interactions	No records of wildfires; woody shrub invasion in cattle exclosures

Table 1.1 Previous Research on Vegetation Change in the Desert Grasslands (Cont'd.)

Study	Location	Reported Cause of Vegetation Change	Reported Inconsistencies
Hastings and Turner, 1965	Southern Arizona	Climate change	Protection from grazing did not prevent woody shrub invasion.
Denevan, 1967	Southwest	Livestock overgrazing, increased intensity of rainfall, erosion	None reported
Cable, 1967	Southern Arizona	Wildfire suppression	Fire controlled burroweed but not mesquite
York and Dick-Peddie, 1969	Southern New Mexico	Cattle grazing, climate change	Climate change would not produce observed patchiness of vegetation change
Cable and Martin, 1973	Southern Arizona	Cattle grazing; Erosion	Mesquite increases even in cattle exclosures
Turner, 1974	Southern Arizona	Climatic change, wildfire suppression	Wildfires may not have been common in the past
Smith and Schmutz, 1975	Southern Arizona	Fire suppression, cattle seed dispersal, climate change	Protection from grazing did not prevent shrub increases.
Bahre and Bradbury, 1978	Southern Arizona	Human impacts such as grazing and land disturbance	Grass cover has increased overall
Gehlbach, 1981	Southern New Mexico and Arizona	Human impacts such as cattle grazing	None reported
Rea, 1983	S. Arizona	Overgrazing, beaver eradication, arroyo cutting	None reported

Table 1.1 Previous Research on Vegetation Change in the Desert Grasslands (Cont'd.)

Study	Location	Reported Cause of Vegetation Change	Reported Inconsistencies
Hennessey *et al.*, 1983	S. New Mexico	Drought	Cattle and rodent exclosures had equal woody shrub increases
Neilson, 1986	Southwest	Climate change	None reported
Humphrey, 1987	Southwest	Cattle grazing	No vegetation change around Santa Cruz River
Gibbons and Beck, 1987; 1988	S. New Mexico	Drought, cattle grazing	Protection from grazing did not prevent shrub increases
Graf, 1988	Southwest	Arroyo cutting caused by climate change	None reported
Brown and Heske, 1990	S. Arizona	Kangaroo rat disturbances favored woody shrubs	None reported
Bahre, 1991	S. Arizona	Grazing, fire suppression, other human impacts	Lack of consistent data in similar settings
Hereford, 1993	S. Arizona	Arroyo cutting caused by climate change	None reported
Archer, 1993	Southwest	Livestock grazing, climate change, carbon dioxide increases	Lack of consistent data in similar settings
Bahre and Shelton, 1993	S. Arizona	Livestock grazing and fire suppression, human disturbance	Lack of consistent data in similar settings
Bahre, 1995	Southwest	Grazing, fire suppression	Lack of consistent data in similar settings
Weltzin *et al.*, 1997a &b	Texas	Prairie dog clipping-control of mesquite	None reported

Climate Change as a Cause for Vegetation Change

Directional change in the climate of the American Southwest has been cited most frequently as the cause of vegetation change (Humphrey, 1987; Hastings and Turner, 1965; Branscomb, 1958; Brown, 1950). Scientists of the early 20th century argued that climate strictly determines the native vegetation of the prairie grassland biome, and that vegetation type is little influenced by human activities (Shreve, 1942; Clements, 1936; Cowles, 1928). A logical outcome of this hypothesis is that vegetation change is a response to changing climatic conditions. More recent studies of vegetation change envision the observed increases in woody shrubs to be a product of human-induced increases in atmospheric greenhouse gases which, in turn, have altered the climate (Johnson *et al.*, 1993; Idso, 1992).

Climatic explanations for vegetation change focus on one or more determinants of vegetation: temperature trends, rainfall variability, seasonality and the effects of historic increases of atmospheric carbon dioxide (Van Devender, 1995; McClaran, 1995; Bahre and Shelton, 1990; Neilson, 1986). In general, moisture availability is considered the limiting factor for vegetation in arid regions rather than temperature fluctuations (Stockton and Meko, 1990; Balling and Idso, 1990; Lewin, 1985). Some authors argue that higher temperatures and decreased rainfall since 1898 have been primarily responsible for changes in plant demographics (Neilson, 1986; Hennessey *et al.*, 1983; Hastings and Turner, 1965:280).

Atmospheric carbon dioxide enrichment has recently been proposed as a causal factor in vegetation change in arid environments, including the study area (Johnson *et al.*, 1993; Idso, 1992). Atmospheric CO_2 has increased over the past 200 years by approximately 30%, from about 270 ppm to 350 ppm (Johnson *et al.*, 1993). Carbon dioxide acts as a fertilizer for plants, but not all plants can utilize the additional CO_2 as efficiently as others. Grasses of the Southwest and other hot and/or tropical grasslands utilize mainly a C_4 photosynthetic pathway, which evolved under conditions of a much lower ratio of CO_2 to O_2. These grasses are believed to be biochemically inefficient at making use of the additional CO_2 (McClaran, 1995; Archer, 1993).

Woody shrubs, on the other hand, typically possess a C_3 photosynthetic pathway, which theoretically confers an advantage with respect to physiological activity, growth and competitive ability under conditions of increased CO_2 (Johnson *et al.*, 1993; Archer, 1993). This has led to speculation by Johnson *et al.* (1993) that historic increases in CO_2 have contributed to widespread replacement of C_4 grasslands with C_3 woody shrubs along ecotones where both structural types are present.

Steven Archer (1993) points out several facts which argue against CO_2 enrichment as an important factor in vegetation change in the Southwest. First, he asserts that CO_2 levels from 1870 to 1925 were not sufficiently high to explain the initiation of vegetation change in the Southwest during that time period. His second point is that an equal replacement of C_4 grasses with C_3 grasses has not occurred even though some C_3 grasses exist in desert grasslands. And his last point is that there are many examples of C_4 grasses that persist while C_3 shrubs have invaded nearby areas with similar soils and edaphic conditions (Archer, 1993).

Many scientists disagree with the hypothesis that climate change might be affecting southwestern vegetation, pointing out that the Southwest has always had cycles of drought and intense rainfall, and that the onset of vegetation change, coinciding as it has with the onset of intensive cattle ranching, is more than coincidental (Bahre and Shelton, 1993; York and Dick-Peddie, 1969; Buffington and Herbel, 1965). In addition, the patchiness of vegetation change in the Southwest runs counter to explanations of climate change, which would affect the environment in a much more uniform fashion (Bahre and Shelton, 1993; York and Dick-Peddie, 1969). Statistical evaluation of the data on long-term temperature and rainfall patterns in southern Arizona and southern New Mexico in three separate studies shows that no significant directional trend has occurred (Bahre and Shelton, 1993; Cooke and Reeves, 1976). Furthermore, studies show that drought acts as a natural control on young mesquite trees, as well as grasses, thereby nullifying it as a means of increasing mesquite in desert grasslands (Archer *et al.*, 1988; Carter, 1964).

Direct Impacts of Cattle as the Cause of Vegetation Change

The second most frequently suggested cause of vegetation change in the Southwest is livestock grazing, in particular overgrazing by cattle and sheep (Bahre and Shelton, 1993; Bahre and Bradbury, 1978; Hastings and Turner, 1965; Branscomb, 1958; Brown, 1950). However, the evidence for a direct link between overgrazing and woody shrub increases is usually anecdotal rather than experimental (Bahre, 1995; Bahre and Shelton, 1993; Gehlbach, 1981; Hastings and Turner, 1965).

The direct effects of overgrazing of the desert grasslands include thinning of the grass cover by grazing and the breakdown of the soil surface by trampling. Glendening and Paulsen (1955) show increased establishment of mesquite seedlings where the ground surface was disturbed and free of grass. The actual physical process may be competition for moisture at the near-surface root zone, but dense grass cover seems to resist establishment of woody shrubs (Hennessey *et al.*, 1983; Brown and Archer, 1989; Martin, 1975; Hastings and Turner, 1965:276).

Grazing exclosures, or fenced pastures intentionally kept free from livestock and/or rodents, have existed on the SRER in southern Arizona since the 1920s, the JER in southern New Mexico since the 1930s, one site in the San Simon Valley, Arizona, since 1958 and another in the vicinity since 1977 (Heske *et al.*, 1994; Bahre and Shelton, 1993; Chew and Whitford, 1992; Buffington and Herbel, 1965). These long-term study sites furnish long-term data about vegetation change in the study area. The data on vegetation change in these exclosures are inconsistent with the hypothesis that livestock grazing directly causes vegetation change in the Southwest (Table 1.1). Exclosures have undergone vegetation change as much as sites that are heavily grazed, according to several studies (Bahre and Shelton, 1993; Bahre, 1991; Brown and Heske, 1990; Brown and Archer, 1989; Hastings and Turner, 1965;Branscomb, 1958).

Data from these sites indicate that cattle grazing and trampling may be irrelevant to observed increases in woody shrubs. Mesquite has increased in some livestock exclosures, while others have experienced increases of tarbush, creosote bush and four-winged saltbush, despite the exclusion of cattle. In addition, some study plots grazed by cattle have experienced no brush increase at all, throwing the issue of the effects of cattle grazing on desert grassland vegetation into disarray (Bahre, 1995; Bahre and Shelton, 1993; Archer, 1993; Turner, 1990).

Indirect Effects of Cattle as Cause of Vegetation Change

Range management practices can intensify the effects of cattle grazing to produce vegetation change. Seed dispersal by cattle, the introduction of exotic grasses on cattle ranges, and increased soil erosion brought about by cattle trampling and overgrazing are topics of ongoing research (Bahre, 1991; Humphrey, 1987; Hennessy *et al.*, 1983; Gehlbach, 1981; Harris, 1966; Hastings and Turner, 1965).

Cattle-induced seed dispersal can indirectly affect vegetation by improving germination success (Archer *et al.*, 1988; Cable and Martin, 1973). Cattle ingest and scarify seeds in their guts, depositing them in fertile manure (Martin and Cable, 1974; Glendening and Paulsen, 1955). The seeds of velvet and honey mesquite are particularly benefited by cattle digestion and dispersal (Brown and Archer, 1989). However, there is no evidence that cattle feed on or disperse the seeds of other common woody shrubs known to be increasing in desert grasslands such as tarbush, four-winged saltbush and creosote bush. Furthermore, cattle exclosure data indicate that mesquite increases even when cattle are totally excluded from large grassland areas (Bahre and Shelton, 1993; Brown and Archer, 1989; Branscomb, 1958).

Increased soil erosion is another indirect effect of livestock grazing that may account for increased woody shrubs in the desert grasslands. The American Southwest has experienced some of the most severe erosion in the United States, in the form of deep arroyo cutting (Cooke and Reeves, 1976; Tuan, 1966; Ross, 1935). Livestock denude vegetation and disturb the soil and, leading to increased surface runoff and down-cutting (Denevan, 1967; Leopold, 1951). Denevan (1967) examined the relationship between the initiation of arroyo-cutting in the Southwest and the tremendous increases in livestock numbers in the 19th century. He came to the conclusion that overgrazing is a significant contributing factor to arroyo-cutting in the modern period.

Prehistoric arroyo formation is well documented, however, and there may be cycles of heavy erosion in the Southwest that are related to cycles of intense rainfall rather than livestock introduction (Hereford, 1993; Graf, 1988; Cooke and Reeves, 1976; Tuan, 1966:583-84). Graf (1993) documents numerous instances of arroyo down-cutting that are closely timed throughout the Southwest, leading him to conclude that they were caused by intense periods of rainfall. There are, however, many cases of deep arroyos forming during the 1920s and 1930s without such intense rainfall (Ross, 1935).

Grasses, particularly native perennial bunch grasses common in desert grasslands, enhance infiltration and water retention in the near-surface layers by developing a dense network of shallow sponge-like roots that help retain water in upper layers of the soil horizon (Burgess, 1995).

Erosion can lead to decreases in grass cover by stripping away the fragile layer of topsoil upon which grasses depend. A surface cover of grasses controls rain-splash erosion and sheet-flow erosion at the soil surface better than a canopy of shrubs and trees (McAuliffe, 1995:118; Cooke and Reeves, 1976). Arroyos change hydrology by acting as locations for concentrated erosion and truncating the important water-retaining clay-rich agrillic horizons, greatly effecting the distribution and duration of soil moisture (McAuliffe, 1995). Surface runoff is increased and the water table is lowered, removing available moisture from the grass root zone and making it accessible only to the more deeply rooted shrubs (McAuliffe, 1995; Walker and Noy-Meir, 1981).

Mesquite and other desert shrubs have deep and extensive root systems which can access moisture at deeper and more stable layers, allowing them to thrive in areas where erosion has stripped away topsoil or lowered the water table by down-cutting the local relief. These conditions diminish grass cover and place woody shrubs like mesquite and tarbush at a competitive advantage (Burgess, 1995). Most researchers agree that once woody plants become dominant in the semi-arid conditions of the Southwest, the combination of surface shading, erosion and depletion of topsoil creates a permanent shift from a grass dominated ecosystem to a desertscrub ecosystem (Burgess, 1995; Parsons *et al.*, 1992; Buffington and Herbel, 1965; York and Dick-Peddie, 1969).

Fire Suppression as a Cause of Vegetation Change

Several studies have examined the effects of wildfire suppression on vegetation in the Southwest (Swetnam, *et al.*, 1999; Swetnam and Baisan, 1996; Bahre and Shelton, 1993; Martin, 1983; Wright, 1980; Martin, 1975). Desert grasslands have been shown to support wildfires, especially when the standing biomass is high (Wright, 1980; Cable, 1961). Other researchers have found that the typical stands of bunch grass on the desert grasslands do not contain enough continuous biomass to sustain widespread fires (Buffington and Herbel, 1965; Wright, 1960). Mesquite and other woody shrubs are susceptible to fire when they are small, especially if there is plenty of fine, dry grass around the base of the plants to act as fuel (Cable, 1961; Reynolds and Bohning, 1956; Glendening and Paulsen, 1955).

Fires have decreased in frequency and intensity in the Southwest since the 1890s (Swetnam, *et al.*, 1999; Bahre, 1991). Settlement and increased value of trees and range grasses have resulted in active suppression of wildfires. Increased grazing pressure on the protected ranges has resulted in decreased biomass and less intense fires when they do occur (McPherson, 1995). Reviews by Wright (1960), Buffington and Herbel (1965), York and Dick-Peddie (1969) failed to discover a significant historical record of wildfires in desert grasslands of southern New Mexico. On the other hand, Bahre and Shelton (1993: 497) found that southeastern Arizona did have a considerable historical record of wildfires. They concluded that reduced fire frequencies and lower fire temperatures over the past century may be a contributing factor in vegetation change.

Branscomb (1958) argued that reduction in wildfires has led to establishment of desertscrub vegetation, even though he was unable to find any references to wildfires in southern New Mexico during the early historic period (Branscomb, 1957, 1958). In a recent article on the role of fire in the desert grasslands, McPherson asserts that the long-term absence of fire produces changes in community structure and function, ultimately leading to shrubland, but also cites a great deal of experimental evidence that fires on desert grasslands are often not hot enough to produce good kill rates for woody shrubs and that most woody shrubs vigorously re-sprout after fires (McPherson, 1995: 141).

Swetnam and other historical ecologists have utilized tree fire-scar data to document regular "regional fire years" between AD 1600 and 1893, in which fires effected multiple forested locations in the Southwest (Swetnam, *et al.*, 1999; Swetnam, 1990). Such fire events undoubtedly would have affected grasslands as well as forests.

Other Human Impacts as Cause of Vegetation Change

Conrad J. Bahre (1991, 1995) has studied the impacts of historic human activities in the landscape of southeastern Arizona. He states that the effects of cordwood cutting, mining and settlement disturbances may have been locally important, leading to erosion and degradation of vegetation at specific sites (Bahre, 1991; Bahre and Hutchinson, 1985). The mowing of native grasses, a common practice in the Southwest between 1850 and 1920, could have weakened grasslands and depleted soil nutrients in the San Pedro, San Simon and Sulphur Springs Valleys, leading to erosion and increases of woody shrubs (Bahre, 1991;

Bahre, 1995). Most wild-cut hay supplied the forts and settlements with fodder for horses, but individual ranches also put up hay for their own stock. In 1899, according to Bahre, ranchers harvested 9,524 tons of wild hay in Arizona (Bahre, 1995: 254). He points out that several locations in Cochise County known for intensive hay mowing are now covered with woody shrubs, including Government Draw near Tombstone, and the lower slopes of the Santa Rita, Dragoon and Huachuca Mountains, for example (Bahre, 1991). Bahre (1995) admits, however, that it is difficult to show a causal connection between woody shrub increases and an agricultural activity practiced over a century earlier that did not physically disturb the ground.

Evidence for Ecotone Regulation by Rodents

Other sections in this chapter refer to research demonstrating important links between rodent activity and ecosystems in the Southwest. This research bears directly on the topic of vegetation change. First, rodents may help establish mesquite seedlings in the desertscrub ecotone. Many studies have examined the keystone effects of kangaroo rats (Chew and Whitford, 1992; Mun and Whitford, 1990). Kangaroo rats disperse mesquite seeds and increase their establishment and survival far more than livestock do (Heske, Brown and Mistry, 1994; Paulsen, 1950; Reynolds and Glendening, 1949). Research by Cox *et al.* (1993) demonstrates that Merriam's kangaroo rats (*Dipodomys merriami*), rather than livestock, may account for the spread of mesquite in the Sonoran Desert by caching viable seeds underground. Banner-tailed kangaroo rats (*Dipodomys* *spectabilis*) have been shown to alter grass species dominance and composition (Fields *et al.*, 1999).

Brown and Heske (1990) regard kangaroo rats as a keystone rodent guild because of their role in controlling the desertscrub/desert grassland ecotone. A study of the removal of three species of kangaroo rats from areas of Chihuahuan desertscrub vegetation resulted in a threefold increase in perennial and annual grasses after 12 years (Brown and Heske, 1990). Reduction in physical disturbance of the soil surface and decreased seed predation seemed to facilitate the establishment and growth of tall grasses, such as *Eragrostis lehmanniana* and *Aristida adscensionis*.

Even though the research on the kangaroo rat shows these animals control the desertscrub-desert grassland ecotone, it still begs the question of what might be causing overall ecosystem change. It is uncertain if kangaroo rats are expanding their range into desert grasslands, or why they might be doing so. Like prairie dog eradication programs, kangaroo rat eradication efforts in the Southwest have greatly perturbed the distribution and abundance of kangaroo rats over the past 70 years, making site-specific historical reconstruction difficult.

A second example of research related to rodent influence on vegetation dynamics has been mentioned previously in the discussion of prairie dogs as keystone organisms. That is--research by Weltzin (1991) and Weltzin *et al.* (1997a, 1997b) demonstrate that prairie dogs suppress mesquite seedlings and plants on their colonies in short-grass prairie ecosystems through active clipping.

This research also indicates that rapid invasion by woody shrubs, primarily mesquite, follows colony eradication (Weltzin *et al.* 1997b).

Multiple Causes of Vegetation Change

Previous research shows that profound but "patchy" change has occurred on the desert grasslands and that vegetation change has increased the density of woody shrubs that were formerly present, but at a low density. This change began in the 1890s and continues today. With the exception of studies of rodent removal, contradictory evidence exists for each of the factors listed above as causal factors for increases in woody shrubs over large areas of the Southwest. Most studies have concluded that causal factors are multiple, interactive and remain poorly understood (Bahre, 1995; Bahre and Shelton, 1993; Archer, 1992; Hastings and Turner, 1975).

The inconsistent results of studies focusing on direct and indirect effects of cattle grazing show that livestock may not be directly causing vegetation change on the desert grasslands. Alternatively, other unidentified factors may be affecting vegetation within some cattle exclosures and on specific grazing sites, confusing the results of studies. Some authors claim this supports the arguments for fire suppression or climate change as significant causal factors (Brown and Archer, 1989; Cable and Martin, 1973). Others argue that the patchiness of brush increases could not be produced by the uniform effects of climate change (Bahre and Shelton, 1993; York and Dick-Peddie, 1969).

Insufficient and/or conflicting data on climate change, erosion, wildfire suppression, and cattle impacts have led several investigators to the conclusion that the causes of vegetation change may be multiple and interactive (Archer, 1993; Bahre and Shelton, 1993; Buffington and Herbel, 1965).

Historical disruptions of keystone rodent ecosystems, including prairie dog colonies, may be a direct cause or contributing factor in vegetation change (Weltzin *et al.*, 1997b; Archer, 1993). Rodent effects may also interact with other processes. Prairie dog colonies, for example, may have concentrated livestock grazing impacts by providing highly palatable vegetation. Furthermore, it is unlikely that grass fires would have propagated across prairie dog towns due to their low grass stature and biomass.

Studies of the effects of rodent removal on the desert grasslands by Weltzin *et al.* (1997a, 1997b) suggest to me that the widespread removal of prairie dogs at the time that the cattle industry and fire suppression were imposed on desert grassland ecosystems in the Southwest may have triggered a cascade of effects resulting in increased brush density in some discrete geographic locations, but not in others. Unfortunately, cattle exclosures in the study area were established without any data on their original or subsequent prairie dog occupation.

There is a clear possibility that rodent-mediated vegetation changes may be affecting outcomes at these experimental sites and other experimental locations in the Southwest. It is clear that lack of data regarding original prairie dog distributions and the ecological consequence of their eradication in the desert grasslands is essential to a better understanding of the puzzle of vegetation change.

RESEARCH SIGNIFICANCE

The study of the history and consequence of eradication of the Arizona black-tailed prairie dog contributes to environmental and historical geography in three ways. First, the study is an important contribution to our understanding of long-term effects of public policy on wildlife resources and human-induced environmental change (Mighetto, 1991; 1988; Dunlap, 1988; Doughty, 1986, 1983, 1975). Geographers have not adequately examined the consequence of massive rodent eradication programs in the United States, especially in terms of ecological change.

Second, this research contributes to the field of biological conservation. It includes biogeographic information about the pre-eradication distribution and population of a rodent subspecies that is relevant to conservation decisions involving black-tailed prairie dogs throughout their range. The National Wildlife Federation (NWF) has recently petitioned the United States Fish and Wildlife Department (USF&WS) to list black-tailed prairie dogs as a federally threatened species (NWF, 1997). The Arizona black-tailed prairie dog is already listed as an endangered genetic sub-species in the state of Arizona.

Re-establishing viable populations of black-tailed prairie dogs in all parts of their historical range will become an increasingly important species conservation objective, for its own population recovery and that of several other associated species. Information on the former locations of prairie dog colonies is already being used to re-introduce black-tailed prairie dogs in the study area.

The third area of significance is in resource management. Vegetation change in the American Southwest is of considerable importance to the future of cattle ranching in the region. For over a century grassland management decisions have been based on the assumption that prairie dogs greatly reduce range grasses and are pests that diminish the overall value of rangelands. This research directly tests the validity of that hypothesis and suggests alternative models regarding desert grassland productivity and resource management.

Chapter 2 outlines both the historical and ecological methods that are used to study the history and consequence of prairie dog eradication. It includes an evaluation of the potential data sources and methods of obtaining historical data, a review of ecological approaches used in other long-term vegetation studies, and a description of the methods applied to investigate the ecological consequences of prairie dog eradication.

Chapter 3 documents the historical distribution of prairie dogs in the study area prior to organized extermination. In this chapter, both maps and descriptive accounts of black-tailed prairie dog locations are provided.

Chapter 4 traces the history of organized eradication of Arizona black-tailed prairie dogs in Arizona, New Mexico and northern Mexico on a county-by-county basis, relying on archival data and first-hand accounts to understand the step-wise process of extirpation in the study area. Estimates are provided for the original (1916) population of Arizona black tailed prairie dogs in the study area, as well as estimates of the overall incidence of prairie dogs in every county of Arizona and New Mexico.

Chapter 5 investigates the consequences of prairie dog eradication. It examines the qualitative characteristics of a sample of more than 61 living and exterminated black-tailed prairie dog towns identified in field reconnaissance. It also presents the results of the ecological studies conducted on living and eradicated prairie dog towns. This includes the results of comparative studies of vegetation structure on 21 dogtowns of different ages since eradication, demonstrating significant long-term vegetation change.

Chapter 6 discusses the results of the study, evaluating the indications and limitations of the findings, and making recommendations for further research.

The contents of interviews conducted as part of the historical reconstruction are provided in Appendix A. The results of soil analyses are provided in Appendix B. Plant Species lists for 21 sampled sites are provided in Appendix C. Historical maps of prairie dog town locations on the JER are provided in Appendix D and Appendix E contains 1915 vegetation structure statistics for the JER.

Chapter 2. Methodology

HISTORICAL METHODS

Historical methods of environmental study were pioneered by George Perkins Marsh in his book, *Man and Nature, Or physical geography as modified by human action,* published in 1864 (Marsh, 1864). Marsh compared contemporary landscapes of the Old World with those recounted by classical authors, demonstrating that temporal change in the environment was related to historic settlement and land use.

Carl O. Sauer furthered historical geography in studies of the origins of agriculture and the use of fire as an instrument of ecological change (1944; 1975; 1982). Historical methods prove to be effective in understanding human impacts on vegetation in ecosystems of the American Southwest. Luna Leopold (1951) applied historical methods to the question of vegetation change. William M. Denevan (1967) also applied historical analysis to the issue of arroyo cutting. Bahre (1991, 1995) has also added a temporal elements to questions of human impacts upon landscape change in southeastern Arizona. Other studies of vegetation change in the Southwest have relied on historical descriptions and accounts, as well (Buffington and Herble, 1965; York and Dick-Peddie, 1969; Hastings, 1959).

Historic Data Sources

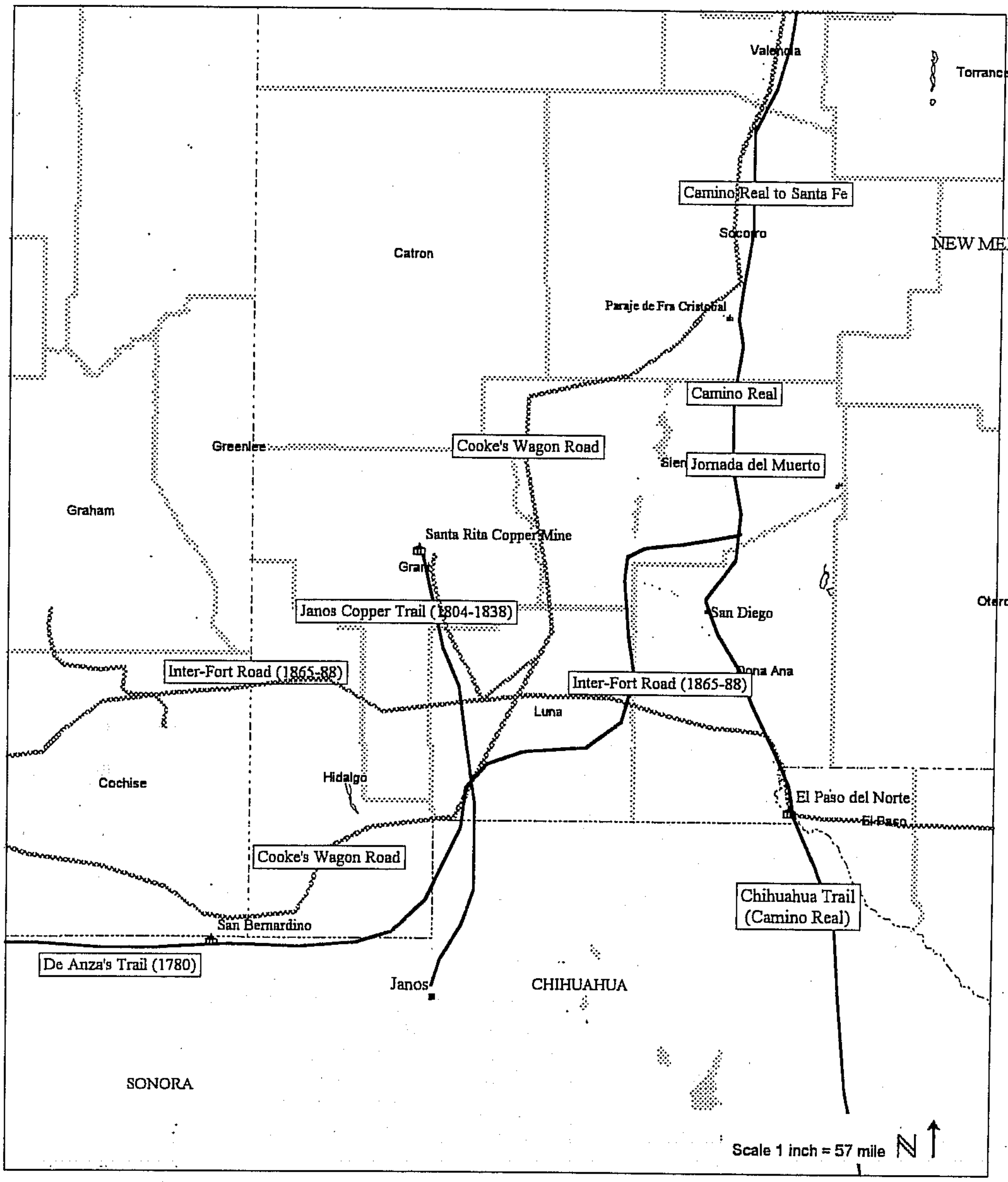
Numerous sources of historic data for the study area contain information on the early location and condition of prairie dog colonies in the Southwest; however, the full spectrum of potential sources and their reliability and utility as an ecological record for these animals have never been assessed for this region.

A complete review of pre-historic and early Hispanic records from the region falls outside the scope of this study. Some primary and secondary sources from the Spanish explorations of Arizona and New Mexico (1581-1598) and the Spanish Colonial Period (1598-1821) provide information about old trails and routes in the study area.

Spanish records of the Camino Real, especially the Jornada del Muerto, were examined for references to prairie dogs. The Rodriquez expedition into New Mexico in 1581 and 1582 and Don Juan de Oñate's expedition in 1598 (Hammond and Rey, 1953: 309-328) both left descriptive accounts of the vegetation and wildlife on the Jornada del Muerto, as did Otermín and the Auto of Xavier during their miserable southward retreat from the Pueblo Revolt in 1680 (Hallenbeck, 1950:163; Hackett and Shelby, 1942, 364-365). Bernardo de Miera y Pacheco's 1700s maps of the Rio del Norte (Adams and Chavez, 1956: 264) provide Spanish place names along the Camino Real through this region.

During the U.S. Territorial Period (1849-1912), many private and military excursions into the Southwest used established trails or created new trails. These sources also provide references to prairie dog locations. Trails used in the Hispanic and U.S. Territorial periods are shown in Figure 2.1

Figure 2.1. Trails used in the Study Area During Hispanic and Early U.S.Territorial Periods



Source: Couchman, 1990: 15; Schroeder, 1989:22; Izard, 1986:112; Williams, 1986:118.

The specific location of the trails is significant in that most authors only recorded conditions in the immediate vicinity of the trails, resulting in data that is biased by a single geographic perspective. Occasionally an individual was part of a hunting or scouting party or had reason to explore new country away from frequented paths, providing fresh information.

Table 2.1 provides a list of 50 non-Hispanic sources that were used in this research. Sources originate from many private and public viewpoints and span approximately 150 years. The majority of sources are from military officers, reflecting a long history of warfare in the study area. These sources consist of personal journals, memoirs, diaries and letters. In reviewing these sources, I sought references to prairie dog colony locations, their size and condition, the date of the observation, and the general attitude expressed about the animals. Less than one-fourth of the sources provided information on prairie dogs in the study area.

Table 2.1. Historical Sources for Southern Arizona and New Mexico.

Author	Perspective	Year	Area	Reference
Pattie	trapper	1824-25	Cooks Peak, Rio Mimbres, Gila River	Pattie, 1831
Hardy	travel	1829	Janos, Sierra Madre, Santa Cruz	Hardy, 1829
Gregg	trade	1844	Jornada del Muerto	Gregg, 1844
Kendall	military	1844	Jornada del Muerto	Kendall, 1844
Cooke	military	1846	Cooke's Road	Cooke, 1964 Bieber, 1938
Bigler	military	1846	Cooke's Road	Bigler, 1932
Bliss	military	1846	Cooke's Road	Bliss, 1931
Jones	military	1846	Cooke's Road	Jones, 1931

Table 2.1. Historical Sources for Southern Arizona and New Mexico, Cont.

Author	Perspective	Year	Area	Reference
Lee	military	1846	Cooke's Road	Lee, 1967
Emory	military	1846	Kearney's Trail	Emory, 1848
Griffin	military	1846	Kearney's Trail	Griffin, 1943
Johnston	military	1846	Kearney's Trail	Johnston, 1848
Ruxton	military	1846	Jornada del Muerto	Ruxton, 1975
Wislizenus	military	1846-47	Jornada del Muerto	Wislizenus, 1848
Doniphan	military	1846-47	Jornada del Muerto	Hughs, 1848
Abert	military	1846-47	Jornada del Muerto	Abert, 1848
Gibson	military	1847-48	Jornada del Muerto	Frazer, 1981
Couts	military	1848-49	Janos, San Bernardino, Santa Cruz	Couts, 1961
Magoffin	merchant settler	1847	Jornada del Muerto and Rio Grande Valley	Drumm, 1926
Chamberlain	military	1849	Gila River	Chamberlain, 1945
Clarke	military	1849	S. Arizona boundary	Clarke, 1852
Cox	military	1849	El Paso to Tucson	Martin, 1925
Durivage	gold rush	1849	Cooke's road	Durivage, 1937
Eccleston	gold rush	1849	Cooke's road	Eccleston, 1950
Evans	gold rush	1849	Cooke's road	Evans, 1945
Marcy	military	1849	Jornada del Muerto Organ Mtns	Marcy, 1850
Bartlett	military	1851-52	U.S.-Mexico border	Bartlett, 1854
Lane	government	1853	Soccoro to Gila River, NM	Carson, 1962
Bell	engineer	1854	El Paso to Tucson	Bell, 1869

Table 2.1. Historical Sources for Southern Arizona and New Mexico, Cont.

Author	Perspective	Year	Area	Reference
Whipple	engineer	1853-55	El Paso to Tucson	Whipple, 1856
Kennerly	military	1853-55	Jornada del Muerto, southern New Mexico	Baird, 1859
Leach	engineering	1858	Southern New Mexico to Tucson	Jackson, 1952
Eaton	military	1858-61	Southeastern Arizona	Eaton, 1933
General Land Survey Records	surveyors notes on economic potential	1858-59	Jornada del Muerto	Archives of the JER
Baird	biological survey	1859	U. S. and Mexico boundary with New Mexico and Arizona	Baird, 1859
Bunyard	emigrant	1869	Kearney's Trail	Myres, 1980
Browne	military	1864	Southeastern Arizona	Browne, 1869
Spring	military	1867-68	Southeastern Arizona	Gustofson, 1966
Bourke	military	1869-75	Kearney's Trail	Bloom, 1934 Bourke, 1950
Bailey	biological surveyor	1889-1931	Sulphur Springs Valley, AZ; Southern New Mexico	Bailey, 1889 Bailey, 1931
Mearns	Boundary survey	1890-93	United States-Mexican boundary and Southeastern Arizona	Mearns, 1893 Mearns, 1907
Streator	Federal biological surveyor	1892-93	Southern New Mexico, Coahuila and Chihuahua, MX	Streator, 1892-93
Price	Federal Biological surveyor	1894	Southeastern Arizona	Allen, 1895

Table 2.1. Historical Sources for Southern Arizona and New Mexico, Cont.

Author	Perspective	Year	Area	Reference
Curry	Settler	1906	Southeastern AZ	Curry, 1997
Vegetation Survey	Range survey scientists	1915	JER	JER Archival Records, 1913-34
Crick, Jardine, Hurtt	Range managers, federal rodent biologists	1916-1918	JER	Unpublished letters from JER Archives 1917
Quesenberry	Range scientist	1917	JER	Unpublished map from the JER Archives, 1917
New Mexico Rodent Control Program	Bureau of Biological Survey, 1918-1964	1918-1964	New Mexico	New Mexico BBS, 1918-1964, National Archives, Records of the USF&WS, RG 22, Box 8
Arizona Rodent Control Program	Bureau of Biological Survey, 1918-1964	1918-1964	Arizona	Arizona BBS, 1918-1964, National Archives, Records of the USF&WS, RG 22, Box 8
New Mexico Rodent Control Program	Predator and Rodent Control Annual Reports, New Mexico	1965-1975	New Mexico	USF&WS, Division of Wildlife Services, PARC Annual Reports, New Mexico, 1965-1975

Establishing Limits of Reliability for Historic Sources

Use of General Descriptive Texts

The problem with the use of historical descriptions from diverse sources is one of interpretation. The precise location of the observation, purpose of the document, point-of-view of the observer, seasonal and diurnal conditions, and other influencing factors can each influence the reliability and utility of the source. Dwight Brown (1993) evaluated the variability of observations about vegetation in historical explorations of the mid-continent plains. He stresses that individual 19th century records need to be reviewed collectively and critically and placed in context with the help of other information sources (Brown, 1993: 593).

Nearly all of the early sources in Table 2.1 mention vegetation and large game animals several times. Some authors, such as Kendall (1844), mention prairie dogs as they passed through other regions, but did not mention them in the study area. Prairie dogs often escaped the attention of writers altogether, or mention of them is limited to a single reference regardless of the actual presence or abundance of the animals.

When prairie dogs are mentioned, the location is often vague or refers to landmarks that are now obscure. The presence of rodents may have been perceived as commonplace or insignificant by explorers and travelers and there seemed to be other noteworthy events (e.g., Apache attacks, lack of water, weather difficulties, wagons mired in mud) more likely to be mentioned in early accounts of the region. Frequently observers described a particularly large colony, or the first colony to attract their attention, then never mention them again despite hundreds of miles of travel through prairie dog habitat.

Military and engineering surveyors traveled through the study very early in the Territorial Period and made extensive notes about the physical environment. Most of these authors fail to mention prairie dogs, probably because of their concern with strategic and economic details, rather than rodent populations.

Fortunately, there are notable exceptions, such as Bartlett (1854) and John G. Bourke (Bloom, 1934).

Each writer carries peculiar observational powers and interests which affect the information conveyed. Bourke, who first traveled through the region in 1869, but wrote about his experiences much later, discusses the problem with considerable candor:

> I wish I could remember as vividly and in proper sequence the general features of the topography of the line of march. My memory is constituted in such a way that I retain for a long time the impressions made upon me by individuals, but in a sense of locality I am lacking in details . . . from Fort Cummings, New Mexico, to Fort Bowie, Arizona, and from the latter post to Camp Grant (since abandoned) by way of Tucson, the country differs but slightly in its main features and but little more in its vegetation and animal life. (Bourke, in Bloom, 1932:58).

A paragraph later contains Bourke's words acknowledging the existence of prairie dogs in the southwest, "In S. W. New Mexico, 'Prairie-dogs' were not unusual. In Arizona they are scarcely ever seen and only along the eastern border" (Bloom, 1932:59). The reader is left to wonder about the meaning of "scarcely" and "along the eastern border." Biologists have cited Bourke's direct statement about prairie dogs as suggestive of a general expansion of the range of prairie dogs into southeastern Arizona after the large-scale introduction of livestock in 1870 (Hubbard and Schmitt, 1983). They have failed to include Bourke's own admission, however, that he possessed little power of discernment in the natural world, and I prefer a more generalized reading of his statements.

Even astute observers of the natural world, such as Bailey and Mearns, who mention prairie dogs frequently in their journals, did not necessarily record every prairie dog encountered. For example, early Spanish accounts as well as accounts from the 1950s indicate that a large colony of prairie dogs existed along the Camino Real at the northern end of the Jornada del Muerto (Hackett and Shelby, 1942, 364-365; Marshall and Walt, 1984; BBS, 1921). Bailey traveled through the Jornada in 1906 but made no mention of prairie dogs there. Did the colony disappear for awhile, then reappear? It was only after a careful reading of Bailey's personal journals in the Smithsonian Institution Archives that I discovered that he traveled by overnight train from Albuquerque and passed through the northern end of the Jornada del Muerto in darkness. His personal journal states that he awakened at dawn in the village of Cutler, about 10 miles south of the prairie dog colony (Bailey, 1906).

Use of General Land Survey Records

Field notes from the General Land Survey, conducted between 1785 and 1923 in Arizona and New Mexico, provide early descriptions of the natural environment in the newly acquired western territories (Bahre, 1991: 59). Researchers interested in vegetation change on the San Pedro River have used field survey notes from southern Arizona in their studies (Woodward, 1972; Bahre, 1991). Studies of vegetation change in New Mexico have also employed General Land Survey data (Buffington and Herbel 1965; York and Dick-Peddie, 1969). Bahre used a randomly selected sample of section lines from the field survey to evaluate vegetation cover over a large area in southeastern Arizona (Bahre, 1991: 60). But surveyors were not required to describe the animals they found along sections lines, and this data source has not previously been used for studying the early distribution of wildlife.

In order to determine if General Land Survey data might contain references to prairie dogs with a frequency and reliability suitable for this study, I examined the Land Survey records, from 1857 and 1858, which were available in the archival files of the JER. Surveyors recorded prairie dogs along four out of a total of 63 section lines for the vegetation study. The descriptions found in the unpublished notes included vegetation type and condition and general extent of the colonies.

Portions of the study area were not included in the Land Survey since they were Spanish Land Grants, such as the Pedro Armendaris Grant. The General Land Survey in other areas, particularly the "boot hill" of New Mexico, are considered unreliable for any purpose by the General Land Office (General Land Office, personal communication 1996). For an intensive study of a particular area like the JER, the General Land Survey notes may yield important information. However, the frequency of observations is considered too low to be of use given the large study area.

Use of Federal Archival Sources

Records of the 20th century include annual reports of rodent control activities of the USDA Bureau of Biological Survey (BBS), Arizona and New Mexico Departments, for 1912-1938. These records are housed with USF&WS reports in the National Archives, Washington, D. C., and provide narrative and statistical accounts, population estimates and financial reports of federal programs for the eradication of prairie dogs and other rodents and lagomorphs.

These records represent the only systematic form of record keeping regarding prairie dogs during the 20th century, and , as such, offer a significant amount of data. The BBS rodent control records have not been previously published or evaluated for use as a data source on prairie dogs in any part of their range.

The USF&WS Predator and Rodent Control (PARC) Division was the successor to the BBS for handling all government rodent control activities between 1939 and 1974. PARC Annual Reports, also housed in the National Archives and, together with the BBS records, form a record of 60 years of eradication statistics and planning reports for every state. For those states with prairie dog populations, most of the material from these records pertains to prairie dogs, including occasional population distribution maps and inventories. Since this is the first study to include this data source, an important element of the research is to evaluate the consistency and reliability of these records.

Non-textual Historic Information

Historic Repeat Photography

Repeat photography, the comparison of historic landscape photographs with subsequent photographs of the same site, taken from the same angle, has been used to evaluate nineteenth century environments and landscape change (Rogers *et al.*, 1984; Hastings and Turner, 1965). This method has been very successful in documenting changes in vegetation structure, soil erosion, and channel cutting in the Southwest (Hennessy *et al.*, 1983; Leopold, 1951; Hastings and Turner, 1965).

Repeat photography has more limited value in studies of vegetation composition or species distribution unless the species in question is highly distinctive, like mesquite or saguaro (Hastings and Turner, 1965). It is also subject to the biases of the initial photographs and may focus on unrepresentative landscape elements (Rogers *et al.*, 1984).

No studies are known to have included repeat photographic sequences on prairie dog colonies (Rogers *et al.*, 1983). However, many repeat photographic sequences are available for portions of the study area,. Some of these sequences may have included prairie dog colonies, providing an additional source of historic information. After reviewing sequences of repeat photographs of desert grasslands to determine if they might supplement historical texts, I ruled this method out for two reasons. First, I suspected that photographers avoided prairie dog towns as undesirable landscape elements. Second, the oblique camera angle and low contrast of early landscape photographs make prairie dog mounds difficult to detect. Even modern black-and-white landscape photos of prairie dog towns, such as that reproduced in David E. Brown's *Biotic Communities: Southwestern United States and Northwestern Mexico,* are difficult to interpret without descriptive text provided by the photographer (Brown, 1994: 118).

Interviews

Historical records were supplemented with personal interviews with agency officials, former employees of the BBS, Civilian Conservation Corps (CCC) and other government programs. Interviews were conducted to identify policies and practices of prairie dog removal in the region and to ascertain the eradication history of prairie dogs towns.

Interviews with local residents in the study area form an important part of the historical record. Many informants are octogenarians living on ranches in the region and their accounts record the nature of ranch life from 1919 to 1970. Knowledgeable individuals were identified through discussions with local and state natural resource agents, ranch owners, and others.

Many local residents whom I interviewed had no recollection of the animals. Others agreed to tell me about their experiences in telephone interviews or in person. I conducted a total of twenty-five interviews between February 1996 and December 1997. Most sources had memories of prairie dogs, but a few other interviews are included because they confirmed that there were no prairie dogs remaining in certain locations at a specific date. Interview transcripts are included in Appendix A.

Positive Records Rule

This study relies on positive records of the historic distribution of Arizona black-tailed prairie dog colonies. It assumes that historic records are always incomplete and the absence of data from a given area is inconclusive. Primary and secondary texts, interviews, maps and statistical reports about prairie dogs in the study area were used to reconstruct original distributions of prairie dogs and the history of their extirpation.

ECOLOGICAL METHODS

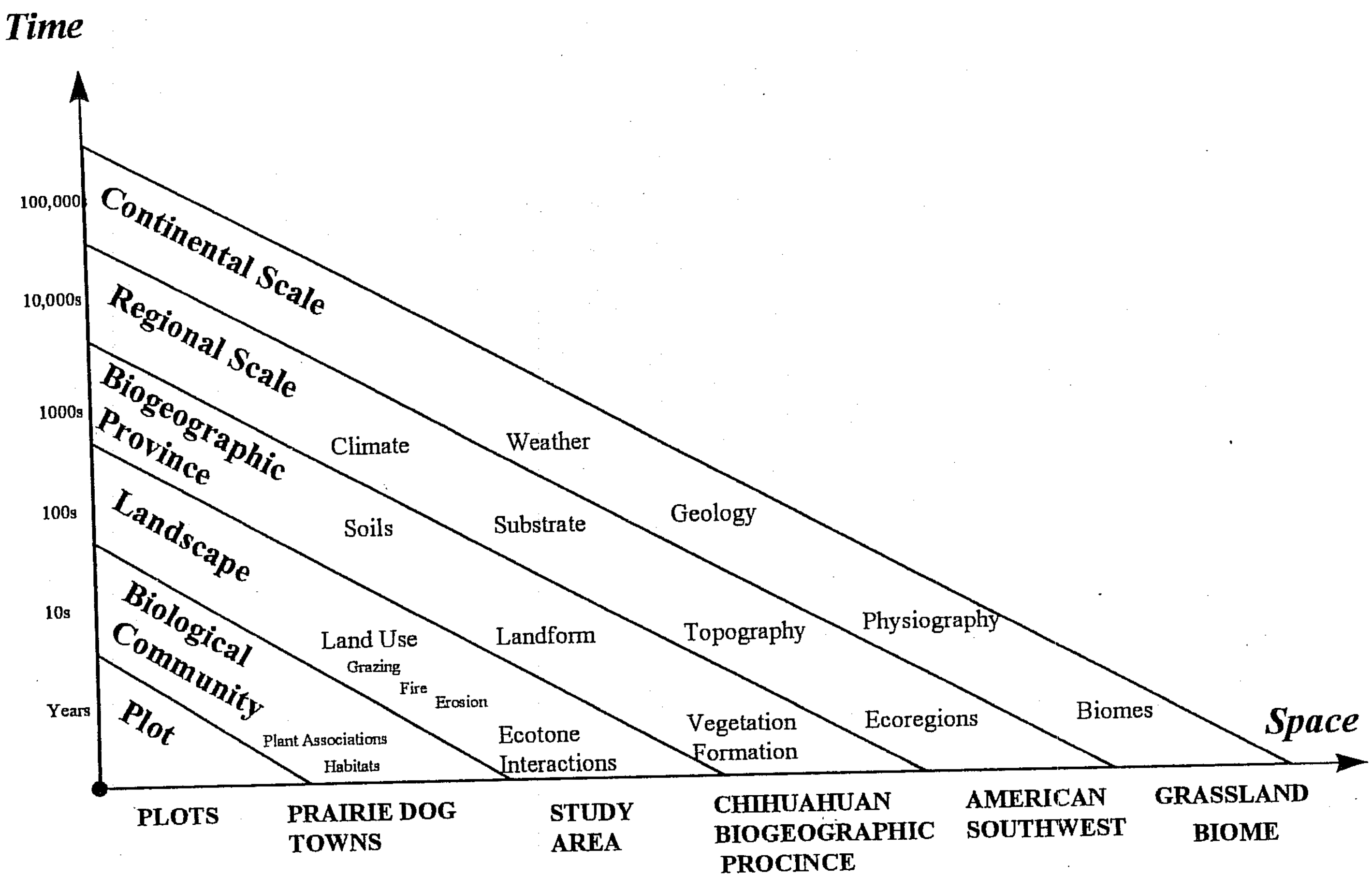
Spatial and Temporal Scale in Biogeographic Study

Environmental histories take place within a biogeographic context of space and time, as described by Bougeron (1994). In Figure 2.2, I have adapted Bougeron's model of biogeographic context to depict the scales available for the study of the history and consequences of prairie dog eradication.

The biogeographic change of interest in this study is successional change that may have occurred on eradicated prairie dog towns in desert grassland ecotones over the past 20 to 100 years. The study, therefore, addresses a difficult intermediate scale of time and space. Directional change in communities and landscapes can only be measured from an established baseline. Historic floral records, agricultural records and land survey records have been used in other studies to establish historic vegetation baseline conditions at intermediate temporal scales (Birch, 1971; Buffington and Herble, 1965; Hastings and Turner, 1965).

Once a historic baseline is established, directional change can be measured by sampling a specific community over several decades. This method has been successfully applied in research on desertification processes and vegetation change (Turner, 1990; Gibbens and Beck, 1987, 1988; Brown and Gibson, 1983; Brown and Heske, 1990). Alternatively, if directional change is disturbance related, sites from different age classes can be compared to known baseline vegetation conditions and to each other (Whittaker, 1975; Chapman, 1976:89; Odum, 1969).

Figure 2.2. Spatio-temporal scales in the study of succession on prairie dog towns (adapted from Bourgeron *et al.*, 1994).



Physically sampling vegetation from many sites across a landscape and over multiple decades is impractical for most studies and unsuited for a study in which potential causal agents have already been extirpated for many years.

In this study I concentrate on the prairie dog town as a distinctive biogeographical unit within the desert grassland ecotone, continually influenced by both internal and landscape-level ecological processes. Therefore landscape processes, especially ecotone processes, across the study area will be the largest scale of inquiry, while vegetation plots within individual prairie dog towns will be the smallest units of investigation in this study.

Ecological Assumptions

The ecological methodology is based on three assumptions. First, there are no "pristine" or undisturbed environments in the study area (Truett, 1995; McPherson, 1995; Bahre, 1991; Sauer, 1944, 1950). All sites examined in this study are assumed to be influenced by several factors, including livestock grazing, fire suppression, exotic plant invasion, soil erosion, and rodent poisoning (Bahre, 1995). The combined effects of other human disturbances are assumed to be random among sites in this study. Such random effects produce variability that can be dealt with statistically. Evidence of ground-disturbing activities, including plow farming, mining, mechanized brush removal, or land scarification, eliminated potential sites from the study.

The second assumption is that regional climate change, including increased carbon dioxide levels, is inconsequential to the results of the study because of its uniform effects across the landscape. This research does not contradict evidence for climate change, but assumes that it is minor in comparison with the impacts of multiple land use changes during the same period. This assumption is supported by Bahre (1991), Buffington and Herble (1965), York and Dick-Peddie (1969), and Archer (1993).

The third assumption is that edaphically similar areas surrounding a confirmed dogtown may have been colonized by prairie dogs at some time in the past and therefore may be undergoing similar processes of change. Other studies of vegetation change on prairie dog towns has compared dogtown vegetation with nearby surrounding vegetation (Weltzin *et al.*, 1997a, 1997b; Agnew *et al.*, 1986; Coppock *et al.*, 1983a, 1983b). Comparisons have been strictly limited in this study to living and former prairie dog towns of known prairie dog occupation.

Even when the location of prairie dog towns is well established for an area at one time, this study avoids any assumptions about where prairie dogs were NOT located. For example, excellent maps locate exact prairie dog colony boundaries on the JER in 1917, just prior to their eradication in 1918 (Quesenberry, 1917). Other historical data from the JER, however, indicate that several thousand acres of prairie dog towns were exterminated only months before these maps were produced (Jardin, 1917). The entire original acreage in prairie dogs, therefore, does not appear in the 1917 maps, and there is no means of knowing which edaphically similar habitats might have previously been occupied by the animals.

Ecological Study of Vegetation Change

Hypotheses of Post-eradication Vegetation Change on Prairie Dog Towns

Post-eradication vegetation change on prairie dog towns constitutes a form of succession. Plant succession is marked by one specific community being replaced by another until a climax community is established (Whittaker, 1975; Goldsmith and Harrison, 1976). A "sere" is an identifiable community that occurs in a stepwise manner on a site during succession. Seral communities are unstable on a spatio-temporal scale and are unable to replace themselves over time, being replaced instead by a new suite of plant species. Climax communities, however, are identified by self-regeneration over time (Goldsmith and Harrison, 1976; Odum, 1969).

Seldom is there sufficient historical vegetation data available for long-term studies of within-site successional change, however (Barber, 1976). "Between-site" studies of vegetation on sites with similar disturbance histories are commonly used to identify patterns of succession in a landscape. Between-site comparisons correlated temporally with respect to a disturbance and showing distinctive vegetative communities are assumed to have experienced similar vegetative associations at earlier time points and to be changing in response to successional processes (Goldsmith and Harrison, 1976; Whittaker, 1975; Odum, 1969). This study provides both within-site and between-site evidence of succession on eradicated prairie dog towns.

Three hypotheses for post-eradication change on prairie dog towns have been identified in the literature, two of which suggest some form of directional change, or succession. I have given each a name to simplify discussion:

1. *The Weed Hypothesis* (Bailey, 1932; Osborne and Allen, 1949; Koford, 1958). Prairie dog removal results in colonization by forbs, then gradual replacement by annual grasses, and finally (in the Great Plains) by a climax community of perennial grasses.

2. *The Tall Grass Hypothesis* (Taylor and Loftfield, 1924; Merriam, 1902). Prairie dog removal results in increased grass biomass on the site. This does not involve succession, but is the natural increase of species already on the site due to release from prairie dog grazing pressure.

3. *The Brush-clipping Hypothesis* (Weltzin *et al.*, 1997a, 1997b). Prairie dog removal results in the release of latent propagules and seedlings of woody shrub species that are controlled by clipping on an active colony. Woody species rapidly increase and alter ecological processes, until they dominate former prairie dog towns.

Testing any of these hypotheses of succession is difficult in the desert grassland, because of the need for a large set of colonies with known eradication dates and reliable vegetation records. Vegetation in the desert grassland landscape is highly variable between sites and even within sites over time (Brown and Lowe, 1980). Replacement of one grass species by another, while relevant at smaller spatio-temporal scales, is not important at the landscape scale, and is probably not a useful indicator of succession.

To overcome the high variability of species-specific measures of between-site similarity, physiognomic structure of vegetation at each study site has been used in biogeographic studies of desert grassland vegetation (Van Devender, 1995; Johnson *et al.*, 1993). In fact, a desert grassland is frequently described first in terms of its structural classes, then by floristics (Dick-Peddie, 1993: 108; McClaran, 1995).

The hypothesis that prairie dog towns are unique patches (communities) within the desert grassland ecotone that are undergoing succession requires, in its simplest form, that multiple dogtowns be regularly sampled after eradication. Where long-term data exist on the pre-eradication vegetation of a former dogtown, same-site comparisons are made.

When long-term historic data are lacking, the study uses eradicated dogtowns of different ages to understand temporal processes. Between-site comparisons are made within the same age class and between age classes. Vegetation structure, specifically the relative cover of grasses, forbs and woody shrubs, is used as the descriptive measure of community change in this study due to the inherent floristic variability between sites,.

The Ecological Hypothesis of the Research

In this research, I test the model of the Brush-clipping Hypothesis of prairie dogtown succession. In this generalized model, living prairie dog towns are distinctive ecological formations in desert grasslands which have a high density of grass and a low density of woody shrubs. Removal of living prairie dogs triggers the process of succession. Succession is believed to be chronological and eradicated colonies of the same age are expected to exhibit similar physiognomic structure.

Three components of the of the Brush-clipping Hypothesis are tested:

1. Active colonies of Arizona black-tailed prairie dogs occur on stable desert grassland ecosystems with high relative cover of grasses.
2. Successional change is a function of time since eradication and is evidenced by a lower percentage of grass and higher percentage of woody shrubs than on living prairie dog towns.
3. A stable climax community of desertscrub develops within 25 years of extermination.

The first hypothetical component is tested to assure the validity of the first two ecological assumptions of this research. If climatic variability and/or change is significant in the region, or if the combined impacts of cattle grazing and fire suppression have produced widespread ecological change, prairie dog colonies today can be expected to be significantly different from colonies living in the desert grasslands 80 years ago. If past and present active dogtowns have similar vegetation structure within the desert grasslands, prairie dog activity is assumed to be the cause of uniformity. Validation of biological uniformitarianism, in which processes of the past are the same as processes in the present, is critical to further comparisons between living and eradicated colonies. Historic vegetation structure is compared between living dogtowns, described in 1917, with living colonies today in order to establish physiognomic structure as a uniform ecological baseline by which to measure succession.

today in order to establish physiognomic structure as a uniform ecological baseline by which to measure succession.

The second hypothetical component addresses the question of directional change or succession on eradicated dogtowns, as suggested by Weltzin and his colleagues (Weltzin, *et al*, 1997a, 1997b). If directional vegetation change has not occurred on former dogtowns or has been random with respect to prairie dog eradication, the test of this hypothesis will fail. This is tested using a within-site comparison of vegetation structure between living (0-aged) colonies and the same sites 60-80 years after eradication. It is also tested between 0-aged and other sites 60-80-years-old.

The third hypothetical component of the Brush-clipping hypothesis, which states that an increase in woody shrubs is expected to occur rapidly after prairie dog clipping control is eliminated, is tested by comparison of vegetation structure on 0-aged colonies with that of a group of extinct colonies between 25 and 35-years-old. Since woody shrub propagules are readily available on desert grasslands, the rate of succession is assumed to occur within a relatively short period, but to vary somewhat according to the distance to nearby stands of woody shrubs (Weltzin *et al.*, 1997a). If woody shrub vegetation does not significantly increase within 25-35 years of extermination, other biophysical processes may be controlling succession.

Qualitative and Quantitative Methods for Comparing Prairie Dog Towns

Qualitative descriptions of physical characteristics of a large set of prairie dog towns provide background ecological information on the types of environments preferred by black-tailed prairie dogs in the desert grasslands. These methods also identify biophysical characteristics and processes common on eradicated versus living prairie dog colonies.

I conducted field visits to 61 sites identified in the historical study. Sites were identified on United States Geological Survey (USGS) 7.5 Minute Topographic sheets and on Soil Conservation Service (SCS) Soil Survey maps. Data gathered during the field study included photographs and qualitative descriptive information. Additional comments were also noted for any special conditions.

Potential study sites were eliminated from the study if they couldn't be confirmed by two or more historic sources or if there was evidence of farming or other ground disturbing activity. Physical access was denied for many sites, eliminating them from further study. Sites were further investigated through interviews with the owners, area resource managers and local ranchers. Details about the eradication history of the site were obtained through interviews and other historic sources. Soil survey data, topographic maps and aerial photographs were analyzed in order to understand the topographic and edaphic factors relevant to the site.

Of the original 61 sites, only those with good information on eradication history were included in the comparative vegetation studies. The resulting sample included 21 prairie dog towns ranging from living colonies to colonies poisoned nearly 80 years previously. The study sites include two sites in Chihuahua, Mexico, three sites in Hidalgo County, two sites in Cochise County, five in Sierra

County, seven in Doña Ana County, one in Otero County and one in Lincoln County. Dogtowns were not found in Luna, Grant or Graham Counties where definite dates of eradication or access could be obtained.

Soil Studies

Soil particle size distribution analysis provides a simple descriptive measure of the range of soil types being used by prairie dogs in the study area. The study analyzed soil from a central location on 19 living and eradicated colonies. Approximately one kilogram samples were taken at a depth of approximately eight inches and dried, crushed and re-sampled (Ball, 1976; USDA, 1951). I used the hydrometer method of analysis for particle-size distribution (Klutz, 1986). Dr. Jeff Herrick supervised the soil analysis at New Mexico State University, Las Cruces, New Mexico.

Vegetation Studies

I conducted a preliminary study on a single site in 1996 to determine the most suitable method of vegetation study. The first technique used a systematic random grid that consisted of 20-one meter square sample areas, randomly selected from the intersections of grid lines paced out in a 100-square-meter plot within the study site in a known prairie dog town. This method was compared with a restricted random method in which I selected 20 one-meter square quadrats from pre-marked random loci on a 100-meter transect line (Goldsmith and Harrison, 1976:104). The results of this comparison showed no significant difference in the measure of relative cover of structural classes and the latter method was selected as being more efficient in the field.

The positioning of the transect line followed rules to reduce sampling bias. Each transect began at a prairie dog mound or burrow entrance within the colony, if one was visible, and ran west. Sample size was further refined by calculating a species-area curve (Goldsmith and Harrison, 1976: 105). A minimum number of seven plots 1 square meter in area represented the vegetation structure well on sites with low to medium species diversity, but additional plots were sampled on sites with high species diversity.

All sites were sampled during the growing season between August and October. I measured the circumference of the plant canopy in the each plot to the nearest 0.2 cm. Canopy area was calculated for each species and summed for each of three physiognomic structural classes found on the sites. Trees were not present on any of the sites sampled. William Dick-Peddie's (1993) structural classification served as a model for classifying woody shrubs and forbs. I collected samples of each species in the field, using letters as temporary identifiers until specimens could be examined. Species identification was carried out for the dominant species in each structural class using the facilities at the University of New Mexico herbarium and various references and keys (Allred, 1997; Roalson and Allred, 1997; Vines, 1960; Gould, 1951).

I conducted four comparative vegetation studies on Arizona black-tailed prairie dog colonies. The first tested temporal stability of the vegetation structure on Arizona-black-tailed prairie dog colonies, establishing an ecological baseline for living dogtowns from which change can be measured. The second study compared historic pre-eradication vegetation structure on dogtowns on the JER with vegetation on the same sites 80 years after eradication. The third study compared vegetation structure found on living dogtowns with that found on old eradicated dogtowns (55 to 80-years-old) at different locations throughout the study area. This is a broader test of succession on eradicated prairie dog towns. The forth test compared vegetation structure found on living dogtowns with that found on young eradicated dogtowns (20-35-years-old). This is a test of the Brush-clipping Hypothesis.

The statistical test used for the comparative studies was the Mann-Whitney U-test, a nonparametric test of the ranked order of the data (McPherson, 1990: 276). It is a test of the significance of the difference in relative cover of each structural class between 0-age class data and x-aged class data.

Chapter 3. History of Arizona Black-tailed Prairie Dogs

THE AMERICAN PERCEPTION OF PRAIRIE DOGS

Making Dogs of Them (1800-1890)

The indigenous people of the plains and southwestern prairies were familiar with the animals now commonly referred to as prairie dogs. Archaeological and ethnographic records indicate that prairie dogs formed an important part of the indigenous diet of New Mexico and Arizona, providing valuable animal protein, particularly during periods of food stress (Haury, 1985; Wetterstrom, 1986).

The Spanish-speaking residents of New Mexico and southern Colorado called these animals "tousa," "tusa," or "tuza," a Spanish term referring either to the short tail of the animal or the closely-cropped grass on their colonies (Gregg, 1844:138; Marshall and Walt, 1984:241; Hoogland, 1995:8).

Lewis and Clark were probably first Americans to "discover" the prairie dogs, sending the first specimen of its kind to the American Museum of Natural History (Hollister, 1916:8). The new animal was incorrectly identified as a marmot, a burrowing European mammal. This led to its first proposed name, *Arctomys ludovicianus,* or Louisiana marmot, given by George Ord in 1815, and subsequent taxonomic confusion (Guthrie, 1815; Hollister, 1916).

Rafinesque (1817) inspected the specimen collected by Lewis and Clark and identified it as a species of squirrel, proposing a new genus, *Cynomys*, after the "barking squirrel" that Lewis and Clark had noted. In 1819, Warden named the

the species *Monax missouriensis*, based on a description by Pike. Then Harlan provided another name in 1825, *Arctomys latrans,* still believing it to be a species of marmot. However, by the time of the publication of Baird's *Mammals of North America* in 1857, the confusion had subsided and scientists agreed that the specimens were part of the squirrel family and of the genus *Cynomys* (Baird, 1857).

Tales of this unusual animal of the western prairies circulated among the growing number of American adventurers and soldiers heading west across the prairies early in the 19th century. They used several common names to describe the animals besides barking-squirrels. These names included wishtonwish, tuza, petit chien, prairie dog, sod poodle, prairie marmot, prairie squirrel, prairie barker, and mound yapper (Gregg, 1844; Hollister, 1916:5; Smith, 1967:6).

A colloquial American understanding about the common name and disposition of the animal took shape in written accounts after the 1830s, from the range of suggested names. The animal's habit of barking and sociability led people to call them "dogs" or "prairie dogs," and their colonies were referred to as "villages" or, more often, "dogtowns."

In 1831, James O. Pattie published a vivid account of his adventures across New Mexico (then Northern Mexico) in which he recounts seeing these animals for the first time near the Platte River:

> Here we saw multitudes of prairie dogs. They have large village establishments of burrows, where they live in society. They are sprightly, bold and self-important animals, of the size of a Norwegian rat. (Pattie, 1988:10)

In 1844, Josiah Gregg also calls them dogs:

> ...what attracted our attention most were the little dog settlements, or, as they are more technically called, dog-towns, so often alluded to by prairie travelers. As we were passing through their streets, multitudes of the diminutive inhabitants were to be seen among the numerous little hillocks which marked their dwellings, where they frisked about or sat perched at their doors, yelping defiance, to our great amusement (Gregg, 1844:241).

George Wilkins Kendall drew a portrait of the animals as highly organized social creatures, noting that "If any animal has a system of laws regulating the body politic, it is certainly the prairie dog"(1935: :193). Kendall, whose dramatic account of the Texan Santa Fe Expedition was widely read, believed they were called "dogs" because of their dog-like bark.

Mearns made extensive observations of Arizona black-tailed prairie dogs during the 1890s, published in *Mammals of the Boundary Survey* (1907). Mearns also describes the animals as dogs:

> In wild regions the "prairie dog", as this squirrel is universally called, is devoid of shyness in the presence of man. As one rides up to one of their so-called "villages" he is greeted as on all sides by the sharp "bark" of the "dogs," scores of whom may be seen seated erect on the large mounds which they have thrown up around the entrances to their burrows (Mearns,1907: 343).

Early written accounts of prairie dogs were positive. The rodents seemed almost human to many authors. Susan Shelby Magoffin recorded her first encounter with prairie dogs in her 1847 diary:

> ...we came upon "Dog City." This curiosity is well worth seeing. The Prairie Dog, not much larger than a well grown rat, burrows in the ground. They generally make a regular town of it...the little fellows like people ran to their doors to see the passing crowd [the wagon caravan]. They could be seen all around with their heads poked out, and expressing their opinions I suppose from the loud barking I heard (Magoffin, 1926:37-38).

Kennerly (1855:40) writes of a particularly large colony he came across near San Luis Spring by the Mexican border in the Animas Valley:

> This interesting little animal, about which so much has already been written…never fails to attract the attention of every traveler on the western prairies; and an approach to one of their settlements, after long and dreary marches, is always hailed with delight as a pleasant change from the monotony of lifeless scenes to one of cheerful activity and motion. (Kennerly, 1855: 40).

Also widely read was Kendall's touching story of being deeply affected by an incident when hunting in a large "commonwealth of prairie dogs":

> . . . one circumstance I would mention as singular in the extreme, and showing the social relationship which exists among these animals, as well as the kind regard they have one for another. One of them had perched himself upon the pile of earth in front of his pole, sitting up and exposing a fair mark, while a companion's head was seen poking out of the entrance, to timid, perhaps, to trust himself farther. A well-directed ball from my rifle carried away the entire top of the former's head, and knocked him some two or three feet from his post perfectly dead. While reloading, the other boldly came out, seized his companion by one of his legs, and before we could reach the hole had drawn him completely out of sight. There was a touch of feeling in the little incident—something human, which raised the animals in my estimation, and ever after I did not attempt to kill one of them, except when driven by extreme hunger (Kendall, 1844: 191).

The degree of empathy and anthropomorphism in early descriptive texts about prairie dogs is remarkable. Portions of Kendall's account were quoted in Gregg's volume, *The Commerce of the Prairie* (Gregg, 1844: 243-44), which was popular after 1844. Through these and other accounts many Americans became familiar with the animal, its common name and human-like character.

Prairie dogs offered diversion to the U.S. cavalry stationed in remote forts in the Southwest. Mearns quotes an 1885 letter from his friend, Dr. Paul Clendennin, stationed at Ft. Davis, Texas, "There are lots of prairie dogs all around the fort. They are very tame indeed, and it is very amusing to watch them" (1907:344). The social disposition of the animal is extolled in a letter written by Charles E. Whilden, a young Army clerk on his way to Santa Fe in 1855:

> Prairie dogs, a very harmless Animal living in Villages underground, and looking more like large Squirrels than dogs, having their own constitution and laws as they say with perfect happiness in company with Rattlesnakes and Owls (Moore: 1965:145).

Children were especially fond of prairie dogs in the remote regions of the Southwest. Prairie dogs were common children's pets in the southwest territories. In Mearns' *Mammals of the Boundary Survey* he writes about the prairie dogs in Arizona,

> An interesting chapter might be written under the caption of 'the prairie dog as pet,' to which every army youngster could contribute something of interest from personal experience. In captivity it is playful, and makes an extraordinarily bright and agreeable pet (Mearns, 1907:347).

Luis Curry tells of his fond memories of prairie dogs in a memoir of his childhood near Rucker Creek in Cochise County in 1906:

> The little fellows would run from one hole to another—maybe 20 or 30 feet--and they'd sit in their hole and look up at you, bark at you and wiggle their little tails. Then all of a sudden you'd see those little ground owls, or burrowing owls. It was a lot of fun to go through the prairie dog town. (Curry, 1997).

Despite such fondness and Kendall's emotional fore-swearing of hunting prairie dogs for pleasure, American's greeted prairie dogs with the usual battery of enthusiasm --gunfire (Doughty, 1983: 82). Shooting prairie dogs for pure sport was a common pastime on military and civilian expeditions.

Gregg (1844:241) recounts that during his expedition on the Santa Fe Trail that prairie dogs were, "heedless of the danger that awaited them from the rifles of our party; for perhaps they had never seen such deadly weapons before". Smithwick (1968:13-16) recounts the poor luck his emigrant party had in shooting prairie dogs as they passed through their towns, "Many pounds of lead were thrown away in the vain attempt to kill a prairie dog."

Clark Streator, studying a colony of prairie dogs near Fort Bayard and Silver City for the BBS in 1892, stated that, "They were the wildest I have ever seen and it was almost impossible to get within shooting distance of them. This was no doubt owing to their being continually used as targets by local sportsmen"(Streator, 1892). A few years later Mearns (1907:343) wrote, "I have seen two troops of cavalry dismount and open fire on them [prairie dogs] for several minutes without frightening them into their burrows."

In the meantime, new scientific descriptions were made of prairie dog species and sub-species during the latter half of the 19th century. Baird's *Mammals of North America*, published in 1857, recognized two species of Cynomys, one black-tailed group, called *C.ludovicianus* and a white-tailed group with the proposed name of *C. gunnisoni*. A new species was described from Wyoming, and later substantiated and named *Cynomys leucurus* by Merriam in 1890. That same year Mearns described a southwestern form of the *ludovicianus* type as *Cynomys arizonensis*. In 1892, Merriam described and named the Mexican prairie dog, *C. mexicanus*.

The BBS took a keen interest in these new taxonomic groups and biologists were dispatched to the Southwest to study their distribution and habits (Merriam, 1902).

One of the qualities possessed by prairie dogs that intrigued many newcomers to the arid southwest was their ability to survive without any nearby source of surface water. Stories circulated among prairie trail guides about prairie dogs burrowing down to groundwater. Kendall (1935:192) first described this understanding, "When they [prairie dogs] find a good location for a village, and there is no water in the immediate vicinity, old hunters say, they dig a well to supply the wants of the community."

Gregg (1844: 381) also alludes to the possibility that prairie dogs may dig down to water, "They must need but little water, if any at all, as their 'towns' are often, indeed generally, found in the midst of the most arid plains—unless we suppose they dig down to subterranean fountains. At least they evidently burrow remarkably deep."

Bailey spent considerable time studying the habits of prairie dogs and in 1892, discussed the subject of prairie dogs digging for water:

> It is a common belief that a prairie dog town always goes down to water, but the belief seems to be based on the question, 'how can they live without water?' It is true that their holes often appear to be very deep, and in some places they might easily reach down to subterranean water, but that this is not always the case there is positive proof. Throughout much of the range of the prairie dog water is not found within several hundred feet of the surface, as at Sierra Blanca, Texas, where they are common and water is reached only after drilling to a depth of 900 feet. . . (Bailey, 1892)

In 1901, Merriam also tried to dispell what must have been a commonly held belief about prairie dogs and water, "With respect to the theory that their burrows are deep enough to reach water, it need only be said that in some of the dog towns artesian wells have been sunk to the depth of 1,000 feet without striking water" (Merriam, 1901:259).

In 1907, Mearns, provides further evidence that this was a widely held understanding:

> The source whence the prairie dogs derives the water necessary for its subsistence is a fruitful topic of discussion among frontiersmen. Some assert that it requires no water for drinking; others maintaining that it digs deep wells, some of which are recognizable by the unusually large mounds about their entrances and the wet tracks of the animals returned from drinking (Mearns, 1907: 343).

Mearns then quotes Stewart Daniels as providing him with the following information regarding the use of a prairie dog colony to aid in the location of water:

> Major Jack Martin, of the California Volunteers, in response to an offer of a sum of money by the United States Government to any person who would find water on this desert [the Jornada del Muerto], resolved to try and selected the only prairie-dog "town" on the route for the scene of his operations. After sinking to the depth of about 90 feet, an abundance of excellent water was obtained (Mearns, 1907:344).

In fact, the location of the first well dug in 1870 on the Jornada del Muerto is at Aleman, also listed in the General Land Office records of 1882 as "Martin's Well" (Marshall and Walt, 1984:242). Regardless of the scientific truth of the matter, the belief that prairie dogs could help locate water in the desert may very well have left a legacy in the physical landscape. Perhaps many wells were originally dug within prairie dog towns in the belief that water was close to the surface.

These combined sources suggest that early American encounters with prairie dogs produced empathy. People admired and enjoyed the animals for their sociability, intelligence, friendliness and playfulness. These qualities and their habit of barking at intruders reminded people of dogs. Settlers also believed that the prairie dog town offered a clue to the location of groundwater, a key to survival in the desert grasslands.

Making Pests of Them (1890-1974)

After control of the new territory was wrested from Mexico and indigenous tribes in the 1880s, Anglo settlement began in earnest, and novelties such as prairie dogs lost their appeal. The harsh economic and ecological limitations of the region became apparent. Lucrative government contracts for hay, cattle and horses for the Apache Wars and Indian resettlement programs were the mainstay of local economics from the 1860s to the 1880s (Wagoner, 1951a; Miller, 1989). These contracts were phased out after 1886, although cattle herds continued to increase (Miller, 1989). By 1891 the cattle ranges were severely overstocked, when a 2-year drought decimated herds and caused widespread economic hardship in Arizona and southwestern New Mexico (Wagoner, 1952).

Human conflict became particularly acute over the use of the fertile valleys and broad bottomlands, where the best year-round grasses and permanent water supplies existed (Wagoner, 1951b:22). Besides being essential for successful ranching, these areas were also desirable for crops and hay-mowing (Miller, 1989). These same bottomlands and river terraces were heavily colonized by Arizona black-tailed prairie dogs, making conflict between agriculture and the native herbivores inevitable. It was in this context that Bailey (1892:5) wrote from New

Mexico that, "prairie dogs, like the Indian, think that they have the first and best right to the country, and do not readily give up their possessions."

References to prairie dogs in newspapers and popular publications become very scarce from 1890 to 1920. Regional periodicals, handbooks and popular publications on the wildlife of Arizona and New Mexico are virtually silent about prairie dogs, preferring to extol the advantages of settlement in the Arizona and New Mexico Territories. Perhaps the American's interest in regional wildlife had waned or, more likely, talking about prairie dogs had become "uncivilized," or backward and unattractive to potential investors and settlers.

The early formulation of the pest concept can be laid on the shoulders of three prominent biologists working at the turn-of-the-century: Mearns, Bailey, and Merriam. Scientists from this period described wildlife as "good" or "bad" in the effort to formulate official opinion and policies towards wildlife (Merriam, 1901; Doughty, 1983; Bailey, 1932; Jencks, 1929). They also studied methods of extermination for injurious species, including prairie dogs (Merriam, 1901; Doughty, 1983: Bailey, 1932:4). Prairie dogs became one of several species identified by scientists of the period as injurious to the economic interests of the region, damaging crops and reducing grass cover (Merriam, 1902). Observations by professional biologists after 1890 began to characterize prairie dogs as destructive pests.

Mearns maintains an old fashioned attitude of affection for the animals and never labeled prairie dogs as pests. His scientific observations about the habits of Arizona black-tailed prairie dogs, however, take on a negative note. He writes:

> Here [Sierra Bonito, Arizona] the "dogs" fairly reveled and overran the country. As we rode amongst them their sharp barking was incessant and their tameness surprising...The energy of their barking and accompanying bobbing motion of their bodies are amusing; but, to the weary traveler in the arid wastes usually accompanied by these barking squirrels, their incessant cries soon become wearisome, if not positively annoying, from the fancied challenge conveyed by their harsh tones and insolent bearing. (Mearns, 1907:342-343)

Mearns also writes of the destructiveness of the Arizona prairie dog, "Its propensity for undermining walls of the buildings and digging up yards is regarded as reprehensible by some."1907:347).

But a hand-written manuscript by Bailey (1892), titled "*Cynomys ludovicianus*," found in the Smithsonian Institution Archives, makes the first clear case for prairie dogs as pests and first mentions schemes for prairie dog poisoning and trapping. He states,

> A low thick buffalo grass (*Buchloë dactyloides*) that is abundant throughout most of their range seems to be a favorite food. It is dug up and the tender, blanched bottom of the stalk is eaten, sometimes the leaves are all eaten and sometimes left lying on the ground with the roots. When dug up this grass does not come in again on the same ground...(Bailey, 1892: 8).

Bailey (1932:3) believed that prairie dogs cause economic damage by eating grass, digging up and eating the roots of grasses, and by destroying grass cover. He also indicates that prairie dogs damage cultivated crops and their holes may cause injury to horses and cattle in this passage:

> If a dogtown is plowed and sown to grain they do not leave but clean out their holes or dig new ones and live on the grain that grows around them. Considerable grain will be destroyed, and in plowing over their holes there is danger of the horses breaking their legs by stepping into holes (Bailey, 1982:13).

The first report indicating that horses or livestock were injured as a result of stepping in their burrows is found in Bailey's 1892 manuscript, as well, despite numerous opportunities for such incidents to have occurred along inter-fort trails and wagon roads in the Southwest. Bailey (1892) did not observe any injuries himself, as he states:

> There is a danger of the horses breaking their legs by stepping into holes. On rare occasions a horse running loose or being ridden steps into one of their holes and breaks its leg, though in several years among ranches in the west I have known of but one such accident (Bailey,1892:13).

From this quote it seems as if stories of horse accidents were already circulating among stockmen, though Bailey seems unconvinced of their veracity.

Merriam relied heavily on the reports of Bailey and other biologists to write his article, "The Prairie Dog of the Great Plains," for the 1901 *Yearbook of the Department of Agriculture*. The article is effectively a political position paper that laid the persuasive cornerstone for the idea of prairie dogs as an aggressive pest in need of government-subsidized eradication efforts.

He reports statistics on the largest colonies of prairie dogs: one colony occupied "25,000 square miles in Texas," and, "nearly one third of Grant County, New Mexico" (Merriam, 1902:258). The prairie dog's appetite for grass is described in terms that every stockman could understand: "32 prairie dogs consume as much grass as 1 sheep, and 256 prairie dogs as much as 1 cow" (Merriam, 1902:258). Merriam states that, according to Professor W. W. Cooke, the grass consumed by prairie dogs on the "great Texas colony" would have supported 1,562,500 head of cattle (Merriam, 1902:258).

Merriam lists other forms of destructiveness attributed to prairie dogs such as damaging agricultural crops, causing irrigation ditches to wash out, and causing injury to livestock and riders when animals step into burrows. In this last point, he ignores Bailey's reservations and declares that, "Running horses often trip and break their legs, and riders are sometimes injured and even killed" (Merriam, 1902:265). No examples are provided, however.

Merriam argues that prairie dogs had increased in both population and range since the coming of the "white man" due to increased food (agricultural crops) and decreased predation. He then provides a lengthy description of various methods of extermination and encourages the passage of legislation and appropriations for organized extermination programs (1902:266-269). The article is a masterful piece of propaganda designed to expand the role of the BBS in prairie dog eradication.

By the 1930s, Bailey had become the spokesperson for prairie dog eradication. He implies in his writings that the animals have value only to Native Americans and children:

> Among Navajo Indians the Zuni prairie dogs have considerable value as game and food. . .When taken young and well tamed prairie dogs are said to make delightful pets for children, and this might give them a real value and fill a long-felt need. On the other hand, their great abundance and the extent of country over which they abound renders them one of the most injurious of rodent pests (Bailey, 1932:130).

Bailey and other scientists of the age staunchly defended the concepts of utilitarian management of wildlife and vehemently rejected newly circulating concepts of a balance of nature. They targeted the prairie dog as the primary impediment to economic progress in the semi-arid West.

HISTORIC DISTRIBUTION OF THE ARIZONA BLACK-TAILED PRAIRIE DOG

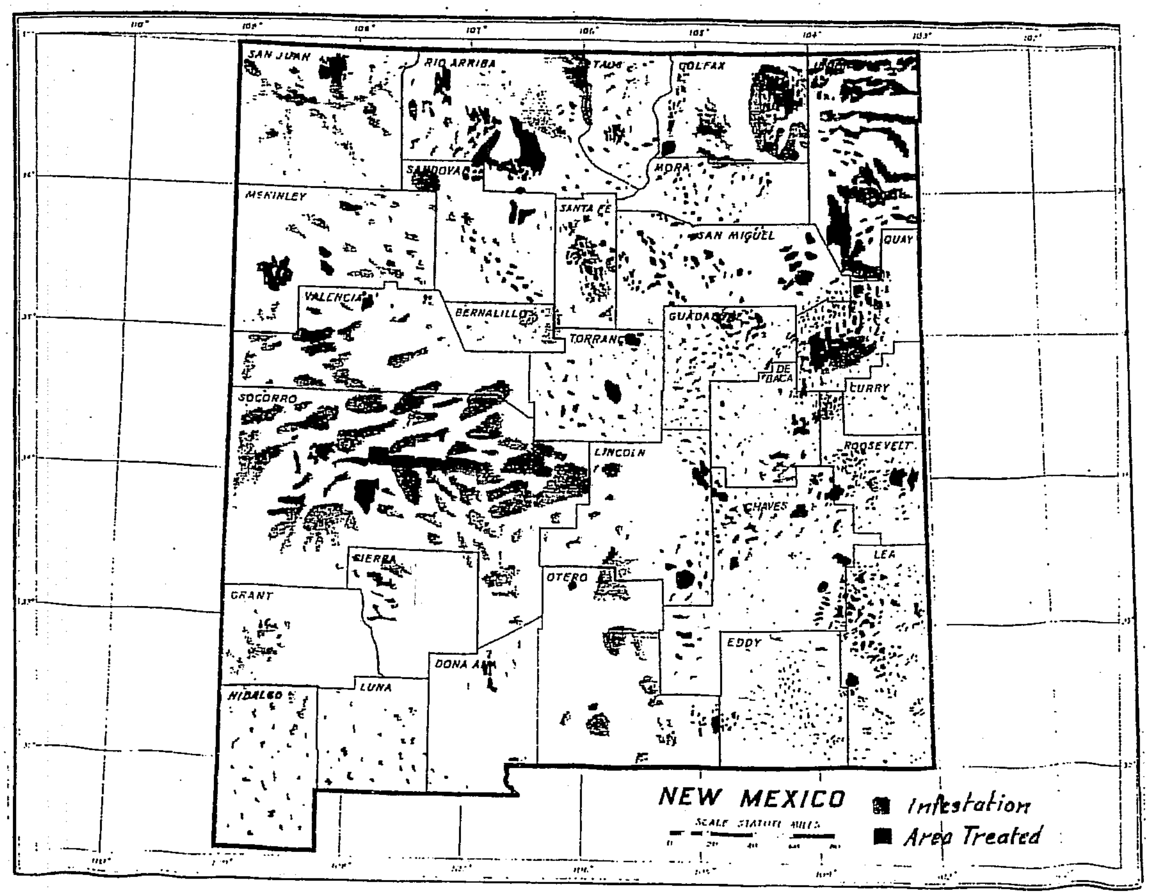
In 1916, Hollister (1916) published "A Systematic Account of Prairie Dogs" to establish the taxonomy of the genus based on a study of 876 specimens. Two subspecies of *Cynomys ludovicianus* are recognized: *C. ludovicianus ludovicianus*, the plains black-tailed prairie dog, and *C. ludovicianus arizonensis,* the Arizona black-tailed prairie dog. All scientific documents between 1916 and 1986 regarding prairie dogs in the study area refer to Arizona black-tailed prairie dogs, *Cynomys ludovicianus arizonensis*, so well accepted was this nomenclature.

Historic data on the locations of Arizona black-tailed prairie dog colonies is presented by county for U.S. portions of the study area. These counties include Cochise, Graham and Greenlee in Arizona, and Grant, Hidalgo, Luna, Sierra and Doña Ana in New Mexico. Data from Chihuahua and Sonora are treated together.

Grant County consisted of all the territory between the Gila River and the Mexican border in the "boot heel" of New Mexico, including all of Hidalgo County during the early Territorial Period until it was divided in 1923 (Couchman, 1990). I have separated sites into the appropriate modern county boundaries.

A hand-colored map of all major "prairie dog infestations" in 1920 New Mexico, produced by the BBS (Figure 3.1) proved to be an important source of information on the locations of prairie dogs. The accuracy and usefulness of the BBS 1920 map is evaluated by comparing the information it contains with that of other sources, including written and eye-witness accounts. Similar early maps were not found for either Arizona or Mexico.

Figure 3.1. BBS New Mexico Prairie Dog Map, 1920 (Source: BBS Annual Report, New Mexico, 1921). Note: Photo-facsimile not to original scale.



Prairie Dog Infestation Map, showing areas treated prior to Dec. 31, 1920.

Sierra County, New Mexico

The primary records of Sierra County proved to be especially diverse, colorful and old. A total of 17 primary sources (Table 3.1) provided information on the location and sometimes the extent of dogtowns, resulting in 22 site locations shown in Figure 3.2.

The Camino Real through the Jornada del Muerto, shown in Figure 2.1, is the location of the earliest records regarding prairie dogs in the study area. This record is from the historical account of Otermín's retreat in 1680 during the Pueblo Revolt down the Camino Real. Auto of Xavier refers to the northern end of the Jornada del Muerto as "*Paraje de las Tusas*" and "*El Alto de Las Tusas*". Marshall and Walt (1884:241) have determined that this name refers to prairie dog colonies that formerly existed there, based on references by Gregg (1844:138) and Julyan (Julyan, 1993:217; Pearce, 1965:172). The implication is that a large prairie dog colony existed in the broad valley along the alluvial toeslope east of the Fra Cristobal Mountains where the Camino Real passes near Red Lake, an intermittent shallow playa (Fig. 3.2 Ref. # S1).

The Jornada del Muerto was a vital short cut that saved approximately 40 miles of difficult travel along the Rio Grande. The trade-off was a more direct route, though waterless and without any settlements during the Spanish Colonial Period. Prior to 1680, travel was extremely light on the Camino Real, with mission supply trains making a round trip between Santa Fe and Chihuahua once every three years until the Pueblo Revolt (Ivey, 1993: 43).

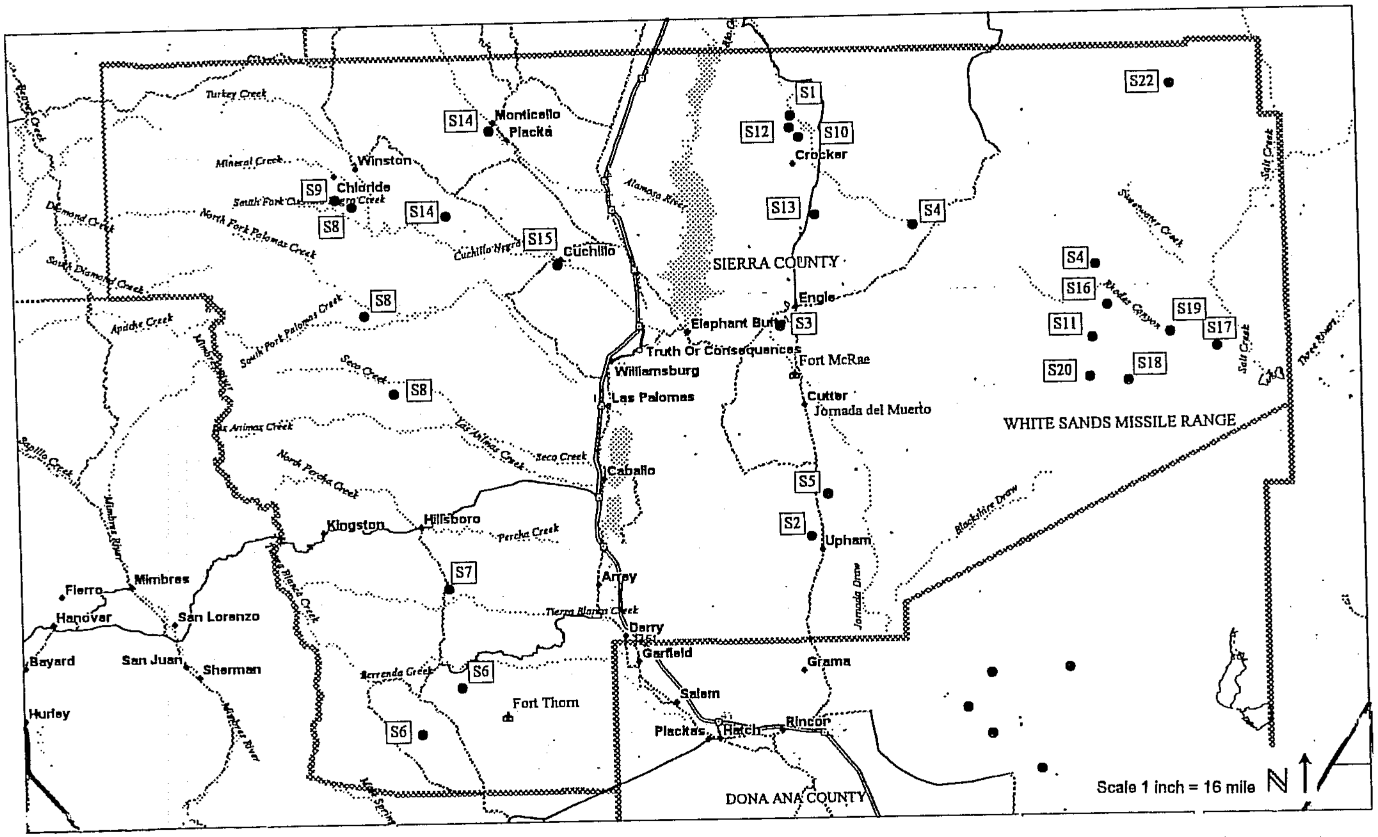
Table 3.1 Historic Records of Prairie Dog Colonies in Sierra County, New Mexico

Ref #	Year	Author	Location	Colony Size	Reference
S1	1682	Auto of Xavier	Jornada del Muerto, between Fra Cristobal and Ojo de Anaya	Not mentioned	Hackett and Shelby (1942) Marshall and Walt (1984: 241)
S2	1846	George F. Ruxton	Jornada del Muerto, along the Camino Real	"prairie dog towns every few miles"	Ruxton, 1847:172
S3	1847	Susan Shelby Magoffin	Jornada del Muerto, Laguna del Muerto (Engle)	"far and wide around"	Drumm, 1926: 198
S4	1892	J. H. Gaut	"both slopes of San Andres Mountains	Not mentioned	Bailey, 1931
S5	1907	Stewart Daniels	Aleman, Jornada del Muerto	Not mentioned	quoted in Mearns, 1907: 344
S6	1909	Goldman	South and East of Lake Valley	Not mentioned	Bailey, 1931; Hollister, 1916
S7	1909	Goldman	8 mi. North of Lake Valley	Not mentioned	Bailey , 1931; Hollister, 1916
S8	1920	BBS Annual Reports, 1920	River drainages on east flank of Black Range	Not mentioned	BBS, NM Annual Reports, 1921
S9	unkn.	USNM collection	Chloride	Not mentioned	Findley, 1976
S10	1920	BBS, 1920	Jornada del Muerto, basin east of Fra Cristobal Mtns.	Not mentioned	BBS, NM Annual Reports, 1921
S11	1920	BBS, 1920	Basin on east side of San Andres Mtns.	Not mentioned	*Op. Cit.*
S12	1930	Joe Turner	Near Red Lake	Several colonies, "real thick"	Interview with Joe Turner (Appendix A)

Table 3.1 Historic Records of Prairie Dog Colonies in Sierra County, New Mexico (Cont.)

Ref. #	Year	Author	Location	Colony Size	Reference
S13	Before 1930	Joe Turner	Deep Well, Jornada del Muerto	Large area	Interview with Joe Turner (Appendix A)
S14	Before 1938	W. Youngblood	HOK Ranch	Not mentioned	Interview with Wort Youngblood (Appendix A)
S15	1938	W. Youngblood	Around Cuchillo and Monticello	All along the valley	Interview with Wort Youngblood, (Appendix A)
S16	1941-44	Luis Cain	Draw north of Rhoades Canyon Road, San Andres Mtns	½ mile long and ¼ mi. wide	Interview with Luis Cain, (Appendix A)
S17	1972	Annon.	WSMR: North of old Tularosa Hwy and west of Salt Creek	Not mentioned, map only	W.S.M.R. Biological records, annon. map of historic colony sites
S18	1964	A. F. Halloran	WSMR: Mouth of Cottonwood Canyon, west of WSMR road 7	Not mentioned	W.S.M.R. Biological records
S19	1978	D. Hansen	WSMR: ¼ mi. southwest of Rhoades Range Center	Not mentioned	W.S.M.R. Biological records, map and notes
S20	1972	Annon.	WSMR:1 mi. southwest of Rhoades Range Center	Not mentioned	W. S. M. R. Biological records, Annon. Map
S21	1982	José Olguín	North end of Jornada del Muerto	Many acres	Marshall and Walt, 1984: 241
S22	Before 1996	Dave Holderman	WSMR: north end of San Andres Mtns	>50 acres	Interview with Dave Holderman, (Appendix A)

Figure 3.2. Historic Locations of Prairie Dog Colonies in Sierra County, New Mexico



During the Spanish and Mexican Periods, the region was considered too arid for settlement and no missions were established there (Marshall and Walt, 1984: 259). Apache depredations had become frequent during the Mexican Period, attacking livestock traders and travelers along the Camino Real and elsewhere in Sierra county and preventing permanent settlement (Gregg, 1844). The fact that Don Pedro Armendaris obtained a Mexican land grant for the northern end of the Jornada del Muerto in 1819-20 is testimony to the abundant grass in the area. He was forced, however, to abandon his lands in 1824 because of repeated Indian attacks (Marshall and Walt, 1984: 262).

Two references to prairie dogs on the Jornada del Muerto date from the very end of the Mexican Period in New Mexico. George F. Ruxton accompanied a trading party on the Chihuahua Trail north out of Mexico in 1846. He departed from the Rio Grande at San Diego and entered the Jornada del Muerto. He writes, "Large herds of antelope bounded past, and coyotes skulked along the trail, and prairie dog towns were met every few miles, but their inmates were snug in their winter quarters, and only made their appearance to bask in the meridian sun" (Ruxton, 1973: 172). It is evident that there were several colonies present in the Jornada, but the exact number, location and size are not given (Fig. 3.2, Ref. # S2).

Magoffin accompanied her husband across the Jornada del Muerto with Doniphan's troops in 1847. Her diary (Drumm, 1926:198) notes an extensive prairie dog colony near Laguna del Muerto: "The little prairie dogs have spread their habitation far and wide around and the whole puts on a gloomy aspect." The colony at Laguna del Muerto (Fig. 3.2, Ref. # S3) described by Magoffin was probably quite large, for the land is open and visible for a great distance.

Ruxton and Magoffin's accounts of prairie dogs on the northern Jornada del Muerto coincide with a period of intensive livestock grazing along the main trail. Even though there were no settlements or permanent herds of cattle on the Jornada del Muerto during the Mexican Period, large flocks of sheep regularly passed along the trail in the mid-1800s. Three locations are mentioned as regular stop-overs on the arid Jornada del Muerto: *Ojo de Anaya* , now known as Tucson Springs, *Laguna del Muerto*, now Engle Lake, and *La Cruz de Alémam*, now called Aleman (Marshall, 1984: 242-43). Sheep drives averaged over 30,000 wethers per year after Mexican independence, with individual drives of 2,000-5,000 animals passing through the Jornada del Muerto several times per year (Baxter, 1993: 106).

During the American Territorial Period (1846-1912) the Jornada del Muerto was hailed as a verdant pasture, but used primarily as a transportation route until the first successful water well was sunk in 1870. Fort McRae was established in the Jornada del Muerto near a small spring northwest of Aleman in 1869 (Marshall, 1984:242). The military used the Jornada as an inter-fort trail connecting Fort Selden, Fort McRae and Fort Craig until 1879. The Atcheson Topeka and Santa Fe Railroad, built in 1881, also closely followed the old *Camino Real* across the Jornada del Muerto (Williams, 1986: 123). Lack of surface water, however, severely limited cattle ranching on the Jornada del Muerto. Ultimately, the prairie dog led American settlers to water: Mr. Martin, believing that prairie dogs dug down to groundwater, dug the first successful well in 1870 by locating it on a dogtown at present day Aleman (Fig. 3.2, Ref. # S4).

The BBS mapped an extensive colony along the northern end of the Jornada del Muerto in 1920. This mapped location shows a linear colony approximately 25 miles long on the east side of the Fra Cristobal Mountains (Fig. 3.2, Ref. # S10). The same location is verified by an ethnographic interview with an elderly Hispanic man, published in Marshall and Walt's (1984:241) historical work on the Camino Real. In this 1982 interview, Mr. Olguín states that the north end of the Jornada del Muerto was known as *Las Tusas* by the Hispanics in the area because "acres of prairie dog towns that exist in that area" (Fig. 3.2, Ref. # S21).

In 1892, James Hamilton Gaut, a biologist working for the Division of Economic Ornithology and Mammalogy, surveyed portions of Sierra County for mammals and found Arizona black-tailed prairie dogs (Fig. 3.2, Ref. # S5) on both the eastern and western slopes of the San Andres Mountains (Bailey, 1932:123).

In Sierra County west of the Rio Grande, there are few early records of prairie dogs. In 1909, Goldman recorded them south and east of the town of Lake Valley (distance unknown) and 8 miles north of Lake Valley (Bailey, 1932:124) (Fig. 3.2, Ref. # S6 and S7). Lake Valley was a highly productive silver mining center from 1878 until 1895. An Arizona black-tailed prairie dog specimen was reported in Hollister's (1916) review of prairie dogs as being collected from the vicinity of Chloride, a mining town in the northwest corner of Sierra County (Fig. 3.2, Ref. # S9).

In addition to the colony on the north end of the Jornada del Muerto, the BBS 1920 prairie dog map shows prairie dogs in the major drainages flowing east out of the Black Range, such as the Alamosa, Cuchillo Negro, Palomas and Percha rivers (Fig. 3.2, Ref. # S8). A very large colony area appears in the San Andres Mountains centered around Rhoades Canyon and other drainages leading outward from the mountains to the east and the west (Fig. 3.2, Ref. # S11).

Personal interviews with long-time residents of Sierra County yielded additional information on prairie dog locations. Joe Turner worked as a cowboy on the north end of the Jornada del Muerto between 1930 and the 1980s and still resides there. He reported several colonies in the valley all around Red Lake and Lava Camp, with the last observation in 1960 (Fig. 3.2, Ref. # S12). He also reported that there was a very large area of empty burrows just north of Deep Well, the largest and earliest well on the ranch (Fig. 3.2, Ref. # S13).

Three long-time residents of the area provided information about prairie dog locations in the 1930s and 1940s. Turner on the Jornada del Muerto, began working as a cowboy on ranches on the Pedro Armendaris Land Grant from 1930 through the 1960s. In the earlier years, he remembered many prairie dog colonies along the valley at the eastern base of the Fra Cristobal Mountains. He recalled that some animals remained between Red Lake and Lava Tank until 1960 (Fig. 3.2, Ref. # S12). He also remembered that there was an empty dogtown near Deep Well on the Pedro Armendaris Land Grant in 1930 (Fig. 3.2, Ref. # S13). He recalled that there were numerous empty burrows that made riding very treacherous that year and that the hired hands had poisoned the prairie dogs one or two years earlier.

Wort Youngblood of Truth or Consequences, New Mexico worked for the rodent control operations of the BBS in the 1930s, poisoning prairie dogs in Sierra County. The BBS organized operations and supplied poison grain, with labor supplied through the CCC. He remembered seeing prairie dogs on the HOK Ranch, in Cuchillo Valley and around Monticello in 1938 (Fig. 3.2, Ref. # S14, S15).

Luis Cain of Aleman on the Jornada del Muerto provided information on prairie dogs in Sierra County. He stated that there were no prairie dogs in the Aleman area (near Ref # S2,S3 and S5) when his family arrived there in the early 1950s, but he remembered a dogtown on the eastern flanks of the San Andres Mountains. From 1941 through 1943 his job included driving cattle out of the San Andres Mountains and across the Tularosa Basin. He remembered a prairie dog town in a draw on the north side of the old Rhoades Canyon Road, locating it on a topographic map (Fig. 3.2, Ref. # S16).

Records from the biological files of White Sands Missile Range (WSMR) showed prairie dog towns around a dry lakebed west of Salt Creek and north of the Tularosa Highway, at the mouth of Cottownwood Canyon below Gunsight Peak, just southwest of the Rhoades Range Center and about 1 mile further south (Table 3.1, Fig. 3.2, Ref. # S17-S20). These sites are mostly along the eastern flank of the San Andres Mountains, at the edge of the Tularosa Basin. The last records are dated from the 1960s and early 70s. V. W. Howard, wildlife biologist with New Mexico State University, conducted a wildlife survey on WSMR in 1975. He indicated that the colonies on the flanks of the San Andres Mountains and Tularosa Basin had disappeared (Appendix A).

WSMR wildlife biologist, Dave Holderman, reported conducting unsuccessful helicopter searches for active prairie dog colonies in 1995. He reported finding one recently empty colony site just northwest of Mockingbird Pass at the north end of the San Andres Mountains (Figure 3.1, Ref. # S23) (Appendix A).

These historical records suggest that Arizona black-tailed prairie dogs occupied alluvial valleys where runoff was reliable, and along playa terraces in the internally-draining Tularosa Basin and Jornada del Muerto. No records of colonies in the Rio Grande Valley were found. One citation shows that prairie dog colonies pre-dated intensive livestock grazing in Sierra County. The record from 1680 implies that prairie dogs were common on the northern Jornada del Muerto before heavy livestock use.

Doña Ana County, New Mexico

Eight references show prairie dog colonies in Doña Ana County (Table 3.2). These yielded a total of 15 general locations, some with multiple colonies. These are shown in Figure 3.3, as locations D1 through D15. Although few in number, these sources are especially detailed.

Wislizenus traveled on the Jornada del Muerto in 1848, but made no mention of prairie dogs (Wislizenus, 1848:38-39). Nor did Marcy, who traveled from Mesilla east and over St. Augustine Pass in the Organ Mountains in 1850.

Then in 1855, Kennerly crossed the southern portion of Doña Ana County on route from El Paso to Arizona and stated that "...a very large extent of country in southern New Mexico was covered by prairie dog burrows" (Baird, 1859). Perhaps some colonies were encountered in the western part of the Doña Ana County where he traveled, but it is uncertain.

The first confirmed record of prairie dogs in Doña Ana County comes from the General Land Survey, conducted on the southern end of the Jornada del Muerto from 1856 through 1858 (Buffington and Herbel, 1965) (Table 3.2, Ref. # D1). While it was not mandatory that surveyors record information on fauna, the surveyors mentioned prairie dogs along four section lines in an area that later became part of the JER: T18S, R1and R2E, between sections 31 and 36 (western ½); T18S, R2E, between sections 30 and 31 (western ½); T18S and T19S, R1E, between sections 1 and 36 (eastern ½); T19S, R1and R2E, between sections 1 and 6 (southern ¾) (New Mexico General Land Office, 1857).

Specimens of *C. ludovicianus* were collected prior to 1916 near Organ City and at an unnamed location on the Jornada del Muerto mentioned in Hollister's (1916) systematic study of the Arizona black-tailed prairie dogs (Table 3.2, Fig. 3.3, Ref. # D2, D3). A series of letters and detailed maps of prairie dog towns found in the archives of the JER indicate that 2,500 acres of prairie dog towns existed on the newly purchased JER, formerly the Turney Ranch, on the southern Jornada del Muerto. Maps drawn the following year show the location of an additional 1,950 acres on (Appendix B and Table 3.2, Fig. 3.3, Ref. # D4, D5).

Table 3.2. Historic Records of Prairie Dog Colonies, Doña Ana County, New Mexico.

Ref. #	Year	Author	Location	Size Of Colony	Reference
D1	1858	General Land Survey	Jornada del Muerto (south end)	Extensive	General Land Office Survey Records of 1858.
D2	before 1916	USNM collection	1 mi. east of Organ City	Specimens only	Hollister, 1916; Findley, 1976
D3	before 1916	USNM collection	Jornada del Muerto	Specimens only	Hollister, 1916; Findley, 1976
D4	1917	G. Hurtt	JER	3,500-4,000 acres	Hurtt, 1917
D5	1917	Fred Quesenberry	JER	17 locations, 10-464 acres each	JER, Prairie Dog Maps, 1917
D6	1918	BBS	JER	7,045 acres	BBS, NM Annual Reports, 1918
D7	1918	BBS Annual Reports, 1918	Cox Range (southern end of San Andres Mountains)	5,500 acres	*Op. Cit.*
D8	1918	BBS Annual Reports, 1918	Issack Range (south of JER)	1000 acres	*Op. Cit.*
D9	1918	BBS, Annual Reports, 1918	Mossman Range, southeast of Las Cruces	650 acres	*Op. Cit.*
D10	1920	BBS, 1921	South end, Jornada del Muerto	Not mentioned	BBS, NM Annual Reports, 1921
D11	1920	BBS, 1921	Plains at north end of Franklin Mtns, east of Anthony	Not mentioned	*Op. Cit.*

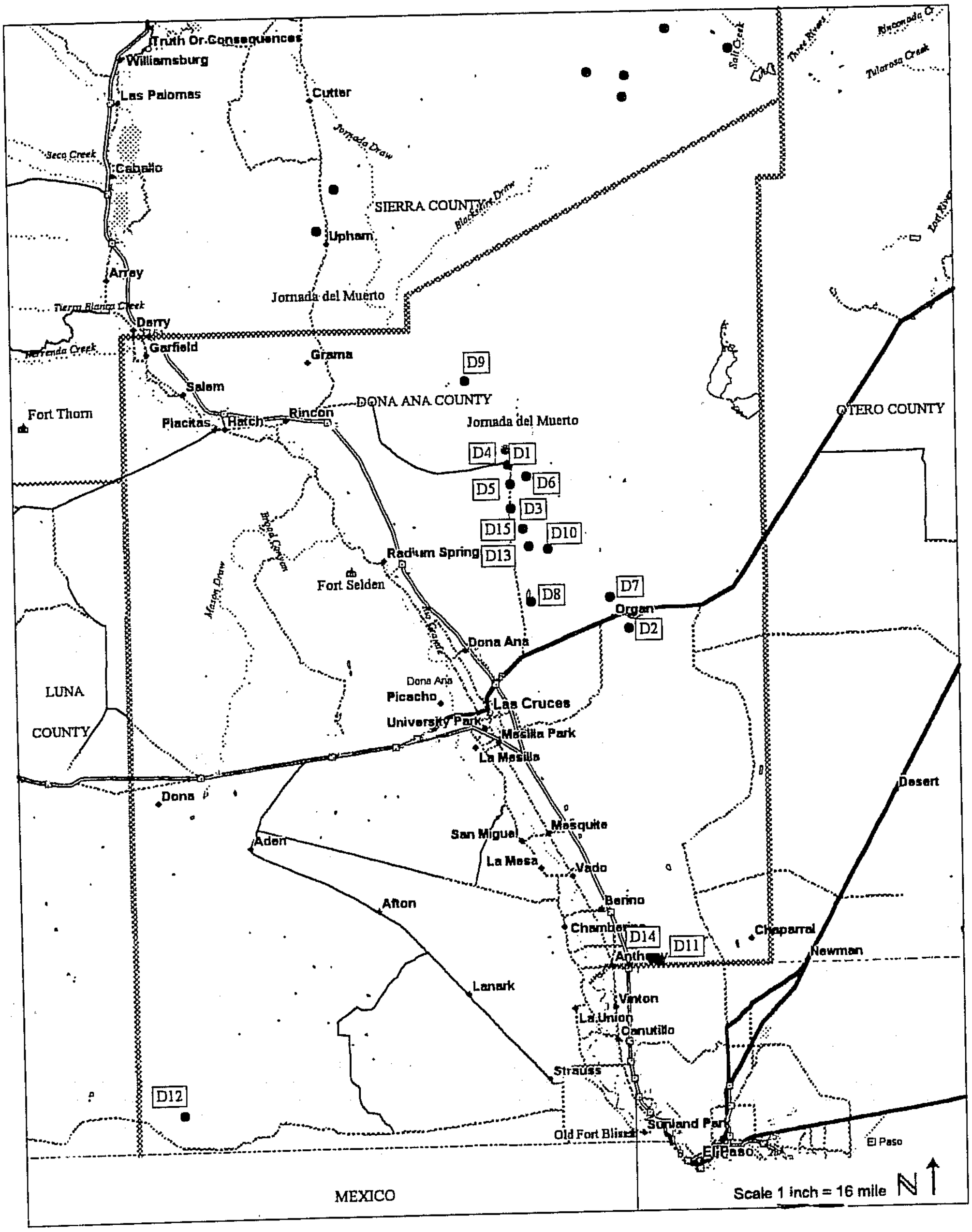
Table 3.2. Historic Records of Prairie Dog Colonies, Doña Ana County, New Mexico (Cont.)

Ref. #	Year	Author	Location	Size Of Colony	Reference
D12	1920	BBS, 1921	East and west of Potrillo Mtns.	Not mentioned	*Op. Cit.*
D13	1923 -24	J. C. Gatlin	JER and adjacent ranges	28,500 acres total	BBS, NM Annual Report, 1924
D14	1922 -23	J. C. Gatlin	U.S. Target Range, southeast of Anthony	Many large colonies	BBS, NM Annual Report, 1923
D15	1934	BBS	JER near Stewart Well	580 acres	BBS, NM Annual Reports, 1934

Records from the 1918 Annual Reports of the BBS indicate that a 7,045 acre prairie dog "infestation" was poisoned on the JER (Table 3.2, Fig.3.3 Ref. # D6). The BBS report also indicates that prairie dog colonies totaling 5,500 acres were found on the Cox Range, on lands at the southern flanks of the San Andres Mountains (Table 3.2, Fig.3.3, Ref. # D7, D8, D9). In addition, the BBS 1918 report shows that 1,000 acres of dogtowns existed on the Isaack Range immediately south of the JER and 650 acres existed on the Mossman Range on lands to the southeast of Las Cruces.

The New Mexico map produced by the BBS depicting prairie dog areas in 1920 (Fig. 3.1) confirms these dogtown locations in the southern end of the Jornada del Muerto, and shows that they were poisoned prior to December, 1920 (Table, 3.2, Fig. 3.3, Ref # D10).

Figure 3.3. Historic Locations of Prairie Dog Colonies, Doña Ana County, New Mexico



This map also shows prairie dog towns located east of Anthony, on the north flank of the Franklin Mountains (Table 3.2, Fig. 3.3, Ref # D11) and around the west and east Potrillo Mountains, a series of low hills in the southwestern corner of the County (Table 3.2, Fig. 3.3, Ref # D12).

Records from the 1923-24 annual report of the New Mexico Division of the BBS show 28,500 acres of prairie dogs towns located on several private ranches on the Jornada del Muerto (Table, 3.2, Fig. 3.3, Ref. # D13). The BBS annual report from 1922-23 indicates that extensive colonies existed on the U.S. Target Range, southeast of Anthony (Table 3.2, Fig. 3.2, Ref. # D14). The final record of prairie dogs in Doña Ana County comes from the JER, where a 580-acre colony was reported near Stewart Well Table 3.2, Fig. 3.3, Ref. # D15).

Of the records from Doña Ana County, the General Land Survey notes from 1856-58, showing a large colony at the southern end of the Jornada del Muerto, is the only record which predates intensive cattle grazing. Lack of surface water and Apache hostilities kept cattle and other livestock off this area at this time.

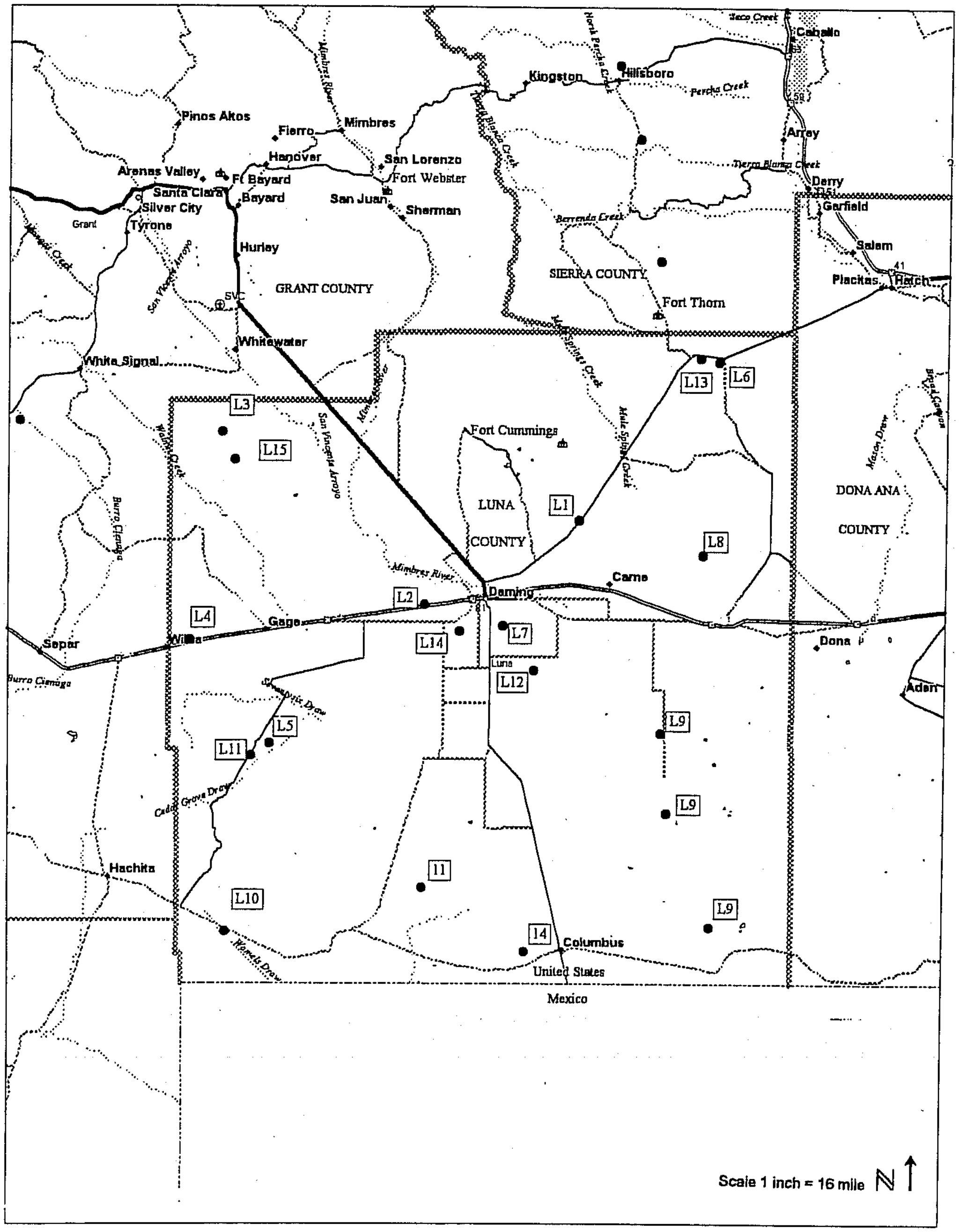
Luna County, New Mexico

Historic references to prairie dogs in Luna County are not numerous. Only ten individual text sources existed, resulting in 11 colony locations in four general areas of the county. The BBS map of prairie dog locations (Figure 3.1) indicates 26 different location, as well. The references are shown in Table 3.3 and the generalized locations shown in Figure 3.4.

Table 3.3. Historic Records of Prairie Dog Colonies, Luna County, New Mexico.

Ref. #	Year	Author	Location	Size Of Colony	Reference
L1	1870	Bourke	Southwestern New Mexico	Not mentioned	Bloom (1934: 59)
L2	1855	Kennerly	West of Rio Grande to San Luis Pass	Large extent	Baird (1859:39-40)
L3	1853	William Carr Lane	NW Luna County	several colonies	Carson, 1962:225
L4	1885	Mearns	Between Gage and Separ	Not mentioned	Mearns, 1907
L5	1908	Bailey	Between Deming and Hachita	Not mentioned	Bailey, 1908
L6	1906	Bailey	North end of Uvas Valley	Abundant	Bailey, 1906
L7	1908	Bailey	Plains about Deming, NM	Numerous	Bailey, 1908
L8	1920	BBS, 1920	Southwest of Good Sight Mtns.	Not mentioned	BBS, NM Annual Reports, Map, 1920
L9	1920	BBS, 1920	East of Florida Mtns.	Not mentioned	*Op. Cit.*
L10	1920	BBS, 1920	Between Hachita and Columbus	Not mentioned	*Op. Cit.*
L11	1920	BBS, 1920	Between Deming and Columbus	Not mentioned	*Op. Cit.*
L12	1923	BBS, 1923	Various ranches near Deming	scattered colonies	BBS, NM Annual Reports, 1923
L13	1941 -42	W. Youngblood	Around Nutt	Not mentioned	Interview with Wort Youngblood (Appendix A)
L14	1937 -42	W. Youngblood	Around Deming and Columbus	a few small colonies	Interview with Wort Youngblood (Appendix A)
L15	1959	Alton Ford	Cow Springs Draw	Not mentioned	Interview with Alton Ford (Appendix A)

Figure 3.4 Historic Locations of Prairie Dog Colonies, Luna County, New Mexico.



Luna County was virtually unsettled during the Spanish Colonial and Mexican Periods. The Janos trail, shown in Figure 2.1, led from northwestern Chihuahua to the Santa Rita Copper mine, across the western sector of Luna County (Couchman, 1990:15; Williams, 1986:112). Lt. Zebulon Pike reported in 1807 that the Santa Rita Copper mine was producing 20,000 mule-loads of copper a year, all transported to Janos via this trail. No mention of prairie dogs was found in his report (Pike, 1807).

Explorations and mass migrations across central Luna County were numerous in the period from 1846 through 1900 (Couchman, 1990). Dr. C. B. Kennerly acted as physician and naturalist from 1853 to 1855 to Lt. Whipple's expedition exploring the future route of the Pacific railroad along the 35th parallel (Bailey, 1932:2). He traveled across the newly established territory and made many observations of wildlife in the region. Kennerly provides a general account of prairie dogs in the desert grasslands, stating that, "West of the later stream [Rio Grande], we observed them [prairie dogs] as far as the Sierra Madre" (Baird, 1859:40). I have included one colony in central Luna County based on this quote (Table 3.3 and Fig. 3.4, Ref. # L2).

Many Forty-Niners came through Luna County on what was then called the "Gila Trail" on their journey to California (Couchman, 1990:70). Nearly 8,000 emigrants used this route in 1849, usually stopping at Fort Cummings and Cook's Springs, then traveling over the Continental Divide to Mimbres Creek (Durivage, 1937; Evans, 1945; Eccleston, 1950; Bunyard, 1980; Chamberlain, 1945). I studied the accounts of six different individuals that made the journey, Cox, Bunyard, Evans, Eccleston, Hayes, and Chamberlain, but found no mention of prairie dogs in Luna County or elsewhere in the study area.

William Carr Lane, first Territorial Governor of New Mexico, traveled from Santa Fe to the Gila River in 1853. His route took him from the village of Doña Ana to Fort Webster, through Mule Springs and Cooke's Springs in northern Luna County (Lane, 1962: 221-222).

From Fort Webster, Lane headed south on the Janos Trail in the northwest corner of Luna County, near Cow Springs, before turning west to the Burro Mountains in Grant County (Lane, 1962:224). Lane (1962:225) recorded in his diary: "Have passed many [prairie] Dog Towns, today." This corresponds to the area between Cow Springs and Gage along the Old Janos Trail (Table 3.3, Fig. 3.4, Ref. # L3).

Mearns (1907: 341, 344) mentions observing a colony located between Gage and Separ in Luna County in 1885 (Table 3.3, Fig. 3.4, Ref. # L4). His biological studies along the Mexican boundary in 1892 included wildlife collections from southern Luna County but did not include specimens of black-tailed prairie dogs from these localities.

Bailey made observations of the flora and fauna of Luna County from a train window on a trip from Rincon to Deming in 1906. He recorded observations of prairie dogs there in his personal journal: "Cynomys: Prairie dogs are abundant over the grassy plains an hour west of Rincon" (Bailey, 1906:89). Bailey makes observations at Nutt just a few lines after this reference (Bailey, 1906:90), indicating that the prairie dogs were most likely located east of Nutt, along the north end of the Uvas Valley (Table 3.3, Fig. 3.4, Ref. # L5). Bailey makes other references to prairie dogs while conducting biological survey duties in Luna County in 1908. He states that, "Prairie dogs are numerous in many places over the plains about Deming and on the way to Hachita"(Bailey, 1908:6). This statement is confirmed in his descriptions of the Arizona black-tailed prairie dog in *Mammals of New Mexico* (Bailey, 1932:123) and provides at least two colony locations in Luna County (Table 3.3, Fig. 3.4, Ref. # L6, L7).

The BBS 1920 prairie dog map of New Mexico shows several (26) colony locations in Luna County (Fig. 3.1). These locations include an area southwest of the Goodsight Mtns (Table 3.3, Ref. # L8), colonies east of the Florida Mountains (Table 3.3, Ref. # L9), between Columbus and the Hachita Mountains (Table 3.3, Ref. # L10), and between Deming and Columbus (Table 3.3, Ref. # L11).

The BBS records for Luna County from 1923 (BBS New Mexico, 1923) confirm some of the locations by stating that "several ranches around Deming" had large prairie dog colonies (Table 3.3, Fig. 3.4, Ref. # L12).

Personal interviews were conducted with Youngblood (Appendix A). He indicated that a few small colonies existed around Deming and Columbus until the late 1930s (Table 3.3, Fig. 3.4, Ref. # L14), confirming some of the locations from the 1920 map and the observations of early authors. Youngblood also indicated that there was a colony in the vicinity of Nutt, in northern Luna County, in the late 1930s (Table 3.3, Fig. 3.4, Ref. # L13). Perhaps this was the same colony observed by Bailey in 1906.

The final record for prairie dogs in Luna County came from an interview with Alton Ford (Appendix A). Mr. Ford was formerly a government trapper, working in Hidalgo, Grant and Luna Counties. He indicated that a small colony persisted in Luna County up until late 1959 in Cow Springs Draw. This colony is indicated in Table 3.3 and Fig. 3.4 as Ref. # L15.

Three references to prairie dogs in Luna County pre-date cattle ranching: Lane's observation of dogtowns near Cow Springs in 1853, and Kennerly and Bourke's general mention of prairie dogs in the area. However, each of these early observations occurs along a major trail where impacts from livestock would have been high.

Grant County, New Mexico

A total of 15 sources provided information about prairie dogs in Grant County, with 30 locations mentioned. Several locations were repeated by different sources in different years, thereby confirming the consistency of reports and the longevity of colonies. From 1849 through the 1880s there were numerous military excursions, cattle drives, stage coaches and caravans of emigrant wagons crossing southern Grant County. This was the main route to Tucson and Southern California and mines were flourishing throughout Grant County and all of southern New Mexico. The railroad was constructed along the same broad plain at Separ in 1881, linking the borderlands from Texas to the Pacific (Couchman, 1990:203-204). With all of this activity, there were many opportunities for records to have been left.

The earliest record I found for Grant County is from Lane, who mentioned several prairie dog towns along the Janos Trail in 1853, probably near Fort Webster (Carson, 1962:224-25). Later in his journey in a location in the Mangas Valley, Lane notes that they shot and killed a prairie dog (Carson, 1962:228) (Table 3.4, Fig. 3.5, Ref. # G1 and G2).

Clark Streator conducted a faunal survey in the area around Silver City, New Mexico from November 25 through December 6, 1892. Streator noted two locations for colonies of black-tailed prairie dogs (Table 3.4, Fig. 3.4, Ref. # G4, G5). He stated, "Quite an extensive town has existed about 3 miles south of Silver City on the [river]. But they are now starving for want of food. Of the three specimens collected they were nothing but mere skeletons. The only thing their stomachs contained was the fruit of cacti. A large town of them is said to exist between Fort Bayard and Silver City." The year 1892 was one of severe drought in the study area, the human population and their livestock herds had increased dramatically in the area around Silver City and Fort Bayard. The poor condition of the observed prairie dog colony may have been the result of the combined ravages of overgrazing and the severe drought that year.

Bailey conducted biological surveys noting black-tailed prairie dogs in Grant County in 1902, 1906 and 1908 (Table 3.4, Fig. 3.5, Ref. # G6-10). He reported in 1902 that "These prairie dogs are common over a wide stretch of mesa 2 to 5 miles east of Silver City." In 1906 Bailey traveled down Duck Creek to Silver City. He found *Cynomys ludovicianus* to be common along Duck Creek from Cactus Flat, 20 miles north of Cliff, on the mesas on the south side of the

Gila River and in the Mangas Valley. In 1908, Bailey reported on a colony observed by between Silver City and Ft. Bayard, probably the same as that observed by Streator in 1892.

During the years that Bailey visited Grant County, Silver City was a small town with a population that ranged from 2,700-3,200 (Sayles, 1986:132). Several years of above average rainfall from 1905 through 1908 led homesteaders to establish dry-land farming in the areas along Duck Creek Valley and the Gila River Valley around Cliff (Ross, 1935:19), where Bailey mentions dogtowns at frequent intervals.

Hollister (1916) reported specimens of Arizona black-tailed prairie dogs taken from locations in Silver City, Cliff and Gila (Table 3.4, Fig. 3.5, Ref. # G12-G14), confirming Bailey and Streator's earlier observations. The BBS 1920 map (Figure 3.1) confirms colony locations in the Upper Gila and Duck Creek, Mangas Creek areas (Table 3.4, Fig. 3.5, Ref. # G15). This map also shows colony locations near Separ and in the area around San Vincente (Table 3.4, Fig. 3.5, Ref. # G16-17).

BBS New Mexico Annual Reports for 1923 and 1929 indicate that prairie dog colonies were present in the area around Cliff, Gila, Duck Creek and in areas around Silver City (Table 3.4, Fig. 3.5, Ref. # G18-19). Interviews with local residents (Appendix A) show that colonies were present on Sacaton Mesa north of Cliff until the 1930s and in Duck Creek Valley in the 1930s and1940s (Table 3.4, Fig. 3.5, Ref. # G20-23).

Table 3.4. Historic Records of Prairie Dog Colonies, Grant County, New Mexico.

Ref. #	Year	Author	Location	Size Of Colony	Reference
G1	1853	Lane	Upper Mimbres near Ft. Mc Lane	"many prairie dog towns"	Carson, Editor, 1962
G2	1853	Lane	Mangas Springs-Gila River Valley	Size not mentioned	Carson, Editor, 1962
G3	1870	Bourke	Southwestern New Mexico	"common in southwestern New Mexico"	Bloom (1934: 59)
G4	1892	Clark Streator	3 mi. S of Silver City on the river	"Extensive"	Streator, 1892 field notes
G5	1892	Clark Streator	Between Silver City and Ft. Bayard	"A large town"	Streator, 1892 field notes
G6	1902	Bailey	Mesa 2 to 5 miles east of Silver City	"common over a wide stretch of mesa"	Bailey, 1902 field notes
G7	1906	Bailey	The length of Duck Creek Valley	several colonies	Bailey, 1906 field notes
G8	1906	Bailey	Mangas Valley	several colonies	Bailey, 1906 field notes
G9	1906	Bailey	Mesa on S. side of Gila River, near Cliff	several colonies	Bailey, 1906 field notes
G10	1906	Bailey	Cactus Flat, 20 mi. N of Cliff	"common"	Bailey, 1906; Hollister, 1916; Findley, 1976

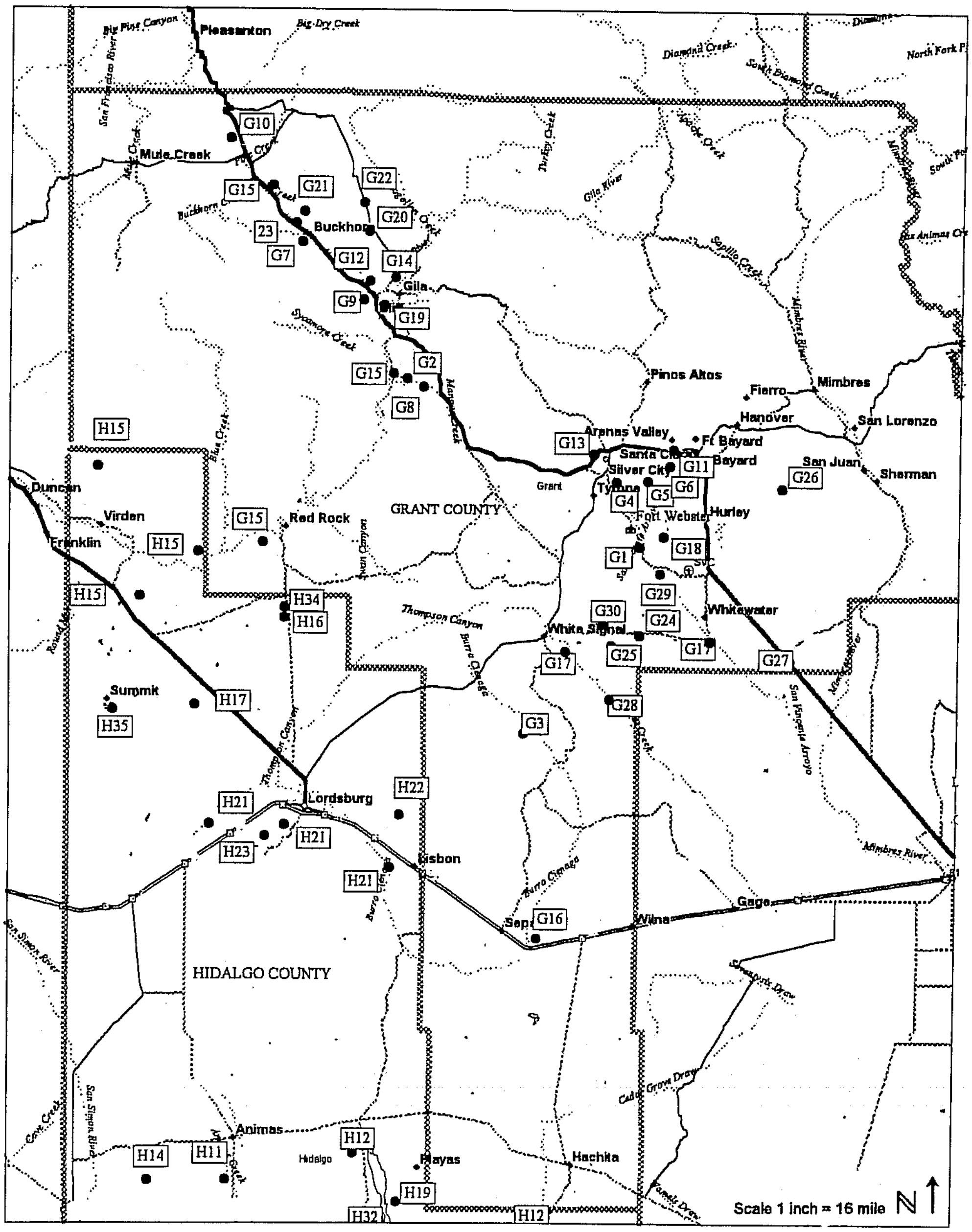
Table 3.4. Historic Records of Prairie Dog Colonies, Grant County, New Mexico (Cont.).

Ref #	Year	Author	Location	Size Of Colony	Reference
G11	1908	Bailey	Between Silver City and Ft. Bayard	Not mentioned	Bailey, 1908 field notes
G12	Before 1916	USNM	Cliff	Specimens only	Hollister, 1916; Findley, 1976
G13	Before 1916	USNM	Silver City	Specimens only	Hollister, 1916; Findley, 1976
G14	Before 1916	USNM	Gila	Specimens only	Hollister, 1916; Findley, 1976
G15	1920	BBS, 1920	Mangas, Middle Gila, and Duck Creek	Not mentioned, map only	BBS, NM Annual Reports, 1921
G16	1920	BBS, 1920	Near Separ	Not mentioned, map only	*Op. Cit.*
G17	1920	BBS, 1920	Around San Vincente Arroyo and White Signal	Not mentioned, map only	*Op. Cit.*
G18	1923	BBS, 1923	various ranches near Silver City	Scattered colonies	BBS, NM Annual Reports, 1923
G19	1928	BBS, 1928	Gila Farms	Not mentioned	BBS, NM Annual Reports, 1928
G20	1928	Otho Woodrow	Sacaton Mesa near Cliff	Not mentioned	Interview with Otho Woodrow, (Appendix A)

Table 3.4. Historic Records of Prairie Dog Colonies, Grant County, New Mexico (Cont.).

Ref. #	Year	Author	Location	Size Of Colony	Reference
G21	early 1940s	F. Drummond	Duck Creek at Buckhorn	scattered small colonies	
G22	1930s	F. Drummond	Sacaton Mesa	scattered small colonies	Interview, Appendix A
G23	1930s -40s	M. Drummond	Buckhorn	small colony	Interview, Appendix A
G24	1955	Dustin Hunt	5 mi. east of White Signal	very small colony	Interview, Appendix A
G25	unkn.	USNM	14 mi. south of Silver City	Specimens only	Findley, 1976
G26	unkn.	USNM collection	9 mi. north of Faywood	Specimens only	Findley, 1976
G27	unkn.	Otho Woodrow	10 mi. north of Deming	large colony	Interview, Appendix A
G28	1959	Alton Ford	Area between White Signal and Gage	4 colonies of 20 acres each	Interview, Appendix A
G29	1959	Alton Ford	Whitewater Draw	Not mentioned	Interview Appendix A
G30	1960	Bruce Hayward	9 mi. east of White Signal	small colony	Interview, Appendix A

Figure 3.5. Historic Locations of Prairie Dog Colonies, Grant County and northern Hidalgo County, New Mexico.



Several reports show prairie dogs in the tributaries of White Water and San Vincente Creek. Local resident, Dustin Hunt (Appendix A), reported having a small colony on his ranch in the mid-1950s, which may be from the same location as Findley's (1976) reported black-tailed prairie dog specimens collected from 14 miles south of Silver City and 9 miles north of Faywood (Table 3.4, Fig. 3.5, Ref. # G24-26). A report by local resident Otho Woodrow (Appendix A) told of a colony to the north of the road between Deming and Silver City (Table 3.4, Fig. 3.5, Ref. # G27). Alton Ford remembered a few small prairie dog colonies surviving in the swales between White Signal and Gage and another in White Water Draw in 1959 (Table 3.4, Fig. 3.5, Ref. # G28-29). Bruce Haywood, retired biologist from Western New Mexico State University (Appendix A), observed a small colony in the area between White Signal and White Water in 1960 (Table 3.4, Fig. 3.5, Ref. # G30).

Hidalgo County, New Mexico

The historical records of Hidalgo County provided many references to prairie dogs, despite its low population density. Fifteen individual sources referred to a total of 35 locations for prairie dog colonies. The oldest record of prairie dogs dates from the 1857 Mormon Battalion diaries: in a synthesis of many unpublished diaries compiled by Ricketts (1996), one anonymous member of the party recorded that prairie dogs were barking all along their way as they were in the vicinity of Bercham's Draw, in the day before they came to the passage in the Guadalupe Mountains. Bercham's Draw is located about 12 miles north of Cloverdale (Table 3.5, Fig. 3.6, Ref. # H1).

Table 3.5. Historic Records of Prairie Dog Colonies, Hidalgo County, New Mexico

Site #	Year	Author	Location	Size Of Colony	Reference
H1	1847	Annon.	Bercham's Draw	Not mentioned	Ricketts, 1996: 86
H2	1850-53	J.R. Bartlett	Las Playas near Janos Trail	"several dogtowns"	Bartlett, 1854: 250-51
H3	1850-53	J.R. Bartlett	South end of Playas Valley	Extensive by implication	Bartlett, 1854:250-51
H4	1855	C. B. R. Kennerly	From El Paso to Sierra Madre (San Luis)	Very large	Baird (1859:39-40)
H5	1893	E.A. Mearns	Animas Valley	Not mentioned	Mearns, 1893
H6	1893	E.A. Mearns	Cloverdale, Animas Valley	Not mentioned	Mearns, 1893
H7	1893	E.A. Mearns	Lang Ranch; Animas Valley (near Boundary Monument 66),	Not mentioned	Mearns, 1893
H8	1893	E.A. Mearns	Dog Springs, NM	Not mentioned	Mearns, 1893
H9	1893	E.A. Mearns	3 miles west of the Dog Mountains to treeline of San Luis Mountains	Extensive by implication	Mearns, 1907
H10	1893	E.A. Mearns	"...both sides of the Animas Valley, west of the San Luis Mountains"	"abundant"	Mearns, 1907

Table 3.5. Historic Records of Prairie Dog Colonies, Hidalgo County, New Mexico, Cont.

Site #	Year	Author	Location	Size Of Colony	Reference
H11	1908	Bailey	Upper and lower Animas Valley	"continuous"	Bailey, 1908
H12	1908	Bailey	Hachita and Playas Valleys	"numerous"	Bailey, 1908
H13	Before 1916	USNM	6 mi. south of Hachita	Specimens only	Hollister, 1916; Findley, 1976
H14	1920	BBS, 1920	SE of Antelope Pass	Not mentioned	BBS, NM Annual Reports, 1921
H15	1920	BBS, 1920	3 colonies around Virden	Not mentioned	*Op. Cit.*
H16	1920	BBS, 1920	Colony south of Red Rock	Not mentioned	*Op. Cit.*
H17	1920	BBS, 1920	Colony east of Summit	Not mentioned	*Op. Cit.*
H18	1920	BBS, 1920	Lower Animas Valley and Cloverdale Lake	Not mentioned	*Op. Cit.*
H19	1920	BBS, 1920	Lower and upper Playas Valley	Not mentioned	*Op. Cit.*
H20	1920	BBS, 1920	Hachita Valley and near Big Hatchet	Not mentioned	*Op. Cit.*
H21	1920	BBS, 1920	Around Lordsburg and Southern Pacific Railroad	Not mentioned	*Op. Cit.*

Table 3.5. Historic Records of Prairie Dog Colonies, Hidalgo County, New Mexico, Cont.

Site #	Year	Author	Location	Size Of Colony	Reference
H22	1920	BBS, 1920	East of Lordsburg and north of Lisbon	Not mentioned	*Op. Cit.*
H23	1923	BBS, 1923	Various ranches near Lordsburg	Scattered colonies	BBS, NM Annual Reports, 1923
H24	1925	BBS, 1925	Robinson Range, near Animas Mtns.	1500 acres	BBS, NM Annual Reports, 1925
H25	1931	A. Alexander	7 mi. n of Gray Ranch	50 acres	Alexander, 1932:302
H26	1931	A. Alexander	Echols Ranch, Animas Valley	3 small colonies	Alexander, 1932:302
H27	1931	A. Alexander	Culberson Ranch, Lower Playas Valley	Not mentioned	Alexander, 1932:302
H28	1937	Donald D. Brand	Antelope Wells	Not mentioned	Brand, 1937
H29	1937	Donald D. Brand	Dog Springs	Very large "metropolitan area"	Brand, 1937
H30	1937	Donald D. Brand	Upper Animas Valley	Not mentioned	Brand, 1937
H31	Before 1948	Alton Ford	Big Hatchet area	Not mentioned	Interview, Appendix A
H32	Unkn.	MVZ	Victoria Cattle Co. horse camp	Specimens only	Findley, 1976
H33	Unkn.	USNM	Animas Valley, 6 mi. east of Cloverdale	Specimens only	Findley, 1976
H34	Unkn.	MSB	Pelloncillo Mtns.	Specimens only	Findley, 1976

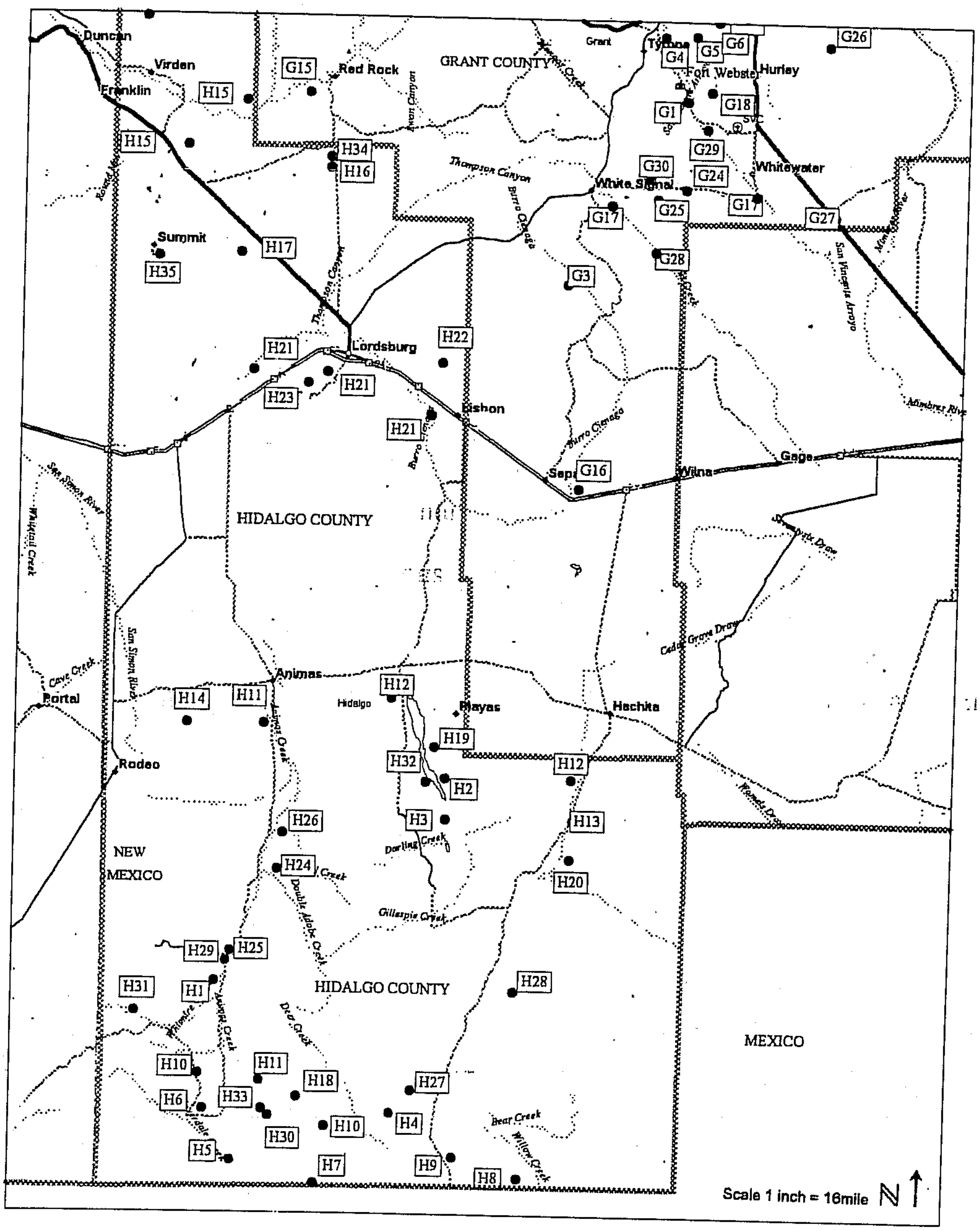
Table 3.5. Historic Records of Prairie Dog Colonies, Hidalgo County, New Mexico, Cont.

Site #	Year	Author	Location	Size Of Colony	Reference
H35	Unkn.	USNM	Playas Valley	Specimens only	Findley, 1976
H36	1960	John Hubbard	Northeast edge of Lake Cloverdale	Large	Interview, Appendix A
H37	1959-60	Bruce Hayward	South of Red Rock	small colony	Interview, Appendix A
H38	1972	Tom Waddell	Near Summit (15 mi. SE Duncan, AZ	large colony	Brown, et al., 1974; Interview, Appendix A

Bartlett (1854) mentions two prairie dog locations in southern Hidalgo County, as well. He observed extensive colonies of prairie dogs at "Las Playas" while traveling along the Janos Trail and also at the southern end of the Playas Valley (Table 3.5, Fig. 3.6, Ref. # H2, H3). Kennerly's statement that prairie dogs were common from El Paso to Sierra Madre (Baird, 1859:39-40) suggest that he may have seen the same colonies, for he crossed the Sierra Madre at San Luis Pass, above the southern end of Playas Valley (Table 3.5, Fig. 3.6, Ref. # H4).

Mearns (1893, 1907) confirms and expands on these early reports of extensive dogtowns in southern Hidalgo County. He reported that Arizona black-tailed prairie dogs were on both sides of the southern Playas Valley, from Dog Springs to the treeline of the San Luis Mountains and that they were along both sides of the southern Animas Valley (Table 3.5, Fig. 3.6, Ref. # H5-H10).

Figure 3.6. Historic Prairie Dog Colony Locations, Southern Hidalgo County, New Mexico



Bailey visited southern Hidalgo County and the Animas Mountains in 1908. His personal journal (1908) from that trip, examined at the Smithsonian Institution Archives, reveals that he found nearly continuous colonies of *C. ludovicianus* as he traveled along the road from the southern Animas Valley, north to Lordsburg (Table 3.5, Fig. 3.6, Ref. # H11). He also found "numerous colonies" in the Hachita and Playas Valleys (Table 3.5, Fig. 3.6, Ref. # H12). Hollister (1916) reported on a specimen of Arizona black-tailed prairie dog in the U.S. National Museum that was collected 6 miles south of Hachita (Table 3.5, Fig. 3.6, Ref. # H13).

The 1920 New Mexico Prairie Dog Map (Figure 3.1) shows several locations of prairie dogs in southern and northern Hidalgo County. Locations are shown southeast of Antelope Pass, in the lower Animas Valley and near Cloverdale, from the lower and upper Playas Valley, the Hachita Valley and Big Hatchet and around Lordsburg, shown in Table 3.5, Fig. 3.6, Ref. # H14, H18-22. This map also shows one location in far northern Hidalgo County, an area for which few other records exist. Colonies are shown in the area around Virden, south of Red Rock and east of Summit (Table 3.5, Figure 3.5, Ref. # H15, H16, H17).

Other records from the BBS include a report in 1923 that there were scattered prairie dog colonies on several ranches near Lordsburg, New Mexico (Table 3.5, Fig. 3.6, Ref. # H23). In 1925, the BBS reported that one ranch in the Animas Valley had 1500 acres of prairie dogs (Table 3.5, Fig. 3.6, Ref. # H24).

An article published in the *Journal of Mammalogy* in 1932 by biologist Annie Alexander reported that very few specimens of *C. ludovicianus arizonensis* could be found in either Cochise or Hidalgo counties and blamed this condition on the active poisoning campaigns of the BBS (Alexander, 1932:302). She reported on three colony locations either still living or recently living in southern Hidalgo County in 1932. These are shown in Table 3.5, Fig. 3.6, Ref. # H25-H27 and confirm several earlier records for colony locations in the Animas Valley and the lower Playas Valley.

In 1936 and 1937, Donald D. Brand conducted studies of the vegetation and natural landscape of northwest Chihuahua. He mentioned *Cynomys ludovicianus arizonensis* in his subsequent publication (Brand, 1937). He states that the animals occur in the upper Animas Valley, Antelope Wells and Dog Springs (Table 3.5, Fig. 3.6, Ref. # H27 and H28). Of Dog Springs, he states, "There seems to be a prairie dog metropolitan area centering on the latter place, to which those vociferous ground squirrels gave name."

Findley (1976) provides records of previously unreported specimens of *C. ludovicianus* that were collected from four locations in Hidalgo County, including one specimen taken from Victoria Cattle Co. horse camp in Animas Valley, another from a point 6 miles east of Cloverdale, one from the from the Pelloncillo Mountains, and one from the Playas Valley, shown in Table 3.5, Fig. 3.6, Ref. # H29-H32.

Personal interviews with Alton Ford (Appendix A) indicated that in 1948, when he first arrived in the county to began his career trapping predators in

Hidalgo County, the ranchers around Big Hatchet told him about large colonies of prairie dogs that had recently been poisoned by the government (Table 3.5, Fig. 3.6, Ref. # H31).

In 1960, biologist John Hubbard conducted studies on the Gray Ranch. He reported (Appendix A) seeing a large colony of black-tailed prairie dogs on the edge of Cloverdale Lake, south of the road to San Luis Pass (Table 3.5, Fig. 3.6, Ref. # H33). These were the only prairie dogs he observed on the Gray Ranch. Bruce Hayward (Appendix A) reported that he had seen a small colony south of Red Rock at about the same time (Table 3.5, Fig. 3.5, Ref. # H34).

The last account of prairie dogs in Hidalgo County was given by wildlife biologist, Tom Waddell (Appendix A). He reported on the location of a colony of Arizona black-tailed prairie dogs near Summit, shown in Table 3.5, Fig. 3.5, Ref. # H35. A reintroduction had been arranged by the Arizona Fish and Wildlife Department using animals from this colony to repopulate a ranch near Elgin, in southern Cochise County. He reported that the reintroduction attempt was made in 1972, but was a total failure. The remaining animals on the original colony were completely exterminated that year by New Mexico Predator and Rodent Control agents.

Cochise County, Arizona

Early records of prairie dogs in Cochise County are not common. The Mormon Battalion, Bartlett and Kennerly passed through along a route from San Bernardino in the southeastern corner of Cochise County, near Douglas, to Tubac on the Santa Cruz River. This route probably followed the San Pedro and

Babocomari River Valleys. The area was a plagued by warfare between Mexican, Apache and U.S. Calvary troops and travelers were subjected to many hardships. In the years prior to 1870 there were few cattle or other livestock present in Cochise County or other areas of the southwest, due to losses from Apache attacks. The military camps kept livestock grazing nearby, however. No reports of prairie dogs were made on these early explorations through southern Cochise County.

The primary route to California shifted north to Willcox Playa in the 1850s after Forts were established to secure the region. Forts Bowie, Buchanan and later, Huachuca were preceded by Camps Crittenden and Wallen. Stage and wagon trails became heavily used as the military expanded in Arizona, bringing not only travelers but also herds of livestock to supply the military Forts with meat and horses.

The first historical record of Arizona black-tailed prairie dogs I was able to find was from a traveler on the new stage road between Tucson and Dos Cabezas in 1860 (Table 3.6, Fig. 3.7, Ref. # C1). The traveler noted "hundreds" of the animals along the route but was not specific about the location. A young cavalry member, Jack Spring, stationed in 1867 at Camp Crittenden, recounts riding often to Camp Wallen, in Cochise County. He observed several "villages" of prairie dogs along the trail, which probably passed along the Babocomari River Valley (Table 3.6, Fig. 3.7, Ref. # C2).

Table 3.6 Historic Records of Prairie Dog Colonies, Cochise County, Arizona

Ref #	Year	Author	Location	Size Of Colony	Reference
C1	1860	Anon. traveler	Stage road between Tucson and Dos Cabezas Mtns	Extensive	*Daily Alta Californian*, July 4, 1860
C2	1867	Jack Spring	Road from Camp Wallen to Camp Crittenden	Several "villages"	J. Spring, Edited by A.M. Gustafson (1966)
C3	1869-75	Bourke	Eastern border of Arizona	Not mentioned	Bloom, 1934:59
C4	1884	A.K. Fisher	Dos Cabezas	small (6 animals)	Fisher, quoted in Hoffmeister, 1986
C5	1885	Mearns	Along Southern Pacific Railroad as far west as Benson"	"immense colonies"	Mearns, 1907:342
C6	1885	Mearns	Junction of the Gila and Salt Rivers	Not mentioned	Mearns, 1907:342
C7	1885	Mearns	Sulphur Spring Valley	Not mentioned	Mearns, 1907:342
C8	1889	Bailey	Road from Willcox to Ft. Grant	"numerous"	Bailey, 1889
C9	1889	Bailey	Dos Cabezas	small (6 animals)	*Op. Cit.*
C10	1889	Bailey	Sulphur Springs Valley	"numerous"	*Op. Cit.*
C11	1890	Mearns	Point of Mountain	Specimen	Mearns, 1892
C12	July, 1890	Mearns	Boundary monument 98, San Pedro River	Size not mentioned	Mearns, 1890
C13	Oct. 1893	Mearns	San Pedro Valley	Size not mentioned	Mearns, 1893

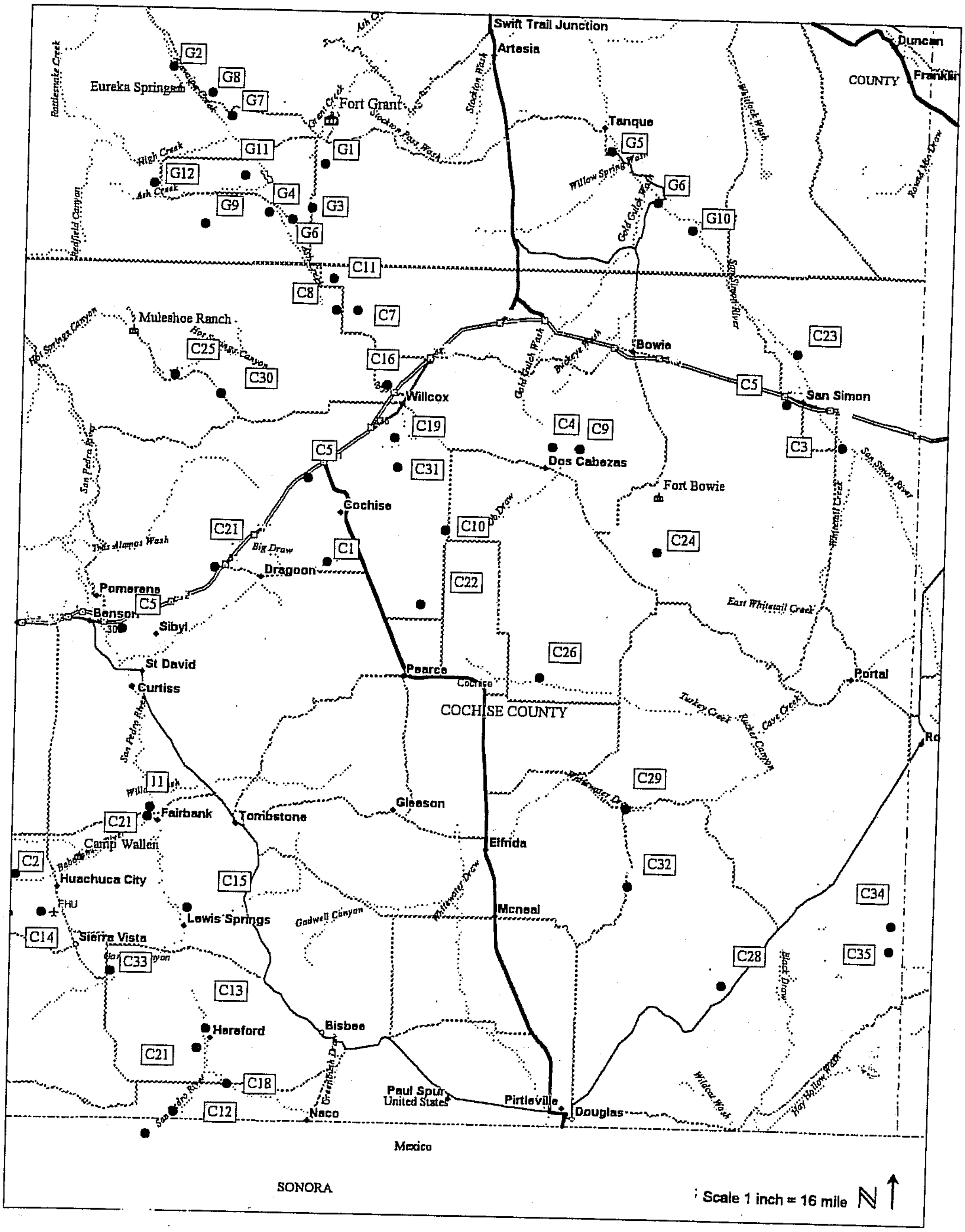
Table 3.6 Historic Records of Prairie Dog Colonies, Cochise County, Arizona, Cont.

Ref #	Year	Author	Location	Size Of Colony	Reference
C14	1894	W. W. Price	Plain at base of the Huachuca Mtns (Fort Huachuca)	20 burrows, approx. 200 animals	Allen 1895:237; Hollister, 1916
C15	1894	W.W. Price	12 miles east of Huachuca plain	Not mentioned	Allen (1895:237)
C16	1894	W.W. Price	Sulphur Springs Valley, especially at Willcox	"numerous colonies"	Allen (1895:237)
C17	1902	BBS Field notes	10 miles southwest of Ft. Huachuca	"small isolated colony"	Hoffmeister (1986: 195)
C18	1902	BBS Field notes	5 miles east of the Huachucas, on the road to Bisbee.	"many"	Hoffmeister (1986: 195)
C19	Before 1916	AMNH	Willcox	Specimens only	Hollister, 1916
C20	Before 1916		Dragoon Summit	Specimens only	Hollister, 1916
C21	1918	Gilchrist	Hereford District, San Pedro Valley and Boquillas	25,000 acres of dogtowns	BBS, AZ Annual Reports, 1918
C22	1920	Gilchrist	Several ranches in Sulphur Springs Valley	large colonies	BBS, AZ Annual Reports, 1920
C23	1920	Gilchrist	Several ranches in the San Simon Valley	large colonies	*Op. Cit.*
C24	1920	D.A. Gilchrist	San Simon Valley and Chiracahua Mountains	30,720 acres	*Op. Cit.*

Table 3.6 Historic Records of Prairie Dog Colonies, Cochise County, Arizona, Cont.

Ref #	Year	Author	Location	Size Of Colony	Reference
C25	1920	D.A. Gilchrist	Muleshoe and Riggs Ranches	large colonies	BBS, AZ Annual Reports, January, 1920
C26	unkn.	Unkn.	1 ½ mi. W of Light	Specimen only	Cockrum, 1960
C27	1930	Roy Boss	Bernardino, near Indian Creek	about 300 acres	Interview with Roy Boss (Appendix A)
C28	1918-1919	Bill Miller, Sr.	Southern end of San Simon Valley, south of Rodeo	Very large	Interview with Bill Miller, Sr., (Appendix A)
C29	1906	Louis Curry	Galleta Flats, White Water Creek, AZ	1 mile wide	Curry, Edited by E. Cline (1997: 6)
C30	1926	C. Lawson	Muleshoe Ranch Road, 2 miles north of Cascabel Rd.	"a big town"	Interview, Appendix A
C31	1931	A. Alexander	6 miles S of Willcox	20 individuals	Alexander, 1932:302
C32	1932	Margaret Glenn	Swisshelm Mtns: Hunt and Leslie Canyons	Big town	Interview, Appendix A
C33	1938	Charles Voorhies	6 mi. SE of Fort Huachuca	Specimen Only	Hoffmeister
C34	1935-38	Bill Miller, Sr.	Darter Ranch, Skeleton Canyon	small; 40-50 animals	Interview, Appendix A
C35	1960	E.M. Mercer	Ben Snur Ranch, Pelloncillo Mtns	small, less than 12 animals	BBS, AZ Annual Reports, Letter dated 3/20/62

Figure 3.7. Historic Locations of Prairie Dog Colonies in Graham County and Cochise County, Arizona.



Bourke spent several years of the Apache Wars in Arizona and passed through Cochise County on several occasions. In his book, *On the Border With Crook* (1892:9), Bourke states that, "the prairie dog… does just cross over the New Mexican boundary at Fort Bowie…," implying that colonies were located in the San Simon Valley (Table 3.6, Fig. 3.7, Ref. # C3).

Mearns provides several prairie dog colony locations in Cochise County:

> In the year 1885 I observed immense colonies of Arizona black-tailed prairie dogs in the region contiguous to the Southern Pacific Railroad in southeastern Arizona, extending as far west as the town of Benson, on the San Pedro River. Other colonies were located in the region about the junction of the Gila and Salt rivers, also in the Sulphur Springs Valley. For miles the burrows of these animals are thickly scattered over the plains south of the Pinaleno Range or Sierra Bonito… (Table 3.6, Fig. 3.7, Ref. # C5-C7)

Mearn's identification of a colony at the confluence of the Gila and Salt Rivers, falls in Maricopa County, but is the only reference found for prairie dogs in this area and not accepted by Hollister (1916), Cochrum (1960) or Hoffmeister (1986).

Bahre reports that farming began in the late 1870s in the Sonoita, Aravaipa, and Babocomari valleys, around San Jose at the mouth of the San Simon River, and the San Pedro River Valley between St. David and Hereford (Bahre, 1991:37). All of these areas are likely to have had prairie dog colonies, based on the records of the period, and conflict with the economic interests of farmers probably occurred.

In addition to hay mowing and farming, cattle, sheep and horse herds increased rapidly after the Southern Pacific Railroad was completed through

Arizona in 1881 (Wagoner, 1951:212; Bahre,1991:36). By 1880 the San Pedro, Sulphur Springs and San Simon Valleys were occupied by scattered herds of cattle and sheep, usually in individual herds of less than 500. Within a decade the land holdings had consolidated into a few huge spreads and herds numbered in the ten-thousands. Ranges were heavily overgrazed throughout southeastern Arizona by 1885 and by 1890 herds had reached their historic peak (Wagoner, 1951:214; Bahre, 1991:117).

In 1884, Fisher reported finding a small colony of 6 animals outside the town of Dos Cabezas (Table 3.6, Fig. 3.7, Ref. # C4). In 1889, Bailey surveyed the same colony. He noted, "... a colony of about 6 live on a smooth part of the valley just above town and feed on the roots of grass. One taken. They are said to be numerous lower down in the valley and also between Willcox and Ft. Grant" (Bailey, 1889). these locations are shown in Table 3.6, Fig. 3.7, Ref. # C9 and C10.

After the Arizona black-tailed type-specimen was first described from Graham County in 1890, numerous biologists traveled to southeast Arizona to study the new sub-species, providing a wave of new prairie dog location records. Mearns collected specimens from the Mexican boundary on the San Pedro River, and further upstream along the San Pedro Valley in the 1890s (Table 3.6, Fig. 3.7, Ref. # C12 and C13). Price (Allen,1895) observed colonies at Fort Huachuca, 12 miles east of the Huachuca Plain (San Pedro Valley) and at Willcox in 1894 (Table 3.6, Fig. 3.7, Ref. # C14 through C16).

Another biologist, quoted in Hoffmeister (1986:195), noted a colony 10 miles southwest of the Huachuca plain, possibly in the San Rafael Valley in Santa Cruz County, and another dogtown 5 miles east of the Huachuca Mountains on the road to Bisbee (Table 3.6, Fig. 3.7, Ref. # C17, C18). *C. ludovicianus* specimens were also collected before 1916 from Willcox and from Dragoon Summit (Table 3.6, Fig. 3.7, Ref. # C19, C20).

Luis Curry, recounts that a colony of prairie dogs about a mile across was up the road to Rucker Canyon in the southern Chiricahua Mountains in 1906 (Table 3.6, Fig. 3.7, Ref. # C29), showing that the animals could live in the broad mountain meadows as well as in the bottomlands.

Bill Miller, Sr. (Appendix A) remembered large prairie dog towns on the ranches in the southern part of the San Simon Valley, south of Apache. He stated that in 1918-1920 there had been large dogtowns all along the bottom part of the valley (Table 3.6, Fig. 3.7, Ref. # C28).

Records of the BBS provided information about prairie dog locations in the early twentieth century. Gilchrist, BBS Director of the Arizona Rodent Control Division from 1918-1924, wrote thorough narrative accounts of the Division's operations. He reported in 1918 that there were over 25,000 acres of prairie dog colonies in the southern San Pedro Valley, called the Hereford District, and in Boquillas (Table 3.6, Fig. 3.7, Ref. # C21). In 1920, Gilchrist reported that several ranches in the San Simon Valley and Sulphur Springs Valley had large colonies of prairie dogs (Table 3.6, Fig. 3.7, Ref. # C22, C23).

Included in the BBS Annual Report of 1920 is a letter from the Chiricahua Cattle Company stating that the ranch had 30,720 acres of prairie dogs (Table 3.6, Fig. 3.7, Ref. # C24). The Chiricahua Cattle Company had operations throughout the San Simon Valley and Chiricahua Mountains. Gilchrist also stated in 1920 that the Muleshoe and Riggs Ranches of the Sulphur Springs Valley in Cochise County had reported very large colonies of prairie dogs (Table 3.6, Fig. 3.7, Ref. # C25).

Chuck Lawson (Appendix A) of Willcox remembered prairie dogs in northwest Cochise County as a young man. He recalled moving from the Muleshoe Ranch on the south of the Pinaleo Range to Willcox in 1926. His family passed through a big prairie dog town on the Muleshoe Ranch Road, about two miles north of the Cascabel turn-off (Table 3.6, Fig. 3.7, Ref. # C25).

Few prairie dogs were left in the Cochise County in the 1930s, according to Alexander (1931). She found what she believed to be the last remaining colony, a small band of 20 individuals six miles south of Willcox (Table 3.6, Fig. 3.7, Ref. # C31). Margaret Glenn (Appendix A) recalled a big colony near her ranch in the Swisshelm Mountains in 1931 or 1932, at the fork of Hunt Canyon and Leslie Canyon Roads (Table 3.6, Fig. 3.7, Ref. # C32). An undated specimen was collected one and a half miles west of Light, as reported by Cockrum (1960), and Hoffmeister (1986) reports that Charles Voorhies collected a specimen of black-tailed prairie dog form Fort Huachuca in 1938. These locations are shown in Table 3.6, Fig. 3.7, Ref. # C26, C33. And Bill Miller (Appendix A) told of shooting the last of a small colony of prairie dogs on the Darter Ranch on the

Arizona side of the Pelloncillo Mountains between 1935 and 1938 (Table 3.6, Fig. 3.7, Ref. # C25).

The final record of the species in Arizona comes from the following memorandum, found in the USF&WS Records in the National Archives, from Everett M. Mercer, District Agent, Phoenix, Arizona, to the Regional Director, Bureau of Sport Fisheries and Wildlife, in Albuquerque, dated March 20, 1962:

> During the time Asst. District [Biologist] Meyers was assigned to Cochise County, 1954-58, there was one minute colony of Black Tail Prairie Dogs there. This colony was located on the Ben Snure Ranch, at Apache, which is about 11 miles southwest of Rodeo, New Mexico, and contained anywhere from two to six dogs. We had a verbal agreement with Mr. Snure to allow the animals to remain. Something happened to most of the dogs, and then in 1959 or 1960 the remaining two were trapped by a museum, according to reports. At this time, this office knows of no prairie dogs in southern Arizona. (BBS, Arizona Annual Reports, 1962)

Graham County, Arizona

No definite historical records for black-tailed prairie dogs were found for Greenlee County, although the records show in New Mexico immediately across the stateline near Virden and Summit (Table 3.4, Fig. 3.5, Ref. # H16, H17, H35). If colonies occurred there, they were probably very small and in the southeast corner of the county.

Numerous records for the animals were found for areas south of the Gila River in Graham County, which also had Gunnison's prairie dogs (*C. gunnisoni*) north of the Gila (Hoffmeister, 1986:194). Seven separate sources provided information on twelve locations for prairie dog towns, shown in Table 3.7.

The first definite record is Mearns' reference to the abundance of the animals in the plains south of the Pinaleno Range in 1885. This places them in the

Bonita area and around Fort Grant. He also states that prairie dogs were further up the Arivaipa Canyon, and he collected a specimen from Point of Mountain, in the upper Sulphur Springs Valley (Table 3.7, Fig. 3.7, Ref. # G1, G2, G4). Bailey found *C. ludovicianus* in numerous colonies on the road from Willcox to Fort Grant in 1889 (Table 3.7, Fig. 3.7, Ref. # G3).

Price found, in 1894, Arizona black-tailed prairie dogs located in both the Sulphur Springs Valley and the San Simon Valley, both of which have their northern extent in Graham County (Table 3.7, Fig. 3.7, Ref. # G6). Price also noted in 1894 that black-tailed prairie dogs were located in the San Simon Valley and on the "plain on the east base of Mt. Graham", probably around Lebanon (Table 3.7, Fig. 3.7, Ref. # G5).

In 1914, Goldman found prairie dogs near Bonito and Eureka Springs (Table 3.7, Fig. 3.8, Ref. # G7). The animals were evidently plentiful on several ranches in the upper San Simon Valley for the BBS reported that several ranches in the San Simon Valley had requested help with large colonies of prairie dogs in 1918, among them the Chiricahua Cattle Company which reported over 30,000 acres of prairie dogs (Table 3.7, Fig. 3.7, Ref. # G10, G11). Gilchrist also stated in the BBS Arizona annual reports of 1919 and 1920 that cattle ranches in the upper Sulphur Springs Valley and Arivaipa Creek areas had a combined "infestation" of 6,400 acres (Table 3.7, Fig. 3.7, Ref. # G8).

Table 3.7 Historic Records of Prairie Dog Colonies, Graham County, Arizona

Ref #	Year	Author	Location	Size Of Colony	Reference
G1	1885	Mearns	Plains S of Pinaleno Range (Sierra Bonito)	thickly scattered	Mearns, 1907:342
G2	1885	Mearns	Aravaipa Canyon	Not mentioned	Mearns, 1907:347
G3	1889	Bailey	Road from Willcox to Ft. Grant	numerous	Bailey, 1889
G4	1890	Mearns	Point of Mountain	Specimen only	Mearns, 1907:339
G5	1894	W. W. Price	"the plain along the east base of Graham Mountain	Not mentioned	Allen (1895:237)
G6	1894	W. W. Price	Sulphur Spring and San Simon Valleys	"numerous colonies"	Allen (1895:237)
G7	1914	Goldman	Near Bonito and Eureka Spring	abundant	Quoted in Hoffmeister, 1986:195
G8	1919	Gilchrist	Hooker, Kennedy and Eureka Springs Cattle Co.s	6,400 acres	BBS, AZ Annual Report, 1919
G9	1919	Gilchrist	Johnson and Cook, Monk Bros., Wilson, Mills, and H.L. Johnson Ranges	15,680 acres	*Op. Cit.*
G10	1920	Gilchrist	Several ranches in the San Simon Valley	large colonies	BBS, AZ Annual Report, 1920
G11	1920	Gilchrist	Sierra Bonita Ranch and upper Sulphur Springs area	large colonies	*Op. Cit.*
G12	1920	W. D. Wear	Sierra Bonita, Oak and Ash Creek	"big dogtowns"	Interview, Appendix A

Other ranches operating in the Pinaleno Mountains and the San Simon Valley reported over 15,000 acres of prairie dog colonies (Table 3.7, Fig. 3.7, Ref. # G9, G10). In 1920, the BBS reported very extensive colonies on the Sierra Bonita Ranch and Upper Sulphur Springs Valley (Table 3.7, Fig. 3.7, Ref. # G11). These colonies may well have been the last in Graham County, because life-long resident, W.D. Wear reported that he remembered the large colonies in Sierra Bonita, Ash Creek and Oak Creek area, around Sunset, Arizona from his childhood. He said that after the poisoning was finished in the early 1920s he never saw any prairie dogs again (Table 3.7, Fig. 3.7, Ref. # G12).

Sonora and Chihuahua, Mexico

Because large colonies persist in this area, Spanish and Mexican archival materials were not researched, nor were any local interviews conducted. Historical references to prairie dogs were sought in English language scientific literature only. Ten authors provided information about prairie dogs, resulting in 28 references for one or more individual colonies. The historical sources spanned over a century.

Several Americans traveled in northern Chihuahua during the middle of the 19th century, including Gregg (1844), Ruxton (1847), Bartlett (1854), Kennerly (Baird, 1859), Clarke (1852), and Couts (1961), all of whom traveled through Janos between 1848 and 1855. Unfortunately, however, no references to prairie dogs were found and the early distribution of prairie dogs in northern Mexico remains uncertain from that period.

The earliest record of prairie dogs from northeast Mexico came from the Lumholtz expedition, a scientific expedition sponsored by the American Museum of Natural History. The expedition remained encamped at Casas Grandes for several months to conduct archaeological excavations and natural history collections. A specimen in the museum was collected in 1890 from Colonia Juarez, near Casas Grandes, by Lumholtz, as reported by Anderson (1972:148). A second specimen was collected during this expedition by A. D. Meed in 1891 from the nearby village of San Diego (Anderson, 1972:148). These locations are shown in Table 3.8 and Figure 3.8, Reference # M1 and M2.

Mearns' (1907) mammal collections along the Mexican boundary in 1892 include a few specimens from Mexico. Mearns collected some specimens south of the Arizona/ Sonora boundary at the San Pedro River and in the lower Animas Valley, according to Hollister (1916:21) and Ceballos *et al.* (1993:109) (Table 3.8 and Figure 3.8, Reference # M2 and M3). Unfortunately, the size of these colonies was not described.

Streator (1892-93)undertook a survey of mammalian life in Chihuahua and Coahuila, Mexico in 1892-93. His field notes provide additional information about prairie dogs in Chihuahua in the late 19th century. He found prairie dogs to be,

> common on the east slope of the Sierra Madre Mtns. About a 100 miles south of the U.S. boundary line in the region about Casas Grandes. A small town exists about 10 miles N.E. of Samalayuca and some point near the Ry. [railway]. between there and San Jose. A small town somewhere between Gallego and Laguna and [*Cynomys mexicanus*] about La Ventura, Coahuila. (Streator, 1892-93).

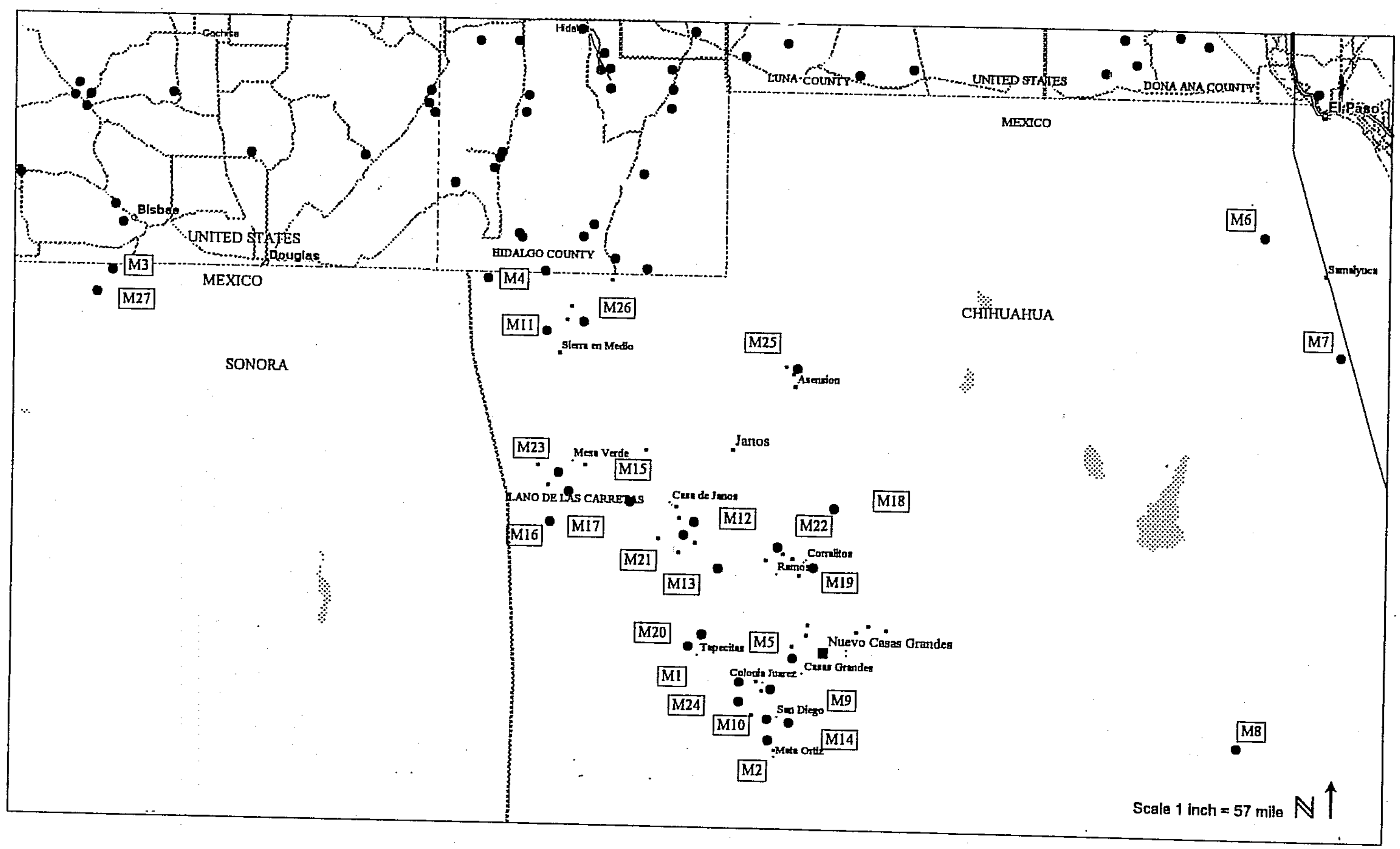
Table 3.8. Historic Records of Prairie Dog Colonies, Chihuahua and Sonora, Mexico.

Ref. #	Year	Author	Location	Size Of Colony	Reference
M1	1890	C. Lumholtz	Colonia Juarez, CH	Specimen only	Hollister:1916:21 Anderson,1972:148
M2	1891	A.D. Meeds	San Diego, CH	Specimen only	Anderson, 1972:148
M3	1892	E.A. Mearns	Sonora, San Pedro Valley	Specimens only	Mearns, 1907
M4	1892	E.A. Mearns	Sonora, lower Animas Valley	Specimens only	Mearns, 1907
M5	1892-93	C. Streator	east slope of Sierra Madre in region of Casas Grandes	common	Streator, 1892-93
M6	1892-93	C. Streator	10 mi. NE of Samalayuca, CH	small	*Op. Cit.*
M7	1892-93	C. Streator	Between Samalyuca, CH and San Jose, near Railway	small	*Op. Cit.*
M8	1892-93	C. Streator	Between Gallego and Laguna, CH	small	*Op. Cit.*
M9	1893	Allen	San Diego, CH	Specimens only	Allen, 1893:28
M10	before 1916	Hollister	Colonia Juarez, CH	Specimens only	Hollister, 1916:21 Anderson, 1972:148
M11	before 1916	Hollister	Sierra en Media	Specimens only	Hollister, 1916:21 Anderson, 1972:148
M12	1932	Bailey	Casa de Janos	large	Bailey, Nov. 1932
M13	1932	Bailey	10 mi. SW of Ramos	40 acres	*Op. Cit.*
M14	1937	D. D. Brand	San Diego	Not mentioned	New Mexico Bulletin
M15	1937	D. D. Brand	Llanos del Carretas	Not mentioned	New Mexico Bulletin
M16	1972	Anderson	Llano de las Carretas, 21 mi. W Cuervo	Specimens only	Anderson, 1972:148

Table 3.8. Historic Records of Prairie Dog Colonies, Chihuahua and Sonora, Mexico (Cont.)

Ref #	Year	Author	Location	Size Of Colony	Reference
M17	1972	Anderson	35 mi. NW Dublan	Specimens only	Anderson, 1972:148
M18	1972	Anderson	13 mi. SE Janos	Specimens only	Anderson, 1972:148
M19	1972	Anderson	Corralitos	Specimens only	Anderson, 1972
M20	1972	Anderson	Tapiecitas	Specimens only	Anderson, 1972
M21	1993	Ceballos *et al.*	Casa de Janos area	5 large colonies (2100-35000 ha ea.)	Ceballos, Mellink and Hanebury, 1993:109-111
M22	1993	Ceballos *et al.*	North of Nuevo Casas Grandes	9 colonies: (50-2,510 ha ea.)	*Op. Cit.*
M23	1993	Ceballos *et al.*	Monte Verde area	4 large colonies (400-3000 ha ea.)	*Op. Cit.*
M24	1993	Ceballos *et al.*	Mata Ortiz, San Diego, Colonia Juarez	3 colonies, (50-75 ha ea.)	*Op. Cit.*
M25	1993	Ceballos *et al.*	Ascensión	small	*Op. Cit.*
M26	1993	Ceballos *et al.*	Area between Sierra El Medio and Dog Springs, NM	5 small colonies	*Op. Cit.*
M27	1994 1997	Van Pelt R. Turner and D. Brown	Sonora, Mesa de las Nutrias, north of Cananea	3 small colonies	Bill Van Pelt and Raymond Turner, personal communications, 1996 and 1997.

Figure 3.8. Historic and Modern Locations of Prairie Dog Colonies in Chihuahua, Mexico



The Casas Grandes colonies are confirmed by specimens collected by the Lumholtz expedition, providing enough information to indicate that there were several large colonies along the valley of the Rio Casas Grandes (Table 3.8, Figure 3.8, Ref. # M5). The other three references, other than *C. mexicanus*, seem to imply small colonies. These colonies have never been reported before and they are widely scattered across the open desert grassland surrounding the playa lakes of northern Chihuahua (Table 3.8, Fig.3.8, Ref. # M6, M7, M8).

Hollister (1916) identifies another area in Chihuahua where specimens were collected but does not give the year or author. This is Sierra en Media, a small isolated mountain south of Dog Springs, New Mexico (Table 3.8, Fig.3.8, Ref. # M9).

Bailey visited Corralitos and Ramos Ranches near Casas Grandes in October and November,1932, leaving detailed field notes with the Smithsonian Institution. He reported that "No prairie dogs were seen in the Casas Grandes Valley bottom, but there is a large dog town near Casa de Janos, and another of some 40 acres 10 miles southwest of Ramos, both on high mesas in Upper Sonoran Zone." (Bailey, Nov.1932). These two sites are shown in Table 3.8, Figure 3.8, Reference # M10 and M11.

Brand noted prairie dogs in Chihuahua, stating that, "The Arizona prairie dog (*Cynomys ludovicianus arizonensis*) formerly was very common over the grassy steppe of Chihuahua, but at present tends to be localized in the northwestern plains around San Diego, the Llanos de Carretas…" (Brand, 1937, P.

5). Both of these locations are indicated in Table 3.8, Figure 3.8, Ref. # M12 and M13.

In 1970, Sydney Anderson reviewed all the U.S. mammalian collections originating in Chihuahua. His article on the mammals of Chihuahua (Anderson, 1972) provides five new locations for black-tailed prairie dogs, in addition to some locations previously identified. A specimen is identified from Llanos de Carretas, 21 miles west of Cuervo (Table 3.8, Figure 3.8, Ref. # M15). This confirms Donald Brand's previous observation (Ref. # 13). One colony is listed as 35 miles northwest of Colonia Dublan, which is near Casa de Janos (Table 3.8, Figure 3.8, Ref. # M16). Another specimen was taken 13 miles southeast of Janos, which would place it near the Rio de Casas Grandes along with the specimen taken at Corralitos (Table 3.8, Figure 3.8, Ref. # M17, M18). The last new location identified in Anderson's study is at Tapecitas, west of Casas Grandes on the eastern flank of the Sierra Madre (Table 3.8, Figure 3.8, Ref. # M19).

Ceballos, Mellink and Hanebury (1993) published a study on the distribution and conservation status of prairie dogs in Mexico in the early 1990s. The reported distribution of *C. ludovicianus* confirms several locations provided by historical references. Their study identifies 27 known prairie dog colony locations, five of them recently extinct (Ceballos, et al., 1993:110). No colonies are reported near Samalayuca or north of Gallego, indicating that these small and isolated colonies did not survive the century since Streator reported on them, and although this paper identifies a colony location at Corralitos, it is reported as extinct in 1993.

I have summarized the data from this report into six general locations (Table 3.8, Figure 3.8, Ref. # M20 through M25). The area around Casa de Janos, just west of the town of Janos has several large colonies today. The area between Janos and Nuevo Casas Grandes contains several small and extinct colonies. The area south of Nuevo Casas Grandes contains three small colonies: Mata Ortiz, San Diego and Colonia Juarez. These colonies confirm the persistence of some prairie dog colonies for over a century. The article also records a colony at Sierra de El Medio, colonies near the U.S. boundary at Dog Springs, and in the area of the Llano de Carretas. Another colony location is shown at Ascentíon, between Columbus and Janos. Altogether, this article shows over 55,000 ha of prairie dog colonies in Chihuahua in 1993.

Bill Van Pelt of the Arizona Fish and Wildlife Department obtained records of three small colonies of black-tailed prairie dogs near Cananea, in northwest Sonora. While working in that area in 1997, biologists Raymond Turner and David Brown reported finding one of these colonies in a remote area on the Mesa de las Nutrias (Table 3.8, Figure 3.8, Ref. # M26).

Summary of Historical Findings

The earliest records of Arizona black-tailed prairie dogs came from travelers, soldiers, explorers, and even the territorial governor. Observations from the period of American exploration and conquest (1846-1889) indicate that prairie dogs were liked by the Americans, who often found the animals entertaining.

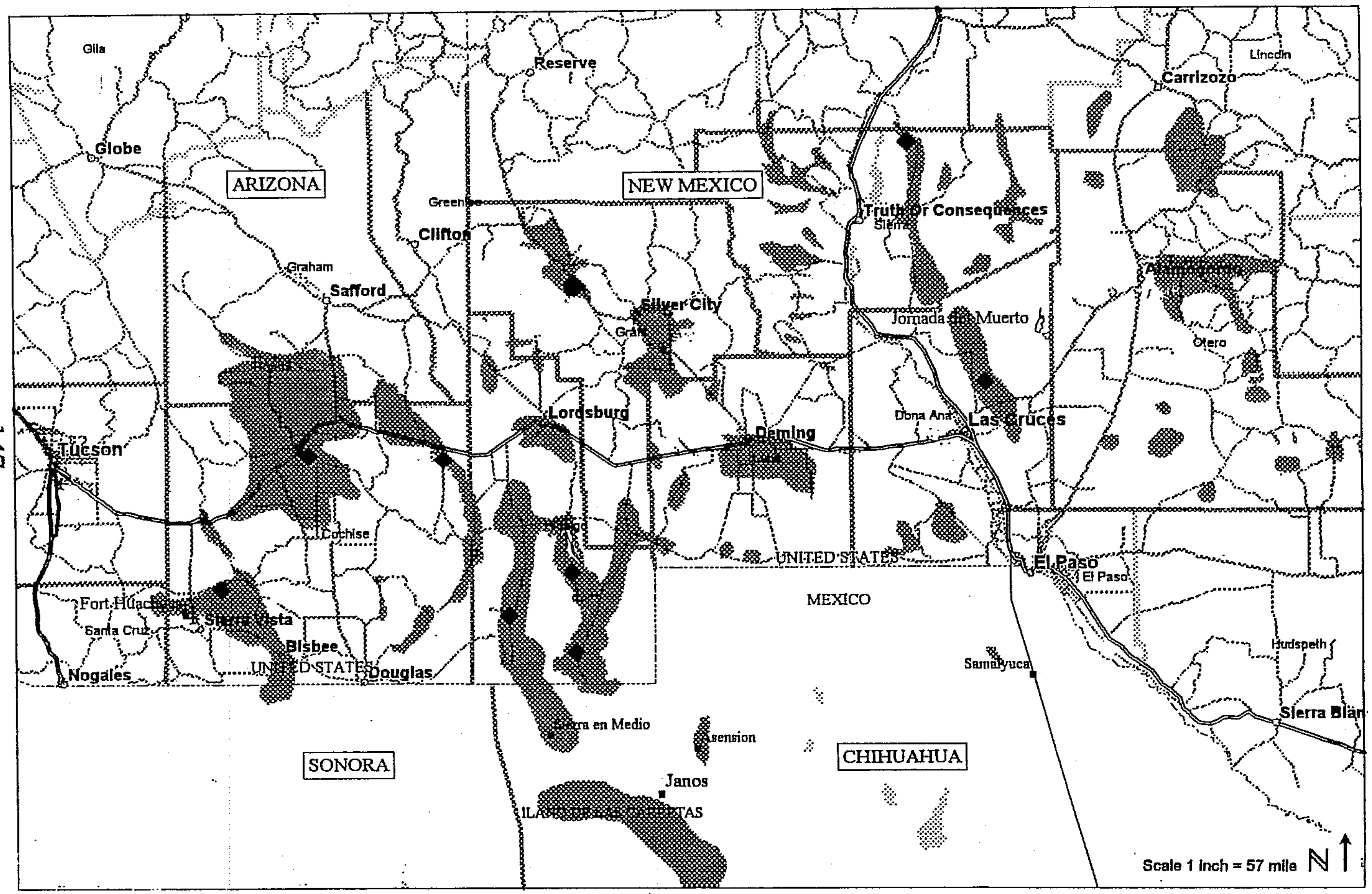
Arizona black-tailed prairie dogs were present across the study area before large herds of domesticated livestock were introduced. Records of prairie dogs that predate major effects from livestock include the 1680 Spanish name of "*Paraje de las Tusas*", or Prairie Dog Park, for the northern end of the Jornada del Muerto, the 1847 report by one of the members in the Mormon Battalion in 1847 of prairie dogs along the Animas Valley near Bercham's Draw, and Bartlett's account of large colonies in the Playas Valley in 1853.

Other records predating large livestock herds are Lane's 1853 report of dogtowns in Grant County, Kennerly's 1855 report of prairie dog colonies in southern New Mexico, the General Land Survey records showing large colonies in Doña Ana County in 1858-59, and the California newspaper account of prairie dogs along the stage route between Tucson and Dos Cabezas in 1860.

Prairie dogs began to be considered pests after permanent settlement began in the study area. Records of prairie dogs from the 1890s through the 1930s came primarily from professional biologists assessing the economic impact of noxious animals.

Arizona black-tailed prairie dog colonies were numerous in specific habitats, particularly in the deep soils of low-lying alluvial basins and river terraces, swales and draws with large watersheds to collect the limited rainfall of the semi-arid region. They were present in considerable numbers in all counties of the study area except Greenlee County, Arizona, for which no definite records were found. Figure 3.9 depicts the general areas where prairie dog colonies were most frequently mentioned.

Table 3.9 Important Population Centers for Arizona Black-tailed Prairie Dogs in the Study Area.



A total of 194 records of Arizona black-tailed prairie dog colony locations were documented dating from 1680 through the present. Of these, at least 72 records (37%) are repeat records for the same general location. Multiple colony records from different sources at different times confirms the long-term stability of prairie dog colonies on the desert grasslands in the absence of human interference. It also confirms the reliability of records from non-textual historical sources that have not previously been used in zoological studies, such as early BBS and USDA maps, general land survey records and interviews. The general accuracy of the BBS 1920 map of New Mexico Prairie Dog Infestation Map (BBS, 1921) is confirmed at more than 30 colony locations in southwestern New Mexico.

The pattern of distribution of Arizona black-tailed prairie dogs in the desert grasslands shows that populations were concentrated in swales and draws, on terraces around playas, on saddles dividing drainages, and on benches along river valleys. Colonies were less likely to occur on hillslopes, ridges, and mountains. The 1920 New Mexico Prairie Dog Infestation Map (Figure 3.1) shows that Arizona black-tailed prairie dog colonies are less dispersed and much more isolated from one another than in other parts of the state. This lighter prairie dog distribution in southwestern New Mexico may be related to the more arid conditions on the desert grasslands.

Chapter 4. Getting Rid of the Pest

EARLY CONTROL METHODS (1870-1915)

Private initiatives for prairie dog extermination began after 1870 in farming and hay-mowing areas of the study area. These areas included the Babocomari and San Pedro Valleys, the Upper Sulphur Springs Valley near Grant, Upper San Simon Valley, and Duck Creek Valley. The first record of prairie dog eradication other than shooting is found in a 1885 issue of the *Southwestern Stockman* (February 28, 1885:4). The article discusses the services being offered by an Englishman in Arizona who is able to kill prairie dogs in their dens with the help of a ferret on a chain. The article states, "Now is the best time to clean out dog towns, before the young ones have appeared. They reproduce very rapidly." The article implies that it is worth paying for extermination of prairie dogs, showing that farmers and ranchers had already come to view prairie dogs as major economic pests.

As homesteaders multiplied on the western frontier, the perceived threats to agriculture grew as well. American farmers and ranchers trying to earn a meager living off the land were quick to label most native animals as vermin (Dunlap, 1988; Doughty, 1983). All predators and rodents, as well as most birds, were considered pests or worse and were shot, poisoned, trapped and killed whenever possible (Doughty, 1983).

A series of federal initiatives, beginning in 1885 with the establishment of the Division of Economic Ornithology and Mammalogy (DEO&M), created a governmental role in the identification of agricultural pests (Jencks, 1929). Provisions in the agricultural appropriations act of June 30, 1886 (24 Stat. L ,100, 101) authorized the study of economic relations of both birds and mammals and agriculture. Under each of these titles the scientific purpose remained the same, to study the natural history and economic impacts of wildlife so that private extermination efforts would be more effective. There was no federal involvement in actual extermination under the DEO&M, which lasted until 1896 (Jencks, 1929: 26).

Private initiatives were not able to control prairie dogs, according to Bailey (1892). He asserted that shooting the animals was ineffectual as a means of extermination. He observed that "after a few have been shot the rest learn that it is safer to retreat into their holes soon when a man is seen, usually before he is near enough to reach them at long range" (Bailey, 1892:4). This is confirmed by Streator (1892) when he states of a colony near Fort Bayard: "it was almost impossible to get within shooting distance of them…no doubt owing to their being continually used as targets by local sportsmen."

Trapping prairie dogs was also of limited success. According to Bailey (1892), "it seems impossible to conceal a trap so carefully that they [prairie dogs] will not know it is there and keep away from the place. If a few are caught in traps the rest become very suspicious and are still more difficult to catch."

There were other early methods of exterminating prairie dogs that were much more effective than shooting or trapping, as observed by Bailey (1892). His work furnishes detailed descriptions of the various methods used by western farmers to destroy the animals. Drowning out prairie dogs was probably the most widely used method , according to Bailey:

> When it is possible to turn an irrigation ditch into a dogtown and by cutting small ditches turn a stream of water into each hole there is no help for the Prairie Dogs. Often a whole colony is exterminated in that way. Forced to leave their holes in a half drowned state and then shot, killed with clubs, or by dogs."(Bailey, 1892:5)

Often the farmers in the bottomlands would just plow up the burrows to drive the animals out, "Mr. Webster of the Vineyard Stock Farm says that plowing up the burrows drives out the dogs far better than irrigating the fields and flooding their burrows (Bailey, 1906:4)" This apparently did not work well when the crop was alfalfa or barley, for the animals just cleared out their burrows and stayed to feed on the crop (Bailey, 1892).

As early as the 1890 farmers were experimenting with various poisons to kill prairie dogs. Bailey (1892:14) wrote that, "Great success has been claimed in smoking them out with sulphur fumes forced through their hole". The role of the Biological Survey within the DEO&M during this period, however, was to record the natural history and effects of the animals on the agricultural economy, not develop newer and more effective means of extermination.

Drowning prairie dogs out was probably widely used during this period wherever lands were irrigated or collected surface water during heavy rainstorms. One such account was given by Bill Miller (Appendix A). He recalled drowning out large colonies on his father's land in Cochise County along the bottoms at the southern end of the San Simon Valley, even though there was no running water in the valley. He said that the young boys would go break down the prairie dog mounds with shovels during the heavy summer rains, allowing storm water to flow down the burrows. The boys would then strike the escaping dogs with their shovels, killing many animals. This was the primary method used, besides shooting individual animals, to reduce prairie dog populations up until the federal agents brought poisoned grain to the ranch in 1919.

County agricultural agents were already recommending various poisoning methods to the ranchers in New Mexico and Arizona from the early 1900s. For example, one agricultural agent in New Mexico advised ranchers in 1903 of a successful poison for prairie dogs, "by dropping a teaspoonful of wheat soaked in a solution of arsenic, croton oil, and a little molasses at each hole, the prairie dog is put to death and grass made to flourish where before was close cropped by the pests"(Parrish, 1962:267-268).

Despite the BBS official statements that private initiatives had little, if any, lasting effect of prairie dog populations (Merriam, 1902; Bailey, 1906; Streator, 1892), there is evidence that some of the early extermination methods were effective when systematically applied over several years. For example, G. A. Bateman, BBS Assistant for the New Mexico District, reported upon arriving in the Nara Vista area in 1918 to begin federal poisoning work for the first time, that, "the ranchmen had been poisoning dogs for years and had, with the exception of forty acres, completely cleared the country of the pest" (BBS, New Mexico Narrative Report, 1918).

Similar news was reported by Fisher in 1917 in a letter to BBS Director, Dr. Bell. He discovered during a tour of southern New Mexico in which he was eliciting support for proposed new cooperative poisoning programs, that prairie dog poisoning had already been used extensively by individual ranchers in the Magdelena area for several years. He states that, "it was very gratifying to find only a few animals [left] when signs showed that thousands existed before treatment" (BBS, New Mexico Annual Reports, 1917).

Given this perspective, private initiatives must have had a significant effect on prairie dog populations in the most populated parts of the study area between 1870 and 1915, and were far more effective than Bailey and the BBS were publicly admitting. Areas with irrigated agriculture, such as the San Pedro, Babocomari, middle and upper Gila, upper San Simon River valleys, and parts of Duck Creek Valley, may have already reduced prairie dog populations before 1915, by using drowning and direct killing of animals, as well as various poisons. Private rodent control efforts in other areas with particularly extensive colonies and low human population, such as the Animas Valley, Jornada del Muerto and the various rangelands of the region, probably had little effect on populations of prairie dogs prior to the implementation of state and federal initiatives.

THE ROLE OF THE BUREAU OF BIOLOGICAL SURVEY IN THE DEVELOPMENT OF EFFECTIVE POISONING METHODS (1896-1918)

The Division of Economic Ornithology and Mammalogy was renamed the Division of Biological Survey in April 25, 1896 (29 Stat. L., 99, 100. 102) and enlarged to the Bureau of Biological Survey (BBS) in 1905 (Act of March 3, 1905; 33 Stat. L., 861, 877). The newly formed agency, called the Bureau or BBS in this study, was organized around two lines of scientific pursuit: studies of animals that had bearing on agricultural economy and studies of the geographic distribution and natural history of species (Jencks, 1929: 26). Studies relating to animal poisoning were conducted within the context of the first mandate and surveys to locate and map important pest species for future control campaigns took place within the latter mandate.

Between 1896 and 1915, details of the natural history and distribution of prairie dogs continued to be included in BBS reports, but increasing emphasis was placed on itemizing the economic injury of the prairie dog pest and devising efficient means of eradication. Merriam's persuasive article on prairie dogs in the USDA Yearbook of 1901 (Merriam, 1902), helped generate increased federal funding for the agency, including rodent control programs. The rodent control work was entirely supported by federal funding from 1905 through 1915, and one of the important goals of this period was the development of an efficient and reliable poisoning method for prairie dog extermination (BBS, Arizona Narrative Report, 1924-25).

Bailey began systematic experiments on Arizona black-tailed prairie dogs in New Mexico using different poisons and poisoning techniques. He reported that prunes and corn were the most acceptable foods to the rodents (Bailey, Carlsbad,1906:5). Bailey then added several poisons to the favorite foods of the prairie dogs. He tried corn soaked in various sweetened mixtures of arsenic, cyanide of potassium, and strychnine, and prunes laced with arsenic or with strychnine--finding very little effect. Only arsenic mixed with cyanide produced limited effect on a colony of about a dozen dogs, "The number decreased gradually after the poison was put out until only 4 remained, 5 days later, and these were bisulfided. The arsenic apparently works slowly and is not palatable to the dogs" (Bailey, Carlsbad, 1906:6).

Fisher and Goldman began conducting similar experiments in 1906 on the J. H. Ranch near Willcox Arizona. Also, S.E. Piper conducted experiments at Prescott, Arizona in 1907 (BBS, Arizona Annual Report, 1924-25). Like Bailey's studies, these studies did not produce uniformly high mortality. For that reason, the agency appropriated additional funds from the Agricultural Appropriations Act of 1909 for the purpose of "experiments and demonstrations in destroying noxious animals" (35 Stat. L., 1039, 1051).

These appropriations led to the assignment, in 1911, of Theodore Scheffer, who continued experimental studies on prairie dog poisoning methods in Flagstaff, Arizona (BBS, Arizona Annual Reports, 1924-1925. This work resulted in the refinement and perfection of earlier poisoning techniques. These methods were tailored to the particular conditions of the Southwest and were followed by organized field trials on the Coconino and Sitgreaves National Forest in 1912 and 1913 (BBS, Arizona Annual Report, 1924-1925).

Two poisoning methods were recommended widely in agricultural bulletins and journals in the Southwest. For example, the New Mexico College of Mechanic Arts and Agricultural Experiment Station sent out the following recommendations, based on Theodore Scheffer's experiments: 1) Fumigation with carbon bisulfide, a volatile liquid producing an explosive gas, was effective when conducting poisoning in damp, rainy weather, and 2) Poisoned grain (wheat, barley or kafir corn) soaked in a mixture of strychnine, sugar and laundry starch was effective in the winter or spring before the growing season (Merrill, 1913). Alternatively, grain could be soaked in a strychnine-potassium cyanide and alcohol-syrup mixture. In dry weather, poison was placed on the ground outside of active burrows, using a half bushel of poisoned grain to 500-600 burrows (Merrill, 1913).

During the period of 1896 through 1914, the Bureau provided scientific research and recommendations, and conducted specific demonstrations of their extermination methods. Budgetary appropriations increased dramatically for "noxious animal": from $25,000 in 1909 to $115,000 in 1914, to be shared between predator control and rodent control projects nationwide. Production and application of poisons was left entirely to local farmers and ranchers, with the exception of a few demonstration areas on National Forests and other federal lands.

Public confidence in the Bureau in conducting rodent control work was gradually being built through demonstration projects that showed that prairie dogs could be eliminated from increasingly large areas with decreasing cost. This also built a basis for Congressional support during budget sessions for agricultural appropriations.

In 1915, the BBS implemented a "Westwide Plan" that envisioned the elimination of the prairie dog pest, along with wolves and other predators from vast areas of western rangelands (Jencks, 1929). The Agricultural Appropriations Act of 1915 not only doubled the budget for studies of pest species, but also gave statutory authorization for the BBS to conduct large scale poisoning operations on National Forests and all other public lands, including reservations, parks, monuments and the public domain (Jencks, 1929:59-60). From this time forward, the economic wing of the Bureau was transformed from an agency of scientific investigation into one of animal destruction.

Increased federal appropriations for rodent control from 1915 through 1917 were used to demonstrate the ability of the BBS in large-scale eradication programs. Campaigns in New Mexico and Arizona focused exclusively on large prairie dog colonies on the National Forests and Federal Range Reserves. The USDA Jornada Range Reserve, later named the Jornada Experimental Range (JER) near Las Cruces, New Mexico, became a model site for the first large-scale poisoning campaign. The BBS hoped to demonstrate the effectiveness of the new rodent control methods and resulting range improvements brought about by eradication of prairie dogs.

The Jornada Range Campaign, conducted from 1916 through 1918, was a Bureau demonstration that brought together the funding and organizational ability of the BBS with the federal manpower of the JER. In 1917, James Jardine, USDA Inspector of Grazing stated in a letter to C. I. Forsling, grazing assistant at the JER, "we are anxious to have both rabbits and the prairie dogs exterminated in order to make the Journada Reserve a demonstration of range development and range management and improvement along all lines." (Jardine, Feb.14, 1917).

Initial prairie dog treatments were conducted in 1916, followed by second poison applications in the spring of 1917 that together exterminated approximately 4,000 acres of prairie dog towns. The task of controlling prairie dogs over the entire Range proved to be more difficult than originally planned. In order to better estimate the amount of poison and manpower to apply the following year, detailed maps were made of the remaining infestation. These maps, reproduced in Appendix D, include coded descriptions of vegetation cover, providing some of the best historic information available on the pre-eradication vegetation that was characteristic of prairie dog colonies in desert grasslands.

Further applications of poisoned grain were made at the Jornada Range in the spring of 1918, followed-up by carbon bisulfide fumigation later in the year to eliminate prairie dogs from an additional 7,600 acres of the Experimental Range.

Although the Jornada Range Prairie Dog Campaign was declared a success by local agricultural agents, the BBS did not consider it a successful model to base further campaigns on. It took 3 years and a large labor force to poison less than 15,000 acres. In the end, the campaign relied on burrow-by-burrow application of expensive carbon bisulfide gas, a method that was not considered an alternative for large-scale applications.

The campaigns on the JER had created a strong working relationship between the BBS and at New Mexico College of Agricultural and Mechanical Arts in Las Cruces. Not surprisingly, the College of Agriculture became the state headquarters for New Mexico BBS cooperative programs in 1918 (BBS, 1918).

The BBS was very interested in demonstrating that removal of prairie dogs had a measurable positive impact on grass density and measures of vegetation palatability. The 1917 maps of prairie dog locations on the Jornada Range (Appendix D) provided exactly the kind of detailed initial background data on vegetation associated with the prairie dog colonies that could have been used to track post-eradication range improvements. There was no evidence, however, in the JER files or the records of the BBS, New Mexico Operations that these data were ever used in follow-up studies on vegetation improvement after rodent eradication.

It was clear from the JER campaign that a more enticing baiting method and a more powerful killing agent were required. The BBS set to work on further experiments to improve their poisoning methods.

The Jornada Campaign demonstrated the importance of accurately mapping prairie dog colonies prior to beginning a campaign prompted the BBS New Mexico office to begin a state-wide mapping project for future campaigns, as evidenced by this statement in their files:

> Maps of prairie dog infestation, showing the areas which have been treated, are being carefully prepared in all counties in which operations are under

> way. Agricultural Agents in counties in which work has not as yet been started have been asked to map all the information they can obtain on the areas of infestation. Preparation of such maps warrants careful attention, for they constitute a valuable working basis and will provide interesting subject material and records (BBS, New Mexico Annual Reports, 1918:9).

The New Mexico *Prairie Dog Infestation Map* (BBS, 1921), shown in Figure 3.1, is an example of such mapping efforts. Agents working for the BBS in the 1930s informed me that they always worked from good maps for any campaign. Unfortunately, this 1920 map was the only map of its kind found in the National Archives or the regional or in the state offices of the Animal Damage Control Divisions of Arizona or New Mexico, the modern counterpart to the BBS.

In addition to the JER campaign, other major demonstration projects occurred on the National Forests of New Mexico and Arizona between 1914 and 1918. Demonstration campaigns on National Forests in Arizona poisoned 632,525 acres during this period while 1,031,500 acres of National Forest were treated in New Mexico (BBS, Annual Reports, Arizona and New Mexico, 1918). These demonstrations were used to show the Appropriations Committee and the voting public that the BBS could deliver on their promise to rid large areas of prairie dogs. The demonstration projects also built experience and enthusiasm and within the Bureau for large projects in rodent destruction. There was a limit, however, to the expenditures the federal government was willing to make to assist private agriculture with prairie dog control (Jencks, 1929). In Washington, D.C., prairie dogs were seen as a western problem, not a national issue and there was little political will to fully fund a "west-wide" federal program for prairie dog eradication in 1917, regardless of intense lobbying by the BBS.

STATE-FEDERAL COOPERATIVE ALLIANCES FOR TOTAL ERADICATION OF PRAIRIE DOGS (1918-1925)

Failures of the 1916-1917 rodent control demonstrations, particularly at the Jornada Range, compelled the BBS to begin work on improved poison effectiveness and delivery in experimental situations in Arizona in 1918 (BBS, Arizona Annual Reports, 1918). In particular, the BBS found that the kill rates were much higher on National Forests where the animals were given poisoned grain for the first time, as opposed to areas where animals had previous experience with poisons (BBS, Arizona Annual Reports, 1918). The objective of the experiments was to find a more palatable poison mixture and a more enticing bait to obtain a higher kill rate. Partially poisoned animals left living on a colony had been shown to avoid all suspicious foods and to train their offspring to also be wary of foreign food items, making future poisoning very difficult (BBS, Arizona Narrative Reports, 1921).

This problem was not effectively solved until 1922 when it was found that pre-baiting every colony with untainted grain at least once prior to application of poisoned grain, would eliminate all suspicion in the colony and bring about a much higher kill rate. The resulting method was more labor intensive and costly but prevented the embarrassment of having agents called back to repeat poisonings year after year on the same site.

In 1917, the national leadership of the BBS was transformed by the promotion of two biologists, Fisher and Piper, who had been in charge of the poison development and demonstration programs in Arizona. This created a strong voice for increased prairie dog eradication programs in Washington, D. C. Gilchrist and Duane Stonier were appointed as Biological Assistants in Arizona and New Mexico, respectively, in order to implement the rodent eradication programs.

This core group of men viewed themselves as efficient business professionals whose job was to sell the concept of prairie dog extermination as an astute business strategy with significant economic benefits. Gilchrist began his appointment in Arizona with this statement of purpose linked with economic rewards:

> ...this destruction of rodent pests should be conducted under systematic, business-like and constructive methods, which should aim at the complete extermination of the pests from given districts.
>
> Net Return on Investment:
>
> Using the minimum savings of $5.00 per acre as a basis, the destruction of at least 95 per cent of the rodents on 106,628 acres of cultivated lands has resulted in an annual saving of $535,140.00, or over half a million dollars. (Excerpts from BBS Special Report, Dec. 4, 1918:3,7)

The scientists of the Biological Survey were absolutely convinced that they had the information and organizational ability to bring about complete prairie dog extermination in New Mexico and Arizona. Stonier envisions total eradication of all prairie dogs from New Mexico within 3 years, according to his 1918 report:

> Areas that have been treated are not to be lost sight of but the work is to be continued and extended in each unit to insure permanency in results and final eradication of the pest.
>
> ...prairie dog eradication on such a broad scale requires thorough organization and the close supervision of trained men. ...Our better knowledge of prairie dog infestation in the state, and of local seasonal conditions, permits planning the work in each district in its proper sequence. It is felt that the campaign will be so systematized and

> thorough-going...that the infestation in the state can be largely covered under the existing plan... and should be practically accomplished within the third year from the beginning of the initial campaign. (BBS, New Mexico Annual Report, 1918:9-10)

The program of extirpation required legislative mandates, increased funding, additional manpower and organizational infrastructure. The BBS sought the additional support from state governments, forging cooperative alliances for the predator and rodent control work. Program directors recognized the tremendous opportunity brought about by the patriotic fervor that was sweeping the nation in 1918. They resorted to patriotic rhetoric in order to justify large public expenditures for their work and to encourage local, state and federal support. Exhibits were set up by the Bureau at the Arizona State Fair and numerous county fairs across Arizona and New Mexico in 1917, 1918 and 1919. The exhibits depicted piles of dead prairie dogs with the caption proclaiming, "These Allies of Germany Will Not Destroy Any More Farm Crops or Forage for Livestock" (BBS, Arizona Annual Reports, 1918, 1919).

Intensive political lobbying by the Bureau took place in support of appropriations bills and cooperative agreements and other measures increasing the political support for rodent control. Stonier, Gilchrist, and their Bureau supervisors traveled across Arizona and New Mexico seeking the support of the cattlemen's and wool grower's associations and the state legislatures. Strongly patriotic language was used in the numerous speeches given around both states in 1917-1919. Gilchrist, for example, noted that

> The year of 1918 found this country in a world war, which brought about so serious a condition, that the saving of every available bit of food was absolutely necessary. Many Arizona stockmen and farmers, who had not

> been privileged to join that splendid force of khaki clad Americans, which was to establish liberty for the entire world, desired to do their bit by feeding that army, and feeding it well. With this noble thought in mind, steps were taken to find out how they could best serve in increasing the production at home. Several practical constructive ideas resulted, among which was the plan of exterminating prairie dogs... (Gilchrist, BBS, June 30, 1919)

Not only did these experts argue that the extermination of prairie dogs would result in higher beef production to feed the military, but would improve lands for the settlement of returning troops, further boosting the local economy. Gilchrist states,

> We hear a great deal about the proposed plan whereby returning soldiers are to settle on certain lands in the West. Very well, the West including good old Arizona, has some very fertile areas waiting only for youth, ambition and energy to convert the same into a valley of the Nile, but do not fail to remember that the rodent pests have first claim upon some of these same lands and that they are waiting only too glad to harvest any crop which might be raised. The boys have been fighting Huns, cooties, and trench rats on the western front but would not necessarily desire to settle in a country over-run with pests and fight them the remainder of their lives. (BBS, Arizona Annual Report, 1918)

Aggressive publicity and political lobbying on the part of the Bureau worked well in forging unique alliances for cooperation among agencies to establish the desired rodent control programs. Large federal appropriations were made available for rodent control in 1918 and 1919. Not only were the agricultural appropriations unusually high that year, but they were supplemented by additional War Emergency Funds, the bulk of which went to prairie dog control projects, (BBS Annual Reports, New Mexico, 1918). New Mexico and Arizona participated more thoroughly than most other western states in the federal initiative to exterminate prairie dogs.

War-time zeal may explain part of the early enthusiasm for the cooperative programs. For example, they were the only states in which the Councils of Defense provided the manpower for poisoning large tracts of public lands in 1918 and 1919 (Jencks, 1929: 60). In 1918, control projects were severely hampered by lack of manpower due to World War I and the subsequent influenza epidemic in the U. S.. The Councils of Defense in Arizona and New Mexico provided additional men at government expense, for rodent poisoning in the Coconino, Sitgreaves, and Apache National Forests of Arizona and the JER in New Mexico.

New Mexico House Bill 338 on March 17, 1919, provided not less than $25,000 per year for predator and rodent control and matched federal appropriations for these programs annually. In addition, Bill 338 provided for the enforcement of treatment of non-cooperative lands in the state (BBS, New Mexico Annual Report, 1919).

The BBS leadership in Arizona, New Mexico and other states presented the public and the state legislatures with their "battle plans" for the elimination of the prairie dog pest. The plan consisted of identifying and mapping the location of major infestations, targeting these areas for systematic poisoning using trained field parties and the latest poisons from the BBS poison research and development operations. Each infestation area (prairie dog town) was to be treated progressively and repeatedly by trained field teams until all animals were destroyed, as described by Stonier,

> Primarily, prairie dog extermination consists in progressive extension of cleared areas. No infested tracts can be left behind even for a short time, because animals spread from them with surprising quickness to the cleared

> lands. An area here and there that can not be treated defeats the thorough-going progress that is a first essential in eliminating the pest.
>
> Concentration of the work… in order that large ranges can be quickly treated, constitutes another of the essential factors of success in complete extermination. (BBS, New Mexico Annual Report, 1919)

State and federal cooperation in predator and rodent control during the World War I proved to be the key to the establishment of a self-sustaining bureaucracy organized around providing an ongoing service to the politically powerful ranching interests in each state. In New Mexico, for example, strong bureaucratic foundations were laid out in initial organizational meetings held in 1918 that set forth a state-wide program. The essential participants were the BBS, the state Extension Service, and the land owners, according to this report of the BBS,

> All cooperative agreements were made on the basis that privately owned lands bear the cost of labor and materials, that state and federal lands be treated at state and federal cost respectively, cooperating agencies supplying at least the labor and grain, Biological Survey poison and fumigants. Extension Service or county agents act in a publicity capacity and bring about a fuller understanding of Biological Survey plans, methods and basis of operation before the interested public. The Biological Survey will supervise the campaigns formulated on the financial basis provided by the state rodent law. In addition, year round poison grain dispensing stations were established in stores in every county of the state. Prepared poison grain was sold to cooperators at cost, storekeepers volunteering their services in handling and reporting sales of grain (BBS New Mexico Annual Reports, 1922:2)

In Arizona, Senate Bill No. 15 appropriated $50,000 a year for 1919 and 1920 for rodent pest and predatory animal work and provided for the State Council of Defense funds to be transferred to the BBS (BBS, Arizona Annual Report, 1919). The bill also provided for cooperative agreements between the State Council of Defense, the Extension Service, the Bureau of Biological Survey and the University of Arizona. The official mandate of the new rodent control program was to produce ever-widening areas of complete extermination of prairie dog pests.

Estimates of Original Area Occupied by Prairie Dogs in Arizona and New Mexico

The BBS began keeping statistical records of their operations in Arizona and New Mexico in 1914, quantifying the extermination of rodents pests. These statistics were reported by each state in annual reports sent to the Bureau Headquarters in Washington, D. C., and are now housed in the National Archives. The statistical reports include data organized by county and include the number of acres receiving first treatments (by rodent species), as well as acres receiving second treatments, the quantity and types of poisons used, and program expenditures. In using these statistics, I will continue the BBS convention of quantifying prairie dogs and prairie dog eradication in terms of acres, forgoing metric conversions.

In 1920, the BBS requested that each cooperating state conduct prairie dog inventories and produce maps showing the distribution and extent of prairie dog occupation in order to allocate funding and plan the rodent campaigns efficiently. I have compiled the 1921 inventory statistics from Arizona and New Mexico and the prairie dog poisoning statistics for each county from 1916 through 1921. By adding the number of acres poisoned prior to 1921 to the acres of living prairie dogs in 1921, an estimated original (1916) population of prairie dogs has been calculated for each state, by county, as shown in Tables 4.1 and 4.2.

The statistical accounts did not always identify the species or subspecies of prairie dog. Arizona had only two taxonomic groups present, Arizona black-tailed and Gunnison's prairie dogs, with the black-tailed prairie dogs occurring in only three counties: Cochise, Graham, and southern Greenlee Counties. No overlap in distribution occurred between the two species, making it easy to determine population quantities for the Arizona black-tailed prairie dog in Arizona.

The New Mexico BBS 1921 inventory and eradication statistics for prior years are reported for all taxonomic groups of prairie dogs. New Mexico prairie dog species overlapped geographically in several counties. Maps and descriptions from Hollister (1916), Bailey (1932) and the BBS records for New Mexico indicate that Grant, Hidalgo, Luna, Sierra, Doña Ana, Otero, and Lincoln counties were occupied solely by the Arizona black-tailed prairie dog. I have made the assumption that 100% of the BBS reported acres of prairie dogs in these counties are of this subspecies. Chaves, Eddy and Socorro counties were substantially occupied by the sub-species, but contained other taxonomic groups. For these counties I have made the simplified assumption that 50% of the acres of prairie dogs reported by the BBS were the Arizona subspecies.

The derived data indicate that in 1916, Arizona contained an estimated 687,676 acres of Arizona black-tailed prairie dogs and approximately 7.322 million acres of all types of prairie dogs prior to systematic BBS eradication.

Table 4.1. Estimated Original (1916) Prairie Dog Population in Arizona, by County.

County and National Forest	1921 Prairie Dog Inventory Results (Acres)	Treatments in Previous Years (Acres)	Original (1916) Acres *C. l arizonensis*	Original (1916) Acres *C. l. gunnisoni*
Apache	2,175,280	45,175	0	2,220,455
Cochise	128,000	289,452	417,452	0
Coconino	1,895,400	50,268	0	1,945,668
Gila	0	0	0	0
Graham	192,000	78,535	270,535	0
Greenlee	12,800	120	12,920	0
Maricopa	0	0	0	0
Mohave	0	0	0	0
Navajo	773,700	27,635	0	801,335
Pima	0	0	0	0
Pinal	0	0	0	0
Santa Cruz	0	0	0	0
Yavapai	772,300	126,066	0	898,366
Yuma	0	0	0	0
National Forests				
Apache	57,600	78,720	0	136,320
Sitgreaves	0	224,000	0	224,000
Coconino	0	132,000	0	132,000
Tusayan	208,180	34,020	0	245,800
Prescott	79,415	163,785	0	243,200
Totals	**6,294,675**	**1,249,776**	**687,676**	**6,635,280**
Original (1916) Acres *C. .l. arizonensis*				**687,676**
Original (1916) Acres All Prairie Dogs				**7,322,956**

(Source: BBS, Arizona Annual Reports and Records, 1916-1921)

Table 4.2. Estimated Original (1916) Acres of Prairie Dogs in New Mexico, by County

County and National Forest	1921 Prairie Dog Inventory Results (Acres)	Treatments in Previous Years (Acres)	Original (1916) Acres *C. l. arizonensis*	Original (1916) Acres all prairie dogs
Bernalillo	125,000	2680	0	127,680
Chaves	650,000	79,820	364,910	729,820
Colfax	630,000	74,073	0	704,703
Curry	3,000	0	0	3,000
De Baca	130,000	45	0	130,045
Doña Ana	85,000	10,090	95,090	95,090
Eddy	120,000	39,512	79,756	159,512
Grant	450,000	40	454,040	454,040
Guadalupe	600,000	63,270	331,635	663,270
Harding	187,500	0	0	187,500
Hidalgo	460,000	0	460,000	460,000
Lea	160,000	85,400	0	245,400
Lincoln	250,000	23,255	273,255	273,255
Luna	no data	no data	no data	no data
McKinley	750,000	41,570	0	791,570
Mora	160,000	42,701	0	202,701
Otero	750,000	2,160	752,160	752,160
Quay	500,000	106,440	0	606,440
Rio Arriba	850,000	35,566	0	885,566
Roosevelt	250,000	25,045	0	275,045
Sandoval	260,000	22,701	0	282,701
San Juan	480,000	39,750	0	519,750

(Source: BBS, New Mexico Annual Reports and Records, 1916-1921)

Table 4.2. Estimated Original (1916) Acres of Prairie Dogs in New Mexico, by County (Cont.)

County and National Forest	1921 Prairie Dog Inventory Results (Acres)	Treatments in Previous Years (Acres)	Original (1916) Acres *C. l. arizonensis*	Original (1916) Acres all prairie dogs
San Miguel	250,000	24,637	0	274,637
Santa Fe	160,000	59,043	0	219,043
Sierra	90,000	20	90,020	90,020
Socorro-Catron	4,800,000	117,300	2,458,650	4,917,300
Taos	350,000	18,395	0	368,395
Torrance	270,000	4,920	0	274,920
Union	187,500	134,045	0	321,545
Valencia	900,000	45,825	0	945,825
National Forests				
Alamo		93,440	0	93,440
Carson		127,890	0	127,890
Manzano		58,970	0	58,970
Datil		116,155	0	116,155
Totals	**14,858,000**	**1,499,533**	**5,359,516**	**16,357,533**
Estimated Original (1916) Acres *C. l. arizonensis*				**5,359,516**
Estimated Original (1916) Acres All Prairie Dogs				**16,357,533**

(Source: BBS, New Mexico Annual Reports and Records, 1916-1921)

New Mexico had approximately 5.36 million acres of Arizona black-tailed prairie dogs, and a total of 16.36 million acres of all types of prairie dogs. It is certain from the narrative accounts of prairie dog eradication by private initiative that prairie dog populations were even higher before Anglo settlement.

These county and state-wide estimates of the extent of prairie dogs are approximate, however, they represent the best available data at this time. These numbers can be compared with actual extermination statistics to determine the general accuracy of the original estimates, expecting the total acreage poisoned to equal the estimates of original acreage at about the same time that prairie dogs are extirpated from an area.

The Arizona Black-tailed Prairie Dog Campaign of 1919-1922

A cooperative structure for prairie dog eradication similar to that in New Mexico was established in Arizona in June of 1918 and adopted in October of that year (BBS, Arizona Narrative Report, Nov. 1918). Cooperative agreements were signed between the State Council of Defense, the BBS, and the state Extension Service placing rodent and predatory animal control work in the state under the supervision of the BBS. State appropriations of $25,000 were matched by federal appropriations, and county tax levys. A detailed map of all public lands infested with prairie dogs was prepared by the State Land Office. Headquarters for the Arizona operations were established at the University of Arizona in Tucson.

The Santa Rita Experimental Range (SRER) was considered an ideal site for BBS-sponsored experimentation with various rodent control methods, and like the JER in New Mexico, would have made a logical choice for important demonstration projects. However, no prairie dogs inhabited the site in 1915.

The BBS believed that populations of the Arizona black-tailed prairie dog in Cochise and Graham Counties would make an ideal target for a major demonstration of the new cooperative programs. Unlike the Gunnison's prairie dogs living elsewhere in the state, which live in forested and more broken country, black-tailed prairie dog colonies were concentrated in broad treeless valleys and dry lake beds that were also used as the primary transportation routes through the state. As such, they were at once highly visible and accessible and highly vulnerable. The BBS state leaders saw certain success in targeting the Arizona black-tailed prairie dog for a campaign and clear advantages for publicity for the newly formed cooperative programs, as suggested in this comment from their files, "...when the Governor of Arizona visited the Fort Grant Industrial School located around thirty miles northwest of Willcox, he was compelled to ride through thirty miles of prairie dog infestation and bare denuded lands lay on every side." (BBS, Annual Reports, Arizona, 1922:3).

The land owners of Cochise and Graham Counties cooperated willingly in the eradication of the Arizona black-tailed prairie dog. Large scale ranchers in southeastern Arizona there had considerable political clout and strongly supported the passage of the Rodent Law and other federal and state programs to help subsidize their operations.

For example, the Chiricahua Cattle Company, the largest cattle company in Arizona in 1919, contained about 25,000 acres of prairie dogs on their range in the San Simon Valley and Chiricahua Mountains, according to BBS records (BBS, Arizona Annual Report, Special Report, 1921). The company ran 40,000 head of cattle on land leased from the federal government for only $20 per section, selling their beef to government concessions for large profits. The BBS estimated that their range was in such depleted condition from overgrazing that even complete extermination of the prairie dogs would only increase production and profits by about $480 per year (BBS, Annual Reports, letter dated May 7, 1920). Even so, they were a very forceful supporter of public expenditures on the eradication campaigns, as were the Hooker, Sierra Bonita, C. M. Johnson and Riggs Cattle Companies--all large-scale operators that profited by "stacking" federal contracts and subsidies.

The prairie dog inventory of 1921 showed that southeastern Arizona contained approximately 700,000 acres of prairie dogs (BBS Annual Reports, New Arizona, 1921). This represented less than 7 % of the total acreage of Graham and Cochise counties. Gilchrist used inflammatory rhetoric to prejudice the public against prairie dogs and encourage support for the campaign. He states,

> Valuable farm crops and grazing lands in Arizona are damaged by rodent pests to the extent of over $2,000,000.00, annually. Organized efforts within the borders of our own state have proven that they can be completely exterminated from large tracts at a cost so slight as to be negligible, yet we neglect this important item and let contemptible little prairie dogs destroy farm crops and over half of the grass on 6,000,000 acres of the best grazing lands in the State...that would pay off that mortgage of long standing or purchase those new clothes for that deserving wife. (BBS, Arizona Annual Report, Nov. 1918)

The cooperative campaigns against Arizona black-tailed prairie dogs began in December 1918 in the Hereford District of the southern San Pedro Valley and in the Boquillas Valley where John Spring had observed prairie dog colonies in 1860 (Gustafson, 1966:116). Work started simultaneously in Graham County at the northern edge of the large colony between Fort Grant and Willcox (BBS, Annual Reports, Arizona, Narrative Report, Dec. 1918). In fiscal year 1918, 25,000 acres of prairie dogs were poisoned on the ranges of the Boquillas Land and Cattle

Company in southern Cochise County and nearly 40,000 acres were treated along the San Pedro Valley. Over 12,000 acres were poisoned in the Sulphur Springs Valley around Ft. Grant, Bonita and the Sierra Bonita Ranch.

In 1919 and 1920, an all-out war was waged against Arizona black-tailed prairie dogs. Large and small holders alike joined in the campaign of eradication. The Chiricahua, Sierra Bonita Ranch, Hooker, Kennedy, Eureka Springs, Johnson & Cook, Mills and the Monk Brothers Cattle companies all took part, as well as the H. L. Johnson, A. W. Wilson, and Muleshoe ranches. Numerous small ranches also participated. Bill Miller (Appendix A) recalled the poisoning crews conducting the campaign on the various ranches in the southern San Simon Valley.

John Riggs of the Riggs Cattle Company, Dos Cabezos, Arizona, stated, "Our entire range has been cleaned of prairie dogs…" (BBS, Arizona Annual Reports, 1921:6). The manager of the Sierra Bonita Ranch, Graham County, was happy about the, "Complete extermination of prairie dogs on the greater part of our range…" (BBS, Annual Reports, Arizona, 1921:4).

BBS projections of rapid extermination proved elusive, however. After three consecutive years of poisoning, additional isolated colonies were still reported every month and the program was plagued by a poor rate of kill that often left behind 10-20% of the animals to repopulate areas. Like the Jornada Range Campaign, the retreatment of colonies proved difficult because the surviving animals refused to take poisoned grain and every burrow had to be individually gassed with carbon bisulfide. Unlike the Jornada Range Campaign, Arizona did not recognize the value of good biological surveys and mapping to assist with their planning. They had underestimated the original populations of prairie dogs by a large amount.

In addition, with the end of World War I, the additional funding made available from the Council of Defense had dried up and new sources of public funding were being sought (BBS, Annual Reports, Arizona, 1921:6). Gilchrist was anxious to announce a "victory" over prairie dogs to the state legislature for the new Cooperative Rodent Control Program. Tremendous effort was poured into the final campaigns of eradication in southeastern Arizona in 1921-22, and publicity became a preoccupation of the Bureau. As ranches were cleared of prairie dogs, the BBS personnel asked landowners to sign petitions and declarations. Moving pictures and pamphlets were made of the "Sulphur Springs Valley Prairie Dog Campaign" to enlist public support.

Sometimes the owner's declarations add precious information about prairie dog locations. For instance, in 1922, Judge Sam R. Holderman of Light, Arizona, declared that the BBS program had, "Completely exterminated the prairie dogs from my 1,280 acres" (BBS, Annual Reports, Arizona, 1922:2). Similarly, one C. D. Condit reported that the program had poisoned 10,000 acres of prairie dogs on his ranch near Douglas (BBS, Annual Reports, Arizona, 1923:3).

During 1921 and 1922, the BBS poisoned a total of 594,132 acres of Arizona black-tailed prairie dogs in Arizona. This led to the first announcement of complete extermination of black-tailed prairie dogs in Arizona:

> On the twenty-fifth day of June, 1922, the last prairie dog was exterminated from Cochise and Graham counties. This was the result of three years of vigorous effort on the part of over eight-hundred farmers and stockmen cooperating with two trained experts from this office. An

> area ranging from Eureka Springs above Ft. Grant in Graham County to Douglas in Cochise County was cleared for this pest. The area was over 120 miles long and averages from ten to twenty miles wide and the actual number of acres infested was a little over 500,000 acres....(BBS Annual Reports, Arizona, 1922)

The 1922 announcement, while politically effective, wasn't accurate. Many pockets of prairie dogs remained in southeast Arizona. Two steps were taken to effectively hide the presence of black-tailed prairie dogs and their continued treatment over the next decade.

First, in 1922, the BBS added kangaroo rats, ubiquitous to southeast Arizona, to the list of noxious rodents to be poisoned. This doubled the "infested" acres in those southeastern Arizona and allowed for increased budgets and continued rodent control operations after the prairie dog was reportedly gone.

The Arizona BBS also changed the reporting procedures after 1923. Instead of listing the acres treated for each rodent species, the Arizona BBS began reporting only the combined acreage of all rodents. These steps allowed the Bureau to continue to perpetrate the myth of complete extermination of the Arizona black-tailed prairie dog in the agency's Washington, D.C. offices. As late as 1930 the Arizona Annual report states that, "the large black-tailed prairie dog, "Arizonensis" has been completely eradicated from the state" (BBS, Annual Report, Arizona, 1930). The Arizona BBS clearly recognized and took pride in the extirpation of a unique biological organism from Arizona, even as it was slow in achieving this goal.

BBS Cooperative Prairie Dog Eradication Statistics for Arizona and New Mexico, 1918-1933

Arizona and New Mexico Eradication Statistics

Creation of the powerful federal-state cooperative alliance resulted in regular funding for state-wide rodent control programs in Arizona and New Mexico. Both Arizona and New Mexico compiled statistics on the acreage poisoned each year.

Southeastern Arizona was not the only area of the state where prairie dog eradication was taking place. Table 4.3 provides state-wide statistics on rodent control operations in Arizona. The BBS statistical record is not complete for Arizona, with data only available for 13 out of 18 years prior to 1934. Based on the available statistics, an average of 335,815 acres of prairie dogs were poisoned each year in the state. Assuming that the number of acres treated during years with missing data was approximately equal to the 13-year average, a total of over 6,000,000 acres of prairie dogs had already been poisoned state-wide by the end of fiscal year 1933. This represents approximately 82% of the 1916 estimated prairie dog population in the state.

The Arizona eradication statistics would indicate that either the 1921 inventory was incorrect, or that the animals were becoming very scarce. However, there is no evidence in the narrative reports or subsequent statistical data that prairie dogs had become scarce in any locations other than in the range of the Arizona black-tailed prairie dog.

Table 4.3 BBS State-wide Prairie Dog and Rodent Treatments, Arizona, 1916-1933.

Fiscal Year	Acres Prairie Dogs Treated	Total Acres Treated (all rodents)	Prairie Dog acres to total (%)	Expenditures
1916	475,740	475,740	100	--
1917	214,880	214,880	100	--
1918	466,820	466,820	100	$59,574
1919	no statistical records			
1920	no statistical records			
1921	465,651	561,736	83	$66,894
1922	351,142	482,755	73	$62,260
1923	390,300	473,030	83	$63,447
1924	227,734	337,211	68	$49,995
1925	342,693	531,579	64	$80,533
1926	no statistical records			
1927	no statistical records			
1928	no statistical records			
1929	231,334	643,941	36	$113,438
1930	76,324	267,504	29	$104,995
1931	375,983	697,825	54	$56,160
1932	522,004	896,341	58	$40,989
1933	224,991	761,696	30	$37,418
Subtotals (data missing)	4,365,596	6,811,058		$1,126,053

Source: BBS Arizona Annual Reports and Records, 1916-1933

There is other evidence that the 1921 prairie dog inventory for Arizona was inaccurate. Between fiscal years 1918 and 1922, the last year in which prairie dogs were statistically separated from other species in Arizona, 949,008 acres of prairie dogs had received first treatments in Cochise, Graham and Greenlee counties. This is 138% of the original (1916) estimated acres for the Arizona black-tailed prairie dogs in the state! Arizona black-tailed prairie dogs had become scarce in the state, but they had not yet disappeared.

Another possibility exists for the discrepancy between the original prairie dog population estimates and the total acres exterminated. Youngblood (Appendix A) indicated that some prairie dogs would often survive poisoning, moving to new locations where they established colonies. New colonies would then be counted as first treatments, thereby increasing eradication statistics over time. Whether the discrepancy is the result of underestimates of populations in the 1921 inventory, or the creation of new colonies after incomplete poisoning, it is clear that prairie dog eradication was not the efficient science that the BBS claimed.

Eradication statistics for New Mexico are shown in Table 4.4. These records indicate that New Mexico budgets were lower than Arizona's, especially when compared to the original estimated prairie dog populations. New Mexico treated twice as many acres of rodents during this period, however. The state-wide figures show that the BBS rodent control program in New Mexico was devoted overwhelmingly to prairie dog eradication rather than other rodents. By 1933, New Mexico statistics indicate that around 67% of the original estimated population of prairie dogs had been treated. This is a much more realistic figure than that of Arizona, given the records in subsequent years and the fact that prairie dogs had not yet been extirpated from a single county.

Table 4.4 BBS State-wide Prairie Dog and Rodent Treatments, New Mexico, 1916-1933.

Fiscal Year	Acres Prairie Dogs Treated	Total Acres Treated (all rodents and lagomorphs)	Prairie Dogs to Total (%)	Expenditures
1914	85,000	85,000	100	--
1915	250,000	250,000	100	--
1916	291,330	291,330	100	--
1917	94,370	94,370	100	--
1918	652,000	652,000	100	$30,948
1919	1,231,297	1,231,297	100	$60,000
1920	1,252,058	1,252,058	100	$49,510
1921	873719	906,635	96	$51,805
1922	900,987	1,055,505	85	$46,539
1923	600,000	750,000	86	--
1924	437,704	532730	82	$36,185
1925	448,114	560143	80	$44,058
1926	370,508	439,047	84	--
1927	400,000	508,056	79	$45,425
1928	499,614	621,024	80	$55,842
1929	640,000	800,000	80	--
1930	778,988	847,856	92	$44,654
1931	595,456	689,503	86	$51,642
1932	408,025	445,283	92	$40,272
1933	236,824	300,277	79	$35,371
1914-1933 Subtotals	11,045,994	12,312,114	Average 90%	$1,021,000

(Source: BBS Annual Reports, New Mexico, 1916-1938; Hubbard & Schmitt, 1983)

The state-wide treatment records in Table 4.3 and Table 4.4 are also instructive in that they show that the initial focus of rodent control was clearly on the prairie dog. As poisoning caused prairie dog populations to decrease substantially, other rodents and lagomorphs (rabbits) became targets for eradication, as indicated by the lower percentage of prairie dog acres treated to that of other species. Some counties in Arizona had no prairie dog populations, making the ratio of prairie dog treatment to total seem low. Both states show a trend of decreasing prairie dog treatment beginning in the late 1920s, presumably because of decreasing prairie dog populations.

Opposition to Prairie Dog Poisoning

Merriam (1902) first alluded to the lack of support for rodent poisoning on the part of individual land owners. From 1902 through the 1920s, the BBS actively lobbied for the western states to pass legislation coercing uncooperative or absentee landowners to control prairie dog populations. Their argument was that exterminating prairie dogs in an area would never be successful unless all surrounding populations were removed as well. Merriam states,

> ...some land owners under-rate the task of extermination...One prominent cattleman wanted to limit poisoning to the "main dogtowns", leaving the more scattered infestations to care for itself! ... to enable the treatment of non-cooperative lands, there must be measures certain in their action, and backed by strong public support. Any failure in this is to allow a few individuals to defeat a state-wide economic operation. (BBS, New Mexico Rodent Control, Report on Operations, July 1, 1918 to June 30, 1919: 5)

Opposition to prairie dog poisoning was a problem in all western states, but seemed strongest in Oklahoma, parts of Arizona and New Mexico, particularly where Native Americans and Hispanic populations were high. One BBS agent poisoning rodents for the Seger Indian Agency in Oklahoma in 1917, stated that, "these people [Native Americans] consider them as food and would rather conserve them for sport and meat than to systematically eradicate them. The Indians depend on them to a large extent." (BBS, Oklahoma Annual Reports, 1917).

The New Mexico BBS complained repeatedly of the opposition problem. In 1918, when the New Mexico BBS was lobbying for the passage of the rodent law, it stated that twenty percent of the private land holdings in New Mexico were owned by "uncooperative" landowners who did not agree with poisoning rodents and would not allow agents on their lands (BBS, New Mexico Annual Reports, 1918). Other reports state that,

> there are a few obstacles to the perfect working of this [prairie dog extermination] plan. Non-resident land owners, some others who for various reasons wish to delay, and a few who are disinclined, constitute the main interference... (BBS, New Mexico Rodent Control, Report on Operations, June 30, 1919: 4)

I could not find any published statements articulating the viewpoint of this minority, however. These land owners were labeled "non-cooperative" by the federal agency and pressure was applied to the various legislatures of the western states to pass laws compelling uncooperative or absentee landowners to submit to mandatory extermination.

There is evidence that many Native Americans in New Mexico opposed rodent poisoning. Youngblood observed Navajo women sweeping the freshly applied poisoned grain from prairie dog colonies with brush "brooms" during the New Mexico campaigns of the 1930s (Appendix A). He said that Navajos enjoyed eating prairie dogs and did not wish to see their food supply eliminated. Indian reservations were often forced into eradication programs, regardless of tribal willingness, and Native Americans were compelled to supply the labor force for application of poisoned grain.

The Arizona BBS records do not directly mention an element of opposition. I found two instances of non-cooperation in the state, however. The BBS Arizona Annual Report of 1934 indicates that, "it was necessary for our Foremen on Indian reservations, especially the Navajo and Apache, to convince the Indians that no "Chindi" (devil) would appear as a result of their handling poison (BBS, Arizona Annual Reports, 1934:3). This was in the context of Indian Agents forcing Native Americans to apply poisoned grain against their will.

Boss, in Cochise County, described rodent control agents poisoning a colony of prairie dogs on his father's land without permission in 1933. He said that his father had purchased the land in 1920 from an Anglo rancher named Claunch who would not allow agents on the land to poison the prairie dogs. Boss's father, likewise, refused to agree to poisoning and the agents poisoned the colony surreptitiously. Unfortunately, he did not give a reason for this case of non-cooperation. From these two cases, I estimate that a minority sentiment against poisoning occurred in Arizona, similar to that demonstrated in New Mexico.

The New Mexico Rodent Law of 1919 forced non-cooperative lands of the state to be treated. It established the use of state and matching federal funds to conduct mandatory prairie dog poisoning, then provided that landowners be assessed taxes to reimburse the state for the costs. The tax assessment required cumbersome legal procedures of the County Commissioners. The county agricultural agent had the responsibility of providing widespread publicity in an area to be treated and securing the voluntary cooperation of land owners (BBS, New Mexico Annual Reports, 1919-1921). The county agent was also requested to make numerous public appearances and conduct a public relations campaign regarding the benefits of eradication. He also had the responsibility of obtaining signatures from land owners verifying their cooperation (BBS, Annual Reports, New Mexico, 1921:12).

By 1921, The county agent's function of providing publicity and obtaining cooperation from landowners in New Mexico was taking so much time from their normal duties, that the job fell to the Farm Bureau. The New Mexico BBS complained to Washington that lack of cooperation among land owners was severely hampering the efficiency of the rodent control programs and resulting in thousands of dollars being tied up in legal disputes between the state and unwilling landowners (BBS, Annual Reports, New Mexico, 1921:12).

The New Mexico BBS was not willing to back down from the requirements for mandatory treatment, however, because they were convinced that complete and permanent eradication of the animals depended on it. BBS reports state that, "permanency of eradication can best be achieved by systematic and progressive field party operations, treating federal, state, privately owned and non-cooperative lands in a unit simultaneously or progressively" (BBS, Annual Reports, New Mexico, 1921:12).

Intense opposition in various locations created pressure for strictly mandatory rodent control projects in 1923-25. BBS records state that, "the operations in progress are a continuation of the compulsory prairie dog control campaign started in 1923" (BBS, Annual Reports, New Mexico, June, 1924). Mandatory poisoning had to be enforced by means of the county sheriff in many areas of New Mexico, and non-cooperative land owners were forced to pay for "services" immediately, rather than through normal tax assessment procedures. Landowners may have suspected a government extortion plot, for the BBS records indicate that the BBS began allowing uncooperative landowners to provide their own men to assist with the work in order the hopes of easing their suspicions of the federal agents (BBS, Annual Reports, New Mexico, 1925:5).

However, the 1925 New Mexico Annual Report indicates that considerable resistance was still being met throughout the state six years after the passage of the Rodent Law. It states that, "the local people are not financially able, in many instances, to purchase the necessary poisoned grain. In the northern portion of the state, particularly in the Spanish-American counties, cooperation is not good. The people do not seem to grasp the idea that we are only giving them the opportunity to help themselves in the protection of crops at a minimum cost" (BBS, Annual Reports, New Mexico, 1925:5). Opposition to rodent poisoning appears to have continued during the large federal programs of the 1930s, from some of the examples already mentioned.

In Arizona and New Mexico, cooperating and non-cooperating land owners were assessed fees according to the valuation of their lands and the number of acres treated. All areas could not be treated simultaneously, therefore a certain amount of political decision-making took place in order to apportion the "benefits" of rodent eradication and the pain of collecting an unpopular tax collection.

Because the Arizona black-tailed prairie dog had been singled out for complete extermination in Arizona, all three counties that contained black-tailed prairie dogs experienced regular poisoning programs, as shown in Table 4.5. Greenlee County received less attention due to lower numbers of the offending rodents. As mentioned earlier, the BBS in Arizona ceased reporting species of rodents by county after 1922. I found no evidence of widespread objection to either the rodent poisoning or the assessment of fees for the work from this period in Arizona.

Table 4.5. Acres of Arizona Black-tailed Prairie Dogs Poisoned in Arizona, 1918-1922.

Fiscal Year	Cochise	Graham	Greenlee
1918	64,000	12,800	0
1919	66,161	31,660	0
1920	133,215	46,000	1,040
1921	245,333	113,942	1,000
1922	189,097	36,023	8,737
	697,806	240,425	10,777

(Source: BBS, Arizona Annual Reports, 1918-1922)

In contrast, some counties in southern New Mexico with large populations of prairie dogs went almost untouched by government eradication programs until the New Deal, beginning in 1937 (Table 4.6). The disparity in treatment occurs between Doña Ana County and other New Mexico counties in the study area, such as Hidalgo and Grant counties.

Doña Ana County, New Mexico, is an example of a county with above-average participation in the programs of the BBS. It was the only New Mexico county in the study area to be assigned regular rodent control programs before the

New Deal. Beginning with the campaign on the Jornada Range Reserve in 1916-18, Doña Ana County was the site of intense campaigns against prairie dogs and other rodent species. The concentration of activity was probably due to the County's close political connection with the BBS and its position as the BBS headquarters for New Mexico.

Initial estimates of Arizona black-tailed prairie dogs in the Doña Ana County indicated that as many as 85,000 acres were covered by the animals (BBS, Annual Reports, New Mexico, 1921). A total of 115,403 acres of prairie dogs were poisoned by 1924 (Table 4.3). This discrepancy is probably the result of poor initial estimates of populations in remote parts of the county.

By 1924, the New Mexico BBS turned its attention to pocket gophers and kangaroo rats in Doña Ana County as prairie dogs became scarce in the county. Over a million acres of rodents were poisoned by 1938, undoubtedly eliminating any surviving prairie dog colonies, resulting in their probable extirpation in the county by the mid 1930s, except for a few isolated locations on WSMR (BBS Annual Reports, New Mexico, 1934). The inequality in treatment is unrelated to the original estimated area of infestation, and may be an artifact of both Doña Ana County's political connection to the BBS infrastructure and lack of cooperation in other counties. Hubbard and Schmitt (1983) pointed out that Doña Ana County continued to have more acres poisoned ever year than any other county in the state through 1981.

Table 4.6. Acres of Arizona Black-tailed Prairie Dogs Poisoned in New Mexico, 1918-1938.

Fiscal Year	Doña Ana	Grant	Hidalgo	Luna	Sierra	Otero	Lincoln
1918	9,950	0	0	0	0	0	0
1919	89,800	0	0	0	0	0	7,890
1920	140	0	0	0	0	0	24,410
1921	5,563	4,040	0	0	20	2,160	2,140
1922	0	3	0	0	10,002	26,995	8,836
1923	0	0	0	0	0	0	0
1924	125,526	0	0	165	0	0	5,730
1925	41,350	0	0	240	0	187	5,194
1927	112,276	0	0	0	0	2,011	6,331
1928	122,272	20	0	680	0	1,928	3,685
1929	0	0	0	0	0	0	0
1930	62,369	2,850	510	250	4,250	5,664	1,680
1931	52,397	80	32	10,432	4	9,409	26,858
1932	44,350	648	560	10	0	1,750	12,372
1933	43,500	128	180	508	1,996	425	1,120
1934	40,886	292	240	1,048	0	5,544	1,692
1935	91,820	0	0	0	0	3,080	1,220
	842,199	8,061	1,522	13,333	16,272	59,153	109,158
1937	*272,925	115,270	366,550	233,720	94,568	*354,587	*233,640
1938	*147,448	88,814	165,750	236,772	71,200	*197,828	*66,601
Original Acres	184,890	454,040	460,000	unknown	90,000	752,160	255,395
Total acres poisoned	*1,262,572	212,145	533,822	483,825	182,040	*611,568	*409,129

(* data includes prairie dogs and other rodents)

(Source: BBS, New Mexico Annual Reports, 1918-1938)

Grant and Hidalgo Counties, by contrast, were mostly untouched by the cooperative rodent control programs until 1937 under the New Deal, even though they were known to contain large tracts of prairie dogs. Less than 10,000 of acres of prairie dogs were treated in both counties between 1918 and 1935. Among all New Mexico counties, Grant, Luna, Sierra and Hidalgo received less poison than any others prior to 1937, making southwestern New Mexico the least treated area during these years (BBS, New Mexico Annual Reports, 1918-1937)!

Early BBS records indicate that these counties had very large colonies of the animals. In 1908, Bailey had observed extensive prairie dog towns in what was then Grant County. In 1921, the BBS estimated the combined acreage covered by prairie dogs in 1921 to be 910,000 acres, or 22% of the total area (BBS, New Mexico Annual Reports, 1921). Yet in 1924, the BBS claimed there was only a single colony of Arizona black-tailed prairie dogs in all of Hidalgo County, on the Robinson Range near the Animas Mountains (BBS Annual Reports, New Mexico, 1924:10). And their report further states that "So far as we can ascertain, there are no rodent problems...except kangaroo rats" in Grant County (BBS, New Mexico Annual Reports, 1924:10).

Detailed poisoning records kept by the Civilian Conservation Corps for Grant and Hidalgo counties during their prairie dogs campaigns in 1937-38 show that the original estimates of prairie dog populations in these counties were correct. Over 736,000 acres of Arizona black-tailed prairie dogs were poisoned there in two years, indicating that between 1922 and 1937 the New Mexico BBS was either completely unaware of the true extent of prairie dog populations in the southwestern parts of the state or were intentionally misleading the state and federal administrators (BBS, Arizona Annual Reports, 1937, 1938).

Of course, poisoned grain was offered at cost to local ranchers in these counties and prairie dog colonies may have been poisoned privately. The difference between the BBS 1921 estimate of prairie dog acres for the counties of southwestern New Mexico and the actual acres poisoned under the New Deal probably reflects the use of private poisoning initiatives.

BBS failure to report the extent of prairie dog populations in the area indicates a widespread conspiracy of non-cooperation in southwestern New Mexico. Most of the land within the range of the Arizona black-tailed prairie dog was private land during the 1920s. With very little public land to access and administer, county agents and BBS agents had to rely exclusively on the communication of ranchers about the conditions on their ranges.

The historic record points to a conspiracy of silence in southwestern New Mexico in order to avoid mandatory government prairie dog poisoning and onerous tax assessments on private land. Unless invited to enter private property to conduct prairie dog inventories, the BBS had no means of verification and were forced to assume that no prairie dogs were present. While ranchers in other areas of New Mexico were being subjected to mandatory poisoning and tax collection, their counterparts in Grant, Hidalgo and Luna counties were possibly able to oppose the programs by refusing to admit that there were any prairie dogs present!

PRAIRIE DOG ERADICATION DURING THE NEW DEAL (1933-1942)

The economy of the nation deteriorated in the late 1920s. Particularly hard hit were the agricultural and natural resource-based economies of Arizona and New Mexico (Waggoner, 1961; Williams, 1986: 153). Rangelands in the Southwest were in deplorable condition from years of overgrazing. A series of small droughts and final implementation of the Taylor Grazing Act of 1929 (Waggoner, 1961b) also placed considerable economic pressure on ranchers. All ranches were required to fence in their ranges and provide their cattle herds with permanent water supplies rather than allowing them to range freely. By 1932, thousands of small and large cattle ranches were bankrupt, out-migration occurred and those remaining in the study area were poor and desperate .

The New Deal in the Southwest sought out existing programs into which money could be poured to stimulate local economies and provide public work as a form of relief for destitute families. The rodent and predator control programs of the BBS were already in place with a cooperative infrastructure and purpose that seemed suited to the times. From the publicity that the BBS had been providing Washington for years, the programs were producing tangible results and enjoyed considerable political popularity with the state governments. Furthermore, any number of additional species could be added to the list of "noxious rodents" in order to expand this federal program. Together with other forms of range improvement, rodent control became the focus of the largest public expenditures in the region since the Territorial Indian Wars.

Under the New Deal programs, the BBS and later the Predator and Rodent Control (PARC) provided organization, team leaders, poisoned grain and other supplies to large crews enlisted and paid for by the CCC and Emergency Conservation Workers (ECW) Act . Crews were stationed in camps across the Southwest. Statistical records for New Deal Rodent eradication are shown in Table 4.7.

Table 4.7 Federal Rodent Poisoning in New Mexico During the New Deal, 1934-42

Fiscal Year	Acres Prairie Dogs Treated	Total Acres Treated for Rodents and Lagomorphs	Ratio of Prairie Dogs to Total
1934	297,522	483,062	62
1935	940,867	1,126,787	83
1936	1,210,000	3,500,000	35
1937	1,216,795	2,981,614	41
1938	764,666	2,018,448	38
1939	15,000	95,000	16
1940	250,000	700,000	36
1941	470,000	1,990,000	24
1942	270,000	1,100,000	25
New Deal subtotal	5,434,950	13,994,911	
1914-1942 Subtotals	16,480,944 (>100% of estimated original prairie dog acres)	26,307,025 (33% of New Mexico land area)	

(Source: BBS, Arizona and New Mexico Annual Reports, 1934-1942; Hubbard and Schmitt, 1983)

The first rodent control programs of the New Deal were implemented in 1934 in the National Forests and Indian Reservations of New Mexico and Arizona, as described in this BBS account:

> Although regular funds of the district were drastically curtailed during the period covered by this report, emergency funds were available in sufficient amounts to enable us to far exceed all previous records of rodent control operations in Arizona....Considerable apprehension was felt in starting work with crews detailed from CCC camps on both National Forests and Indian Reservations. (BBS, Arizona Annual Report, 1934:3)

In 1937, the New Deal programs became much larger in scope, providing large teams to treat both public and private lands. Grant and Hidalgo counties, long ignored by the Las Cruces offices of the BBS, were assigned to the Arizona operations. Hubbard and Schmitt (1983) indicate that the year of maximum rodent poisoning occurred in Grant County in 1942, in Hidalgo County in 1937, and in Lincoln, Luna and Otero County in 1936.

In Doña Ana County, significant prairie dog poisoning campaigns had already occurred and the New Deal programs allowed any last scattered prairie dogs to be eliminated. One colony of over 500 acres was poisoned near Stewart Well on the JER in 1934, along with other colonies on the surrounding ranches on the Jornada Plain (BBS, New Mexico Annual reports, 1934).

In Arizona, extensive poisoning campaigns were conducted in Cochise and Graham Counties, primarily for kangaroo rats. No specific records were found for the number of acres of black-tailed prairie dogs poisoned during the New Deal, but interviews and other historic records show that small isolated colonies were discovered and poisoned during this period. State-wide statistics show that over 2 million acres of prairie dogs were poisoned in Arizona between 1934 and 1938 (BBS, Annual Reports, Arizona, 1934-1938). Records were not available by county during this period, however.

In addition to the extensive acres of prairie dog colonies poisoned during the New Deal, hundreds of thousands of acres were treated for kangaroo rats and rabbits. The extensive poisoning programs continued through 1943 in many parts of the study area.

In 1938, rodent control was transferred from the Department of Agriculture to the Department of Interior, where it was reorganized into a new Division, the PARC. The BBS had managed rodent control for a total of 25 years, and in many ways the transfer to a new federal department seems to have had little effect on the conduct of the programs under PARC.

A change is apparent, however, in the statistics on prairie dog eradication versus the eradication of other rodents and lagomorphs from 1939 forward. Tremendous importance was given to prairie dog eradication by the BBS, as seen in the high ratio of prairie dog treatments to other rodents in Tables 4.4, 4.5 and 4.6 before 1939. In 1939, the year of transition to the PARC, very little field work was accomplished. In New Mexico from that time forward, the ratio of prairie dog treatment to total treatment acres dropped from an average of 82% before 1939, to an average of about 28% for the 25 years that PARC controlled the program after 1939. The closing years of the New Deal programs, from 1939 through 1942, show the most dramatic drop in prairie dog treatments under PARC management. Youngblood, in describing the CCC campaigns in New Mexico, stated that so many millions of animals were killed during 1938 and 1939, that the men had to leave the carcasses to rot. He said that whole counties smelled like something dead during those years (Appendix A).

Summary statistics for New Mexico, shown in Table 4.7 indicate that by 1942, over 16.48 million acres had been treated for prairie dogs, closely matching the original estimated acreage for these animals. Treatments for all rodents and lagomorphs amounted to over 26 million acres of the state of New Mexico, or 33% of its land area. These statistics provide strong evidence that all of the original prairie dog colonies had been poisoned at least once. Any remaining colonies after 1942 were likely to be very small, isolated, and highly wary of people and poisoned grain.

Prairie Dog Eradication and Erosion

The New Deal programs included the cooperation of the SCS as part of the ECW Act. Records from the SCS and BBS allude to, but don't directly implicate, prairie dog eradication to serious erosion problems being encountered in mountain valleys after prairie dogs were poisoned. For example, in 1934 the following statement is given when describing the treatment of extensive prairie dog colonies on the National Forests of New Mexico:

> In prairie dog control… a large percentage of the acreage treated was in the high mountain valleys of the State in which trout streams are located, and on which erosion control, in many instances was a part of the ECW program…Unless rodent control is inaugurated in conjunction with proper range management, erosion will eventually place so much soil in solution in the various fishing streams that trout will be killed, and a valuable National Forest asset ruined. (BBS, Annual Reports, New Mexico, 1934: 8)

An internal report of the Safford District of the SCS in Arizona regarding the history of erosion in the upper Gila River in Arizona and New Mexico chronicles some important erosion features in the region in a manner that suggests a relationship between prairie dog eradication and subsequent erosion (Ross, 1935:7-27). One description of a major erosion feature forming during the 1930s is on the San Pedro River at Benson, Arizona. The author describes the unusual erosion features visible in 1935:

> Natural bridges of treacherous earth span the arroyos here and there; while, completely hidden several feet below the surface, run subterranean channels which ultimately become, as the roof falls in, open trenches. In fact, there are aspects of the destruction which resemble the action of chemically -charged waters upon limestone in a cavern. Most baffling of all are the roughly circular, well shaped holes. (Ross, 1935:7-27)

The author ascribes the erosion completely to overgrazing by livestock, but the information from this research may explain the subterranean channels and strange holes on the surface near the arroyo walls. Records from Chapter 3 indicate that the San Pedro Valley around Benson was originally a large prairie dog colony, as described by Mearns and others. This area was poisoned during the Cochise County campaign of 1918-1922.

In fact, during the 1930s, gullying was reported from several areas listed in Chapter 3 as sites of major prairie dog colony complexes. A severe gully nearly one mile wide and 20-feet deep formed in the early 1930s through old prairie dog towns on the Chiricahua Cattle Company lands, creating San Simon Wash where a broad basin formerly existed (Ross, 1935; BBS, Arizona Annual Reports, 1920). Duck Creek, described by Bailey in 1908 as a flat valley densely covered with prairie dogs, had become the site of a deep gully (Ross, 1935; Bailey, 1908). The southern San Pedro Valley around Hereford, where 15,000 acres of prairie dogs were poisoned in 1918, became the site of a gully 10-12-feet deep in the late 1930s (SCS, 1938). A former grassy meadow extending from 1.5 miles west of Douglas, Arizona northward to McNeal had become an entrenched gully 18 miles long during the 1920s. This was the location of early homesteads and farms between 1910 and 1920, and a large prairie dog colony that was poisoned there in 1918 (SCS, 1938:4; BBS, Arizona Annual Report, 1919-1921).

The SCS agents in the study area attribute each of these major gullys to various human impacts of the period, such as overgrazing, deforestation, inappropriate plowing practices, and mining or other ground disturbances (SCS, 1938; Ross, 1935). I was unable to find any direct mention of prairie dog eradication as a factor in these erosion events in the archival files of SCS, Region 8, and no specific policy statement was found regarding the need for erosion control in conjunction with prairie dog eradication. Even so, implementation of erosion control on poisoned prairie dog towns was practiced during the New Deal programs in the study area. Long-time resident of Cochise County, Alden Hays, described the various erosion control measures put into place by the SCS in the San Simon Valley and Antelope Pass area of Hidalgo County after poisoning prairie dogs there in 1942-43 (Appendix A).

ERADICATION OF PRAIRIE DOGS SINCE 1943

PARC Poisoning Programs, 1943-1951

From 1939 through 1974, federal rodent control programs were administered by the USF&WS and PARC. After World War II, rodent control budgets were reduced, but elimination of prairie dog pests remained one of the highest priorities of the agency. Table 4.8 provides rodent control statistics from The ratio of prairie dogs treated in New Mexico to total rodent treatments remained approximately 50% during this period (PARC, New Mexico Annual Reports, 1943-1951). The statistics emphasize the fact that prairie dogs were considered the single most important rodent pest in the state, despite greatly diminished prairie dog populations in all parts of New Mexico following the treatment of over five million acres during the New Deal. PARC was committed to ridding the state of every last colony.

Prairie dog treatment became far more lethal in the post-war era. In 1945, PARC announced field tests using a new organic compound, sodium fluoracetate, as a rodenticide (PARC, Annual Report, 1945:185). This compound, known as 1080 and was widely used to lace grain bait for prairie dog control. The compound was highly toxic to prairie dogs and many other vertebrates. It was reported to result in 100% kills when colonies were properly pre-baited with untainted grain.

Table 4.8 Rodent Control Statistics, New Mexico, 1943-1974.

Fiscal Year	Acres Prairie Dogs Treated	Total Acres Treated	Prairie Dogs to Total (%)
1943	250,000	450,000	56
1944	220,000	500,000	44
1945	108,099	352,270	31
1946	120,000	373,909	35
1947	200,000	340,000	59
1948	180,000	263,552	68
1949	120,000	381,184	31
1950	195,000	337,274	58
1951	100,000	309,074	32
1952	31,000	545,190	7
1953	20,000	747,417	3
1954	70,000	504,262	14
1955	40,000	523,143	8
1956	50,000	500,000	10
1957	60,000	360,000	17
1958	65,000	160,000	41
1959	30,553	662,803	5
1960	36,045	428,133	8
1961	45,000	443,648	10
1962	36,128	379,827	10
1963	65,000	540,000	12
1964	71,854	136,637	52
1965	30,000	150,000	20
1966	65,000	75,000	87
1967	65,000	100,000	65
1968	18,000	200,000	9
1969	22,000	210,000	10
1970	25,000	180,000	14
1971	25,000	40,000	63
1972	6,732	25,000	80
1973	20,000	20,000	100
1974	22,000	60,000	37
1914-1974 Prairie Dog Treatments in New Mexico			**16,792,944**
1914-1974 Total Treatments for All Species			**27,367,025**

(Sources: USFWS, Annual Reports, 1943-74; Hubbard & Schmitt, 1983).

During the nine-year period from 1943 through 1951, PARC reports indicate that federal programs poisoned an average of 165,000 acres of prairie dogs in New Mexico per year, resulting in the elimination of an additional 1.49 acres of prairie dogs. Unfortunately, the records of PARC housed in the National Archives do not include county statistics, and the state records have been lost or destroyed. By 1951, nearly 18 million prairie dog acres had been eradicated in New Mexico, about 110% of the original estimated population in the state.

Prairie Dogs as Victims of Sylvatic Plague

Fear of sylvatic plague spreading to humans from infected prairie dogs was partly responsible for continued antipathy towards prairie dogs in the Southwest during the Post-War Era. Sylvatic plague, or wild bubonic plague, is a disease of the Old World that spread to the Western Hemisphere on infected rats. The disease infected wildlife populations in California as early as 1908 and spread east.

The disease is caused by the bacterium, *Yersinia pestis*, the same organism that caused the Black Death in Europe and Asia in the 14th century. Fleas, particularly rodent fleas, act as the vector for the bacterium and plague-infected fleas carry the bacteria from one animal to the next. (Poland and Barnes, 1979). The disease still results in human fatalities and, although it can be treated with antibiotics today, this was not the case prior to World War II.

The occurrence of plague in wild populations of ground squirrels and other native rodents spread gradually east from California (Barnes, 1993). In New Mexico, scientists first noted the disease organism in rodent populations in 1938 in both Dona Ana and Catron counties (Hubbard and Schmitt, 1983). Plague commonly kills entire colonies of black-tailed prairie dogs and makes the site uninhabitable to the rodents for many years (Barnes, 1993).

News that rodents such as ground squirrels and prairie dogs could be carriers of the plague organism evoked great concern in public health officials and among rural citizens and motivated PARC to continue prairie dog eradication programs even after their populations had been severely reduced in New Mexico. In 1938, PARC issued warnings and procedures for the safe handling dead prairie dogs after campaigns (Appendix A). The first human case of plague in New Mexico occurred in 1949 and the disease continues to infect humans and wildlife populations in the state occasionally.

The spread of sylvatic plague into the study area was a double-edged sword for the remaining prairie dog populations. Poisoning of prairie dog colonies continued at a high level because of the perceived threat to public health. In addition, prairie dog populations have been reduced by the disease itself, although the impact of the disease has not been quantified for any prairie dog populations (Barnes, 1993). Given the combined effect of poisoning and occasional plague outbreaks within their rapidly dwindling colonies, black-tailed prairie dogs can well be viewed as victims of the plague, rather than villains.

PARC Prairie Dog Poisoning, 1952-1960

Data presented in Chapter 3 suggest that, by 1952, Arizona black-tailed prairie dogs still occurred in at least one location in southeast Cochise County, several locations in Hidalgo County and southern Grant County, and at several sites within WSMR and adjacent lands in Doña Ana, Sierra, Lincoln and Otero counties. These colonies were small, between 5 and 500 acres each, and isolated from one another. The sub-species was already extirpated from Graham, Greenlee, and Luna counties. There is no official estimate of the size of the remaining populations of any taxonomic groups of prairie dogs, however.

In 1952, PARC sharply decreased the amount of prairie dog poisoning in New Mexico, dropping from an average of 165,000 acres per year for 1943-1951, to an average of 40,000 acres per year between 1952 and 1974. At the same time, PARC increased its efforts in poisoning kangaroo rats, pocket gophers, field mice and other rodents (PARC, New Mexico Annual Reports, 1952-1974). Budgets were unaffected and PARC records do not give an explanation for the sudden decrease in attention to prairie dogs.

The decrease in prairie dog eradication after 1951 may have been the result of increasing opposition to PARC poisoning activities, particularly the severe impacts of poisoning on wolves, foxes and prairie dog populations. Thomas Dunlap provides historical perspective on the rising tide of public and scientific opposition to the wholesale eradication of native American wildlife, including prairie dogs (Dunlap, 1988: 54-112). The BBS had fought down a frontal attack on its eradication programs by the American Society of Mammalogists in the 1920s and 1930s. At that time, the public took little interest in the debates, and the BBS was able to successfully defend its programs before Congress (Dunlap, 1988: 56-61).

By 1950, two other sources of opposition had joined the scientific community in decrying the indiscriminate killing of wildlife by PARC. The 1940s conservation movement had spawned the International Union for the Conservation of Nature (IUCN), The Sierra Club, Audubon Society, Wilderness Society and the Conservation Foundation, all of them critical of the ecological toll of poisoning. The Society for the Prevention of Cruelty to Animals and the American Humane Association objected to the animal suffering inflicted by PARC programs (Dunlap, 1988). Increasing concern was voiced by conservation organizations, particularly the American Society of Mammalogists and the IUCN, that Arizona black-tailed prairie dogs were being threatened with extinction.

Dunlap (1988: 119) dismisses these groups as ineffective in changing the policies and practices of the agency during the 1950s. I view the drastic reduction in prairie dog poisoning in New Mexico in 1952, however, as an act of caution on the part of an agency coming to realize that they were near the population limits of prairie dogs and that the public would not accept the extirpation of prairie dogs from New Mexico.

Alton Ford worked for PARC as a trapper during this period. He indicated that, in the early 1950s, little attention was paid to the few prairie dogs left in southern New Mexico because the colonies were so small (Appendix A). In the late 1950s, PARC agents began to take an interest in prairie dogs in the study area again, questioning Ford, local ranchers and SCS agents to determine the locations of any remaining prairie dog colonies in each county (Appendix A). In 1959 and 1960, Ford indicated that federal rodent control projects began again in Grant and Hidalgo, poisoning all the remaining colonies in these two counties, or so they believed at the time. Information from Turner indicates that similar poisoning occurred on private ranches in Sierra County in 1960, as well (Appendix A).

1961 and 1971 PARC Prairie Dog Inventories

In 1960, Biologist Lendell Cockrum reported on the extirpation of the Arizona black-tailed prairie dog from Arizona and reduced populations of black-tailed prairie dogs throughout their range (Cockrum, 1960). Concern over the uncontrolled poisoning of prairie dogs also came from within PARC. An internal memo from PARC District Agent for Arizona, Everett M. Mercer to the PARC Regional Director in Albuquerque, New Mexico, suggests a few individuals within PARC held deep concerns for the survival of prairie dogs at this time. Mercer states:

> During the past five years prairie dog colonies have disappeared far more rapidly than new colonies have been established…I have been trying to get people to understand that the public will not tolerate extermination of a specie of animal like prairie dog…The Game Department will not go along with me on setting aside some of the colonies and protecting them. My efforts presently are directed toward seeing that extermination of prairie dogs in this state will not finally be held by the public to have been brought about by the Bureau of Sport Fisheries and Wildlife (Mercer, September 19, 1961).

In 1961, Howard A. Merrill, Acting Chief of PARC, ordered a survey of prairie dog populations in the U. S., by state and county (PARC New Mexico Annual Reports, 1961). His letter to state program leaders states, "Because of the increasing number of articles and news items implying that prairie dogs are becoming extinct, it is desirable that we make an inventory of the approximate acreages presently populated with these animals"(Merrill, 1961).

State offices were given until October, 1961 to submit their inventories. The results of the inventory have not previously been assessed for consistency and reliability. Data from New Mexico and Arizona appear fairly complete, however, and the resulting 1961 estimates of prairie dog populations for individual counties in New Mexico and Arizona are given in Table 4.9 and 4.10. These tables also contain the results of the BBS 1921 survey for comparison.

Table 4.9. Arizona Prairie Dog Inventories, 1921 and 1961.

County	1921 (all prairie dogs)	1961 (all prairie dogs)
Apache	2,175,280	7,109
Cochise	128,000	0
Coconino	1,895,400	246,061
Gila	0	0
Graham	192,000	0
Greenlee	12,800	0
Maricopa	0	0
Mohave	0	20
Navajo	773,700	191,668
Pima	0	0
Pinal	0	0
Santa Cruz	0	0
Yavapai	772,300	532
Yuma	0	0
National Forests		
Apache NF	136,320	
Sitgreaves NF	224,000	
Coconino NF	132,000	
Tusayan NF	245,800	
Prescott NF	243,200	
Arizona Totals	**6,928,800**	**445,390**

(Source: BBS Arizona Annual Reports, ,1921; PARC Arizona Annual Reports, 1961)

Table 4.10. New Mexico Prairie Dog Inventories, 1921 and 1961

NEW MEXICO	1921 (all prairie dogs)	1961 (all prairie dogs)	1961 *C. l. arizonensis*
Bernalillo	125,000	4,200	
Catron		1,500	
Chaves	650,000	800	800
Colfax	630,000	600	
Curry	3,000	930	
De Baca	130,000	350	
Dona Ana	85,000	0	
Eddy	120,000	750	
Grant	450,000	10	10
Guadalupe	600,000	490	
Harding	187,500	1,360	
Hidalgo	460,000	0	
Lea	160,000	950	
Lincoln	250,000	550	550
Luna	no estimate		
McKinley	750,000	9,055	
Mora	160,000	240	
Otero	750,000	2,730	2730
Quay	500,000	480	
Rio Arriba	850,000	7,000	
Roosevelt	250,000	1,400	
Sandoval	260,000	3,700	
San Juan	480,000	302,930	
San Miguel	250,000	2,160	
Santa Fe	160,000	2,000	
Sierra	90,000	340	340
Socorro	4,800,000	400	400
Taos	350,000	2,520	
Torrence	270,000	2,000	
Union	187,500	2,790	
Valencia	900,000	7,500	
New Mexico Totals	**14,858,000**	**359,735**	**4,830**

(Source: BBS New Mexico Annual Reports, 1921; PARC New Mexico Annual Reports, 1961)

The 1921 prairie dog inventory for Arizona indicates that the state contained 332,800 acres of Arizona black-tailed prairie dogs in three counties. In 1961, this prairie dog was reported to be extirpated. In 1921, Arizona reported a total of 6,929,800 acres of prairie dogs in 1921. Only 445,390 acres remained in 1961, representing a loss of 94%.

The 1921 New Mexico inventory showed 14,858,000 acres of prairie dogs of all species, excluding Luna County, for which no estimates were available. The 1961 inventory shows that overall prairie dog populations have been reduced to 359,735 acres in the state. This represents a loss of nearly 98%. I previously estimated the 1921 population of Arizona black-tailed prairie dogs to be 5,280,041, based on assumptions about their county distribution. In 1961, only 4,830 acres of the subspecies remained, representing a decline of 99.9%.

There were strong reasons for the federal agencies to overestimate the occurrence of prairie dogs in both the 1921 and 1961 inventories. Both inventories were compelled by the need to justify expanded budgets before both the state legislatures and the federal appropriations committees, and, in 1961 to show that prairie dog populations were not imperiled.

The 1961 survey data from New Mexico confirms that a 4,830 acres of Arizona black-tailed prairie dog colonies persisted in Grant, Sierra, Otero, Lincoln, Socorro and Chaves Counties at that time, but shows the sub-species extirpated from Doña Ana, Luna, and Hidalgo counties. The survey is mistaken for Hidalgo County, however, since a small colony was located there up until the 1970s (Table

3.6). In other respects, the 1961 inventory agrees with the historical data from other sources for Arizona black-tailed prairie dogs in the study area.

The inventory also demonstrates the severe decline of all prairie dog populations in Arizona and New Mexico, understandable after forty years of systematic poisoning. Overall prairie dog populations declined by approximately 94% in Arizona and 97.6 % in New Mexico, leaving all taxonomic groups perilously small. Arizona black-tailed prairie dog populations had declined by 100% in Arizona and 99.9% in New Mexico, leaving this sub-species on the brink of extirpation.

The 1961 inventory reported an additional 4,460 acres of Arizona black-tailed prairie dogs in Texas, located in Hudspeth, Culberson, Reeves, Jeff Davis, Brewster and Pecos Counties (PARC, Administrative Reports, 1961). This brought the U. S. total for the sub-species to 9,290 acres, centered in Eastern New Mexico and the West Texas.

The prairie dogs that remained in New Mexico in 1961 were overwhelmingly Gunnison's prairie dogs, based on county distribution. But the most striking fact about the surviving populations was that they occurred on Navajo and other tribal lands in the state. San Juan County, with 84% of the state's prairie dogs in 1961, is 59.8% Native American-owned. McKinley County, with the second highest prairie dog population in the state, is 61.8% reservation land (McAllister, 1981:116). Not only were these counties poor, but information provided earlier indicates that the Native Americans, especially Navajos and Apaches, may have resisted federal poisoning programs.

PARC never published the 1961 survey. The agency concluded that prairie dogs were still abundant in all states where they had original distributions and that poisoning programs had not resulted in the loss of any species. In 1962, Clifford Presnall replaced Merrill as Chief of the Branch of PARC. He moved quickly to squelch the 1961 Inventory. He provides his own interpretation of the results in a letter to USF&WS superiors:

> I am inclined to believe that there has been little change in the distribution of prairie dogs for many years. You will note that the distribution as given on the enclosure [tabular report of the 1961 Inventory] includes all of the States where they were originally found. In going over the reports from the several States used in compiling this tabulation, we found a number of instances where there had been slight actual extensions of prairie dog range...the numbers of prairie dogs within the existing range has undoubtedly decreased due primarily to conversion of grazing lands to croplands with attendant control of the animals...(USF&WS Records, Dec. 31, 1962)

The results of the survey had no impact on the poisoning programs in the following years in New Mexico, as shown in the poisoning statistics for 1962-74 (Table 4.8). The programs continued to treat an average of 40,000 acres per year. With only 359,735 acres of the animals left, this treatment rate could be expected to extirpate prairie dogs from the state in less than 10 years. In Arizona, where Mercer had been urging PARC to protect some colonies of prairie dogs, PARC increased prairie dog poisoning dramatically, from a little over 6,000 acres in 1960 to over 58,000 in 1962. Mercer's voice of moderation had been overruled by the agency now under Presnall's leadership.

PARC was determined to continue its programs wildlife of eradication during the 1960s, despite criticisms from the American Society of Mammalogy and the newly founded conservation organizations. In 1966, PARC collaborated with the U.S. Forest Service to obtain approval to eradicate all black-tailed prairie dogs on the recently established National Grasslands. An internal memo states, "There are approximately 17 National Grasslands which are administered by the Forest Service. These people have determined that prairie dog control will be necessary to protect the flora on these areas (Bureau of Sport Fisheries & Wildlife, internal memo dated August 15, 1966).

From Pest to Threatened Species

The 1961 prairie dog provided with PARC with the information it needed to either protect the perilously small populations of black-tailed prairie dogs or the kind of detailed information needed to eliminate the animals from the state. The PARC program, based as it was on a mandate of complete extermination of the prairie dog pest, determined to proceed with its systematic poisoning.

In 1967, the IUCN listed both subspecies of *Cynomys ludovicianus* in their conservation *Red Book* as "Rare" (IUCN, 1967). The publication showed that the numbers, colonies, and distribution of all black-tailed prairie dogs was greatly reduced. This listing temporarily halted prairie dog eradication on federal lands, to the consternation of PARC officials.

A memo dated June, 1967 from the Assistant Regional Director of Cooperative Services (PARC) in Albuquerque to the Director of the Bureau of Sport Fisheries & Wildlife, shows that PARC was determined to undermine this first step to protect black-tailed prairie dogs. The memo makes the following request:

> In view of the recorded extent of Black-tailed Prairie Dog occupancy of range areas in this Region, consideration should be given to a reclassification review. The extent of known populations may substantiate removal from Red Book [IUCN] listings, since continued designation as a rare species in this publication will create control problems throughout our various states (Lewis R. Garlick, June, 19, 1967)

In 1971, the New Mexico PARC conducted another prairie dog inventory. This new inventory, like its predecessors, was probably biased towards overestimating prairie dog populations in order to justify continued program funding. The New Mexico inventory reported that approximately 840 colonies occurred in the state, covering 248,000 acres (PARC, New Mexico Annual Report, 1971:2;). The 1971 Annual Report omitted any reference to Arizona black-tailed prairie dogs, although there were indications that the sub-species had declined further since 1961. A PARC Annual Report in 1975 supplies the missing data on the *arizonensis* subspecies by stating, "The initial survey (1971) indicated that there are four towns of *arizonensis* covering 185 acres in the State [of New Mexico] (PARC, New Mexico Annual Report, 1975:2)." Locations for the four towns were not given.

The results of the 1961 and the 1971 inventories are compared in Table 4.11 to determine the relationship between poisoning and population declines and to estimate the relative error in the inventories. Error is expected in all the statistics related to prairie dog inventories and reported acreages poisoned. An estimated inventory result can be obtained by subtracting the acres reported as poisoned during a period of time from the initial inventory value. The percent difference between the estimated inventory result and the actual inventory value can be considered a measure of the error in all three statistics. The estimated inventory error is relatively low in 1921 and 1961, based on the actual number of acres poisoned. There is only a 6% difference between the estimated population in 1961 and the actual reported value of 359,735. The population decline is directly related to poisoning programs, and the 1921 and 1961 inventories appear to be accurate.

Table 4.11 Relationship of Poisoning to Prairie Dog Decline in New Mexico 1916-1975.

Data Source	Reported Total Prairie Dog Population	Acres Poisoned (since previous record)	Expected Inventory Result	% Inventory Error
Author's 1916 Population Estimate	16,357,533	Unknown	---	---
1921 BBS Inventory	14,858,000	3,856,055	12,501,478	16% above expected total
PARC 1961 Inventory	359,735	14,520,586	337,414	6% above expected total
PARC 1971 Inventory	248,000	422,982	-63,247	75% above expected total

(Source: USF&WS (PARC) Records, 1961-1971; BBS, 1918-21)

The 1971 New Mexico prairie dog statistics, however, appear to be inaccurate. According to PARC records for the period of 1961 through 1971, 422,982 acres were poisoned, 18 % more acres than even occurred in the state in 1961! Yet the 1971 survey showed 248,000 acres of prairie dogs remaining: an error of 75 % over the predicted inventory amount, indicating the 1971 data are flawed and the actual population of prairie dogs in the state was probably much lower.

Even if the state-wide figures for 1971 are to be believed, they indicate that an overall population decline of 31 % occurred for prairie dogs in New Mexico over the previous decade, showing an accelerating rate of decline, from 2.45 % per year between 1921 and 1961 to 3.1 % per year over the following decade.

Even though their own statistics showed extirpation or extremely low population levels in several counties, PARC continued to insist that their programs only attempted to "control" expanding or nuisance populations of prairie dogs, and that their programs were not resulting in threats to the viability of any species (PARC, New Mexico Annual Reports, 1971-1974).

The possibility existed that the Arizona black-tailed prairie dog sub-species was on the verge of extirpation in the state and New Mexico Game and Fish Department began to take steps to list this taxonomic group. The provisions of the Endangered Species Act of 1973 (ESA) extended protection, in theory, to all animals, insects and plants whether on public or private land. Only disease organisms and insect pests were excluded from the ESA. As a distinctive sub-species, the Arizona black-tailed prairie dog was likely to be listed as threatened or even endangered in Arizona and New Mexico, based on recent population surveys for the animal.

In an attempt demonstrate that there was a viable population of *arizonensis* remaining and avoid limitations on their poisoning programs, PARC announced that a new inventory of these animals would be conducted:

> Jaime Provencio, a Student Trainee, was employed during the summer of 1973 and 1974, and assigned to inventory and outline the current range of the Arizona black-tail prairie dog in southern New Mexico. The status of the Arizona black-tail prairie dog is undetermined at this time; and,

> hopefully this inventory will lead to determining the proper status of this sub-species (PARC, New Mexico Annual Report, 1974:1).

PARC records show that Provencio collected thirty-seven specimens from forty-seven suspected Arizona black-tail prairie dog towns encompassing over 2,000 acres (PARC, 1974:2). The situation was grave for the sub-species: without change in the rate of decline of 3.1 % per year, the animal faced certain extirpation in New Mexico sometime in the early 21st century. Furthermore, the average size of the colonies was reported to be less than 43 acres, indicating severe fragmentation of this highly gregarious species. PARC, however, concluded in their 1974 annual report that: "these prairie dogs [*arizonensis*] do not appear to be in jeopardy" (PARC, 1974).

In 1975, PARC was removed from the USF&WS, amidst complaints that the agency was incapable of regulating its own activities. The agency was reorganized as the Animal Damage Control (ADC) Division of the USDA, with little change in personnel. The newly formed agency determined to continue its mandate of eradication of both predators and prairie dogs, but the status of Arizona black-tailed prairie dogs under the regulatory provisions of the ESA remained undecided. The ADC was relieved, therefore, when a new study of the taxonomy of black-tailed prairie by Pizzimenti (1975) cast doubt on Hollister's separation of *Cynomys ludovicianus* into two sub-species. Pizzimenti found that animals from within the range of the Arizona black-tailed prairie dog were not separable from black-tailed prairie dogs from other locations based on several genetic and morphological criteria.

Subsequent studies were conducted on the species by Hansen (1977) and Chesser (1982) which contradict Pizzimenti's study on different grounds. Scientific debate over the best interpretation of the taxonomic classification of the animal had significant ramifications in light of the provisions of the ESA. Hubbard and Schmitt (1984), of New Mexico Game and Fish Department, point out several technical flaws of all three studies. They state, "In our view, the analyses do not inspire confidence, and thus we conclude that they do not resolve the question of whether *arizonensis* is a valid race"(Hubbard and Schmitt, 1984:28).

In the ensuing controversy over the taxonomy of these beleaguered animals, political expediency won. Instead of assuming the original taxonomy by Hollister in 1916 to be the standard, the U.S. Fish and Wildlife Service chose to list the Arizona black-tailed prairie dog as a Candidate Species (C2) until its taxonomic status could be clarified. As Hubbard and Schmitt (1984) point out, however, "hopes for any definitive resolution of the validity of *arizonensis* may be impossible—especially considering that the Willcox and most other nearby populations are extinct."

Complicating matters, New Mexico Department of Game and Fish elected to agree with findings by Hansen (1977) that a taxonomically distinct group, the "Tularosa" taxonomic race, was unique only to New Mexico (Hubbard and Schmitt, 1984). In this politically astute maneuver, New Mexico extended endangered species protection to remnant populations of the [former] Arizona black-tailed prairie dogs in Lincoln and Otero counties without admitting that an entire sub-species was on the verge of extirpation in the United States or openly challenging the USFWS's C2 designation of *arizonensis*.

There is evidence that these remaining colonies in Lincoln and Otero counties have continued to be killed during the 1980s and 1990s, despite their New Mexico Endangered Species status as "Tularosa prairie dogs".

In 1982, Bodenchuk a biologist with ADC, conducted an indirect survey for New Mexico prairie dogs using questionnaires distributed to land owners in the state. The results of his survey depended on extrapolated values based on the percentage of respondents versus non-respondents, and has been criticized as being based on unwarranted assumptions (Hubbard and Schmitt, 1984). The results of the study showed a population of 497,012 acres of prairie dogs in the state in 1982 (Bodenchuck, 1982).

Compared to the PARC estimate in 1971, this would indicate that prairie dog populations had <u>increased</u> more than 100% in 11 years. Bodenchuck did not mention the presence of earlier inventories. Nor did he use this or other available eradication data to evaluate his own inventory results. Thus, Bodenchuck's report of "nearly 500,000 acres" of prairie dogs in New Mexico in 1982 is the only prairie dog inventory statistic published for New Mexico between 1919 and 1998 (Hubbard and Schmitt, 1984; Knowles, 1998).

Knowles (1998) reviewed current information from a variety of private and public sources to make the most recent estimate of over-all prairie dog populations for New Mexico. He estimates that, approximately 15,000 acres of prairie dogs occurred state-wide in 1998, with most black-tailed prairie dog colonies limited to 25 acres or less. Only one colony in the state was large enough to be considered a secure population.

Federal protection for prairie dogs is long overdue. The Arizona black-tailed prairie dog was removed from the C2 candidate species for protection when the ESA ranking method was revised in 1995. Black-tailed prairie dogs (both subspecies) were proposed by the National Wildlife Federation for federal listing as a threatened species under the ESA in 1999 (National Wildlife Federation, 1999).

While state and federal initiatives for protection and recovery of prairie dog populations have been abject failures, two private conservation initiatives have implemented black-tailed prairie dog reintroductions in the study area: the Ted Turner Endangered Species Fund and the Animas Foundation. These reintroduction programs began in 1996 with a small (60+) animal reintroduction at the site of the oldest record for Arizona black-tailed prairie dogs in the study area. This site is at the northern end of the Jornada del Muerto on Turner's Pedro Armendaris Ranch. Source animals were acquired from the nearest black-tailed prairie dog colony (unknown sub-species), and their numbers have increased substantially as of this writing. Subsequent reintroduction projects have been implemented successfully on Turner's Ladder Ranch, also in Sierra County, and on the Gray Ranch, owned by the Animas Foundation, in southern Hidalgo County.

PRAIRIE DOG CONTROL IN MEXICO

Since Mexico has not had federally-sponsored rodent eradication programs to keep records, I have not been able to thoroughly document the extent of prairie dog eradication there. There is some evidence in American sources, however, that the areas of northern Chihuahua have had privately-sponsored prairie dog poisoning for many years.

Cattle ranches of Chihuahua have had a long association with their counterparts in southern New Mexico and Arizona, exchanging breeding livestock and new ideas on range management. The intensive prairie dog campaigns being conducted by the BBS in southern Arizona and New Mexico during the 1920s probably introduced the concept of prairie dog control as a form of range management to Mexican ranchers.

In 1932, ranchers in northern Chihuahua invited Bailey and other BBS agents to assist with their predator control operations. Bailey (1932:6) reports that, "No prairie dogs were seen in the Casas Grandes Valley bottom". Previously, Streater (1892-93) had reported that prairie dogs were common in the region about Casas Grandes (Streator, 1892-93).

Bailey relates information about extermination campaigns that had been conducted on the Mexican ranch he was visiting in Chihuahua. He states:

> They [the prairie dogs]were fat and healthy and one was cooked in camp and voted fairly good eating. Houghton [the ranch foreman] says that there used to be thousands of these prairie dogs, but consistent poisoning for a few years to save the grass has resulted practically in their extermination on the Corralitos property (Bailey, 1932:6)

From this description, it seems likely that many ranches in Chihuahua had developed their own poisoning compounds and were putting them to use destroying prairie dogs.

Brand confirms that the prairie dog of Chihuahua had recently experienced a contraction in its range. Brand conducted research in 1936-37 in northern Chihuahua, where he reported on several locations for prairie dogs (Brand, 1937). He spent time around Casas Grandes but didn't report any prairie dog colonies in this area. He reports that, "The Arizona prairie dog (*Cynomys ludovicianus arizonensis*) formerly was very common over the grassy steppe of Chihuahua, but at present tends to be localized in the northwestern plains around San Diego [and], the Llanos de Carretas" (Brand, 1937:5). From these two accounts, it seems likely that the colonies in the broad plains around Casas Grande were poisoned during the late 1920s.

PARC officials were invited back to Chihuahua for technical exchange in 1950 (PARC, Annual Reports, 1950). Predator and rodent control projects were conducted to demonstrate modern control methods, and introducing the use of highly toxic 1080 as a predator and rodent control poison.

Ceballos *et al.* (1993), reported that *C. ludovicianus* occupied approximately 55,000 ha in northeastern Chihuahua in 1990. They also report that prairie dog poisoning took place during their study in 1989, eradicating a 4,930 ha colony. The Mexican government now lists the black-tailed prairie dog as a threatened species, although little enforcement takes place. Ecologists are concerned lest these last remaining large prairie dog complexes of Arizona black-tailed prairie dogs disappear (Ceballos *et al.*, 1993; Frey, 1998; Knowles, 1998).

SUMMARY

Prairie dog extermination began after the 1870s in the study area. Early extermination consisted of unorganized private efforts that included trapping, hunting animals out with ferrets, shooting, and drowning.

Political pressure supporting organized prairie dog eradication came from within the BBS after 1900. Publicity campaigns were mounted by the public agency to persuade ranchers and legislators of the pest status of prairie dogs and of the economic benefits to be gained from eradication. The BBS initiated research into effective poisons and poisoning methods in 1905, followed by large-scale prairie dog poisoning demonstration projects in Arizona and New Mexico in 1914.

Cooperative programs were established in these two states in 1918 with the clear objective of total prairie dog eradication. These programs were mandatory for all property owners, even though as much as 20% of landowners in these states objected to the programs during the 1920s. Prairie dog eradication programs reached their peak in the study area in 1938 using the funding and manpower of the New Deal Programs, such as the CCC.

Total eradication of prairie dogs proved to be more difficult than the BBS planned on, and was never achieved for either Arizona or New Mexico. Extirpation of the animals was accomplished in counties with populations of Arizona black-tailed prairie dogs, however. Concentration of these colonies into the moist bottomlands and valleys surrounded by inhospitable mountain ranges and tracts of Chihuahuan desert scrub may have contributed to their early extirpation. These isolated colonies were more readily targeted by people for extermination and there were no nearby populations to naturally recolonize an area after eradication.

The last living Arizona black-tailed prairie dogs were extirpated from Graham and Luna counties during the 1930s. The last record of the animals in Grant County dates from 1960. The animals persisted on White Sands Missile Range in Sierra and Doña Ana counties until approximately 1972. Small active colonies of black-tailed prairie dogs in the range of the *arizonensis* sub-species still exist in remote areas near Fort Bliss and WSMR in Otero and Lincoln counties. These colonies are on federal lands and have been protected from poisoning since 1972. By contrast, large colonies of these prairie dogs still occur on the desert grasslands of Chihuahua, Mexico.

Chapter 5: Ecological Consequences of Eradication

Qualitative Conditions on Living and Eradicated Prairie Dog Towns

Prairie dog eradication combined with livestock ranching have been the most consistent pattern of human agency in the Southwest since 1870, affecting millions of acres of land. This chapter examines the ecological consequences of prairie dog removal on the desert grassland ecosystem within the context of ongoing livestock ranching in the American Southwest.

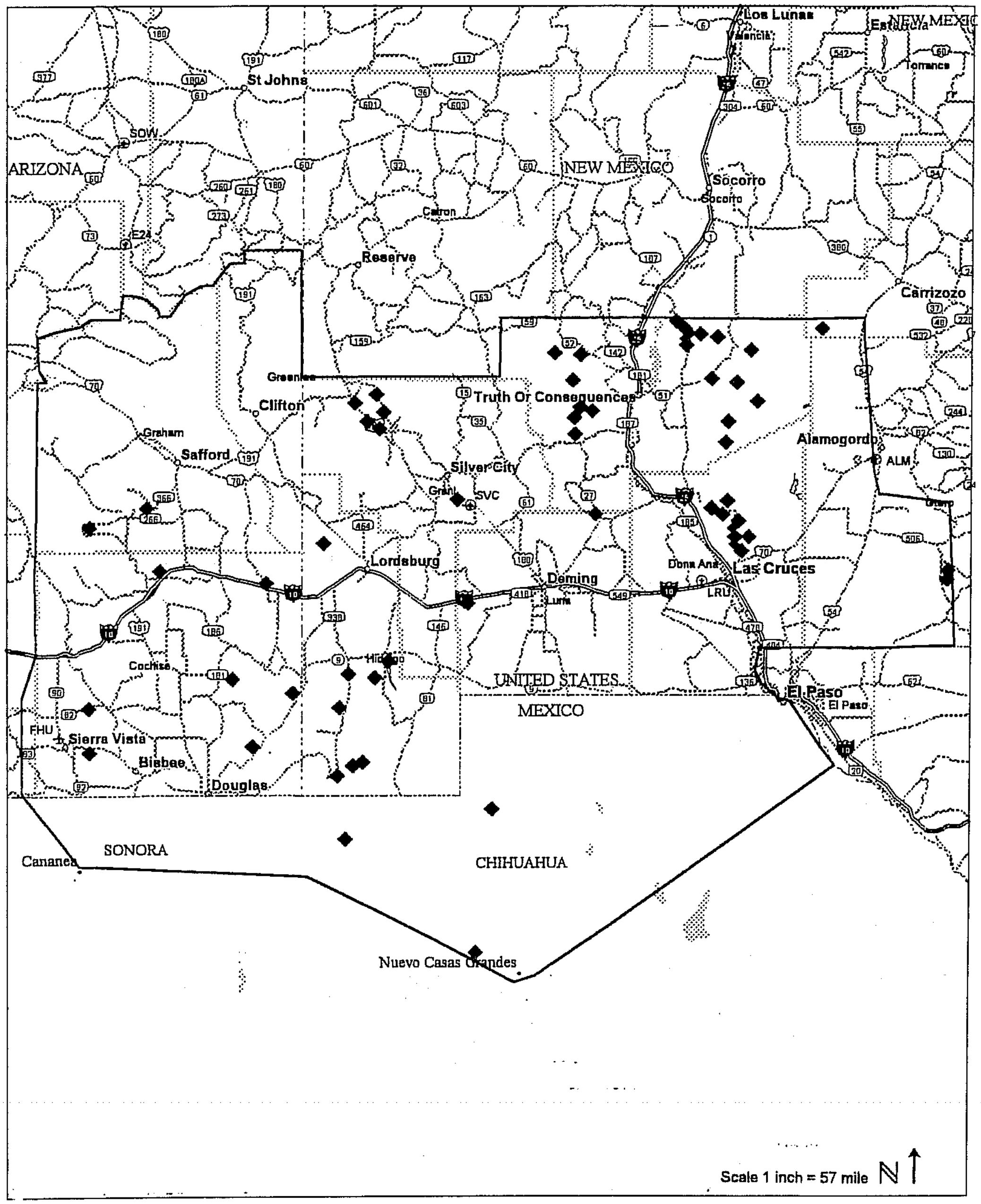
I visited many of the prairie dog town locations identified in Chapter 3 in order to locate former and living prairie dog towns on the ground and investigate their condition. Some sites have been completely changed by human development. For example, housing estates now cover many acres where prairie dog colonies were formerly found around Willcox and Sierra Vista in Arizona, and around Silver City, Lordsburg, and Deming, New Mexico. Orchards and other extensive agricultural developments have changed the vegetative conditions in portions of the Sulphur Springs Valley, San Pedro Valley and Upper San Simon Valley, as well. Many former prairie dog towns were not modified by human activities other than those associated with range management.

Between 1996 and 1998, I obtained access to 61 sites with historic prairie dog colonies on private and federal land for qualitative study. The study incorporates dogtowns from as many geographic locations as possible, but study sites are not uniformly distributed in the study area. I was unable to obtain access to some of the prairie dog colonies identified in Chapter 3. Private land holdings of the Animas Foundation (Gray Ranch) in Hidalgo County, Ted Turner Enterprises (Pedro Armendaris Ranch and Ladder Ranch) in Sierra County (Figure 1.2) and members of the Malpais Borderlands Group in Cochise County provided access to large land areas, making these three counties the most heavily represented. Access was granted to large land areas by the USDA Jornada Experimental Range and White Sands Missile Range in Doña Ana and Sierra counties, making these areas represented disproportionately, as well.

A total of 61 former and living prairie dog colonies were qualitatively described. Extinct prairie dog towns made up 56 of these sites, 20 of which were located in Sierra County, ten in Doña Ana County, eight in Hidalgo County, six in Grant County, seven in Cochise Counties, two each in Graham and Luna counties and one in Chihuahua. Living colonies could only be found at the southwestern and eastern edges of the study area. These five sites include one in the southwestern corner of Lincoln County, two in Otero County, and three in Chihuahua. Locations of the sites are shown in Figure 5.1.

Land ownership was varied among the prairie dog towns studied. A total of 21 sites were located on federal lands managed by the Bureau of Land Management (BLM) (7), Department of Defense (DOD)(6), and USDA (8). The remainder of sites were located on private ranches.

Figure 5.1. Locations of 61 Living and Extinct Prairie Dog Colonies Included in the Study



Qualitative descriptors were standardized and are defined in the glossary. Qualitative descriptions of prairie dog towns included the following characteristics and methods:

Location--Coordinates were taken in latitude and longitude using a Garmin GPS II or were determined manually from 7.5-minute USGS quad sheet.

Historical Record—Each extinct colony required verification by at least two historic records from Chapter 3 or one historic reference and the presence of distinctive burrow structures. Historic references are noted with the same reference symbols used in Chapter 3.

Eradication Date— I sought complete historical information regarding the date of eradication of each site from the records of the BBS and PARC and from owners, nearby residents and ranch hands (see Appendix A). The last date of prairie dog occupation was given, based on any available information. If the information was only accurate to within five to ten years, the date was given to the nearest decade.

Terrain—Description of terrain included landform category, site drainage and a field estimate of slope. Landform categories included arroyo/wash, *playa*, bench, valley, *bajada*, terrace, low rise, draw, swale, alluvial toeslope, plain, ridge, and saddle. Site drainage categories were normal, shedding, and receiving (Ball, 1976:310).

Erosion Features—Indicators of soil erosion were recorded if present. Descriptors included sheet erosion, rills, gullies, blow-outs, collapsed pipes, chimneys, and discontinuous gullies (Ellis and Mellor, 1995: 178-186).

Burrow Features—The visible features of prairie dog burrow systems including mounds, burrow entrance, collapsed burrow entrance, collapsed linear burrow, and collapsed burrow chamber. Features are described as either recent, weathered or revegetated.

Vegetation—Since detailed vegetation studies were conducted as part of the ecological studies, only general descriptions of the vegetation were made using four categories: denuded (<20 % cover), desert grassland (<30 % woody shrub cover), desert scrub (>29 % woody shrub cover), and weedy (>50 % forbs).

Colony locations and current site conditions are qualitatively described in Table 5.1. Each colony has been given a reference name and number that is used throughout the ecological studies.

Sites were most commonly found in bottoms of swales and on open and relatively smooth terrain, with slopes of 0 to 4% most common. Some colonies were located in mountain valleys, particularly in the flat-bottomed and gentle valleys that are known in the Southwest as "draws." Benches along rivers and terraces around playa lakes were also common locations.

Table 5.1. Qualitative description of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. date	Terrain	Erosion Features	Burrow Features	Vegetation
1. Lava Tank	Sierra N33 26.743 W107 02.77	S1;S10; S12	1961-62	Alluvial toeslope, receiving, flat	Rills, 8-10 in., sheet erosion	Collapsed entrances and tunnels (18 in. deep X 2- 6 ft. long)	Desert grassland
2. Tucson Draw	Sierra N33 24.050 W106 55.43	S1	Unkn.	Draw, normal, 1-2% slope	6 ft. deep gullies with piping, chimneys and blowouts	Tunnel blow-outs, linear tunnel collapses (3-6 ft.)	Desert grassland
3. Red Lake	Sierra N33 29.039 W107 03.66	S1; S10; S12	1961-62	Broad plain, receiving, flat	Sheet erosion, rills	Collapsed entrances (12-18 in.) and tunnels	Desert grassland
4. Ishmael	Sierra N33 27.097 W107 02.84	S1; S10; S12	1950s	Draw, normal, 1-2% slope	Rills, 10-20 in., sheet erosion	Collapsed entrances and tunnels (10-12 in. deep X 2-4 ft.)	Desert grassland
5. Lava Gate Camp	Sierra N33 28.570 W107 03.35	S1; S10; S12	1950s	Draw, normal 1-2% slope	Rills, 8-10 in. , sheet erosion	Collapsed & intact burrows	Desert scrub vegetation
6. Deep Well	Sierra N33 18.958 W107 00.13	S1; S10; S12	1925-1930	Plain, receiving, flat	Rills, Blow-outs	Collapsed burrow network: (18 in. to 3 ft. deep X 20 ft. long)	Desert scrub vegetation

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. Date	Terrain	Erosion Features	Burrow Features	Vegetation
7. Chaves Swale	Sierra N33 23.550 W106 51.34	None	Before 1930	Swale, normal, 1-2% slope	Discontinuous gully, 1-2 ft. deep	Collapsed burrow network (12 in. deep X 6 ft.)	Desert grassland
8. Shot Site	Sierra N33 01.713 W106 32.04	S4; S18	1973-74	*Bajada*, normal, 3-4% slope	Sheet erosion, rills, gully, 1-3 ft.	Collapsed & intact burrows (18 in. deep X 3 ft.)	Desert scrub vegetation
9. Henderson	Sierra N33 07.020 W106 31.52	S4; S18	1973-74	*Bajada*, normal, 3-4% slope	Sheet erosion, rills, gully, 2-3 ft.	Collapsed & intact burrows	Desert grassland
10. Salt Playa	Sierra N33 07.806 W106 26.14	S4; S17	1973-74	Terrace and swale, normal, 1% slope	Sheet erosion, rills 10-18 in.	Weathered burrows with some evidence of mounds	Desert grassland
11. Rhoades Draw	Sierra N33 09.834 W106 33.19	S4, S19; S16	1973-74	Draw and *bajada*, normal, 3-4% slope	Blow-outs, discontinuous gully, 15 feet deep	Collapsed entrances, tunnel blowouts (18 in. deep X 3 ft.)	Desert grassland
12. Rhoades Pass	Sierra N33 12.847 W106 42.59	S4	Before 1943	Valley, normal, 4-5% slope	Discontinuous gully 20 ft. deep, 1 mi long)	Water eroded burrows (no mounds) leading into gully blowouts	Desert grassland
13. Mockingb ird	Sierra N33 29.748 W106 10.59	S4, S11	Unkn.	Plain, receiving, flat	None	Intact mounds and entrances	Desert grassland

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. date	Terrain	Erosion Features	Burrow Features	Vegetation
14. Wild Horse	Sierra N33 02.298 W107 27.27	S8	1937-38	Swale on mesa, receiving, 1%	Blow-outs and discontinuous gullies, 1-2 feet deep	Collapsed entrances and tunnels (10-12 in. deep X 3 ft.)	Desert grassland
15. Ladder	Sierra N32 59.721 W107 30.23	S8	1938-40	Alluvial toeslope, receiving, 1%	Blow-outs and discontinuous gullies, 1-3 feet deep	Collapsed entrances and tunnels (18-20 in. deep X 4 ft.)	Desert grassland
16. Ladder Airstrip	Sierra N33 08.265 W107 30.33	S8	1938-40	Swale, normal, 2% slope	Small blow-outs and gullies 1-2 feet deep	Collapsed entrances and tunnels (12 in. deep X 3 ft.)	Desert grassland
17. Lobo Tank Draw	Sierra N33 28.516 W107 03.36	S8	1938-40	Valley headwater, normal, 4-6% slope	Blow-outs, 10-14 ft. gully, chimneys, piping	Burrows visible in sides and on uphill of arroyos	Desert grassland
18. Grayback Arroyo	Sierra N32 58.14 W107 26.23	S8	1938-40	Alluvial toeslope, normal, 1-2%	Blow-outs and discontinuous gullies, 3-6 ft. deep	Collapsed entrances and tunnels (20-24 in. X 6 ft.)	Desert grassland
19. Chloride Valley	Sierra N33 18.609 W107 38.49	S8	Unkn.	Mountain valley, normal 1-2%	Gully, 3-4 ft. deep	Collapsed entrances and tunnels (8-10 in. X 3 ft.)	Desert grassland
20. HOK Ranch	Sierra N33 19.223 W107 32.65	S8	Unkn.	Draw, normal, 2-3%	Deep gully, 10 ft. deep	None	Desert scrub vegetation

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad Date	Terrain	Erosion Features	Burrow Features	Vegetation
21. White Signal	Grant N32 33.221 W108 13.32	G24; G28	1956-60	Swale, normal, 1% slope	None	Collapsed burrow entrances (12 in. X 2 ft.)	Desert grassland
22. Mud Spring Mesa	Grant N33 04.789 W108 39.58	G20; G22	Before 1945	Draw, normal, 1% slope	Sheet erosion	Collapsed burrow entrances (8-10 in. X 3 ft.)	Desert grassland
23. 916 Gate	Grant N33 08.650 W108 39.42	G20; G22	Before 1945	*Bajada*, normal, 1% slope	Rills and sheet erosion	Collapsed entrances and tunnels (12-18 in. X 3-6 ft.)	Desert grassland
24. Buckhorn	Grant N33 02.333 W108 42.29	G23	1945-50	Valley, normal, 1-2% slope	Deep gully, 10 ft. deep	None—had been farmed	Disturbed
25. Cactus Flat	Grant N33 09.820 W 108 48.13	G10	Unkn.	Valley, normal, 3-4% slope	Blow-outs and shallow gullies	None	Desert grassland
26. Duck Creek	Grant N33 04.250 W108 44.32	G7; G15;G21; G23	Unkn.	Valley, normal, 3-4% slope	Deep gully. 8 ft. deep	None	Desert scrub vegetation
27. Uvas Valley	Luna N32 33.650: W107 24.91	L6; L13	1937-38	Alluvial toeslope, receiving, 1-2% slope	None	Collapsed burrow entrances (10-16 in. deep)	Desert grassland

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. Date	Terrain	Erosion Features	Burrow Features	Vegetation
28. Wilna	Luna N 32 13.430 W108 12.18	L4	Unkn.	Low rise and and swale, normal, 1% slope	Sheet erosion	None visible	Desert scrub vegetation
29. Lake Isaack	Doña Ana N32 27.430 W106 42.90	D8; D10	1934	Terrace and *playa*, receiving, 0-1% slope	Gullies and sheet erosion, 2-3 ft. deep	None visible	Desert scrub vegetation
30. Upton	Doña Ana N32 48.950 W107 01.52	D13; D10	Unkn.	*playa*, receiving, flat	None	Collapsed entrances and tunnels (12 in. deep X 3-4 ft.)	Desert grassland
31. West Well	Doña Ana N32 36.008 W106 50.78	D5; D6;D10	1918	Swale, receiving, 0-1% slope	Dunes	None visible	Desert scrub vegetation
32. Middle Well	Doña Ana N32 41.988 W106 47.06	D1; D5;D10	1918	Broad plain with swales, receiving, 0-1% slope	Sheet erosion, dunes	None visible	Desert scrub vegetation
33. Stewart Well	Doña Ana N32 29.035 W106 44.01	D6; D10; D15	1934	Terrace and *playa*, receiving, 0-3% slope	Rills and small gullies around terrace slopes	Collapsed entrances and tunnels (18 in. deep X 3-6 ft.)	Desert grassland
34. JER Headquart ers	Doña Ana N 32 37.250 W106 44.59	D3; D5; D10	1918	Depression, (receiving, flat) surrounded by slopes of 2-3%	Slumps, sheet erosion and small gullies, dunes	None visible	Desert scrub vegetation

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. Date	Terrain	Erosion Features	Burrow Features	Vegetation
35. Antelope	Doña Ana N 32 30.995 W106 45.40	D5; D6;D10	1918	Broad plain with swales, receiving, 1-2%	Rills, sheet erosion and Eolian dunes	None visible	Desert scrub vegetation
36. Corner Tank	Doña Ana N33 31.572: W 106 43.09	D5; D6;D10	1918	Plain, receiving, flat	Sheet erosion, dunes	None visible	Desert scrub vegetation
37. Big Sandy	Doña Ana N 32 36.390 W106 45.20	D5; D6;D10	1918	Depression surrounded by slopes of 2-3%	Sheet erosion, dunes	None visible	Desert scrub vegetation
38. S Well	Doña Ana N32 32.310 W106 44.90	D5; D6;D10	1918	Plain, receiving, flat	Sheet erosion, dunes	None visible	Desert scrub vegetation
39. Playas Valley	Hidalgo N31 58.20 W108 36.93	H4; H12; H19; H35	Unkn.	Plain, receiving, flat	None	None	Desert grassland
40. Animas Loop	Hidalgo N31 52.277 W108 47.52	H11; H30	Unkn.	Broad plain and swale, receiving, 0-1%	None	Collapsed entrances and tunnels (8-12 in. deep X 2-3 ft.)	Desert grassland
41. George Wright	Hidalgo N31 24.504 W108 43.04	H11; H30;H34	1935-40	*Bajada*, normal, 3-4% slope	Rills, 1 foot deep, sheet erosion	Collapsed entrances and tunnels (18 in. deep X 2-3 ft.)	Desert scrub vegetation
42. Cloverdale	Hidalgo N31 25.100 W108 53.61	H5;H10; H11; H18	Before 1930	Broad swale leading, 1-2% slope	Artificial erosion-control channels	None	Desert grassland

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. date	Terrain	Erosion Features	Burrow Features	Vegetation
43. San Luis Draw	Hidalgo N31 23.648 W108 46.89	H5;H10; H18; H36; H33	1961-62	Alluvial toeslope, normal, 1-2%	Gully, 3 ft. deep	Collapsed entrances and tunnels (12-18 in. X 3-4 ft.)	Desert grassland
44. Lynch Tank	Hidalgo N31 24.504 W108 43.04	H4; H9	1930s	Draw and *bajada*, normal, 4-6% slope	Sheet erosion and gullies, 2-3 ft. deep	Collapsed entrances and tunnels (12 in. deep X 3 ft.)	Desert grassland
45. Above Playas	Hidalgo N31 54.84 W108 41.67	H12; H19	1930s	Draw and *bajada*, normal, 4-6% slope	None	Collapsed entrances and tunnels (12 in. deep X 2 ft.)	Desert grassland
46. Summit	Hidalgo N 32 28.386 W108 59.51	H17; H38	1974	Broad plain and *playa*, receiving, flat	Rills and sheet erosion	Collapsed entrances and tunnels (18 in. deep X 3 ft.)	Desert grassland
47. Hereford	Cochise N31 26.180 W110 05.74	C21;C33	1918-19	River bench, normal, 1-2%	Deep gully erosion and blow-outs	None	Desert scrub vegetation
48. Hunt Canyon	Cochise N31 38.55 W109 27.91	C32	1930s	Draw, normal 3-5% slope	None	None	Desert grassland

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. Date	Terrain	Erosion Features	Burrow Features	Vegetation
49. Miller Ranch	Cochise N31 45.928 W103 03.64	C28	1919-20	Plain and *playa*, receiving, flat	Rills and sheet erosion	None	Desert scrub vegetation
50. Boss Ranch	Cochise N31 31.711 W109 18.15	C27	1932-33	*Bajada* and swale, normal 2-3% slope	Rills and sheet erosion	Collapsed entrances and tunnels (18 in. deep X 2-4 ft.)	Desert grassland
51. Willcox	Cochise N 32 16.04 W109 52.51	C16; C5; C8	1919-20	Broad *playa*, receiving, flat	Rills, 8-10 in. , sheet erosion	None	Desert scrub vegetation
52. Babo-comari Grant	Cochise N31 39.852 W110 17.07	C2	1918-19:	Terraces, normal, flat	Sheet erosion, gullies 2-3 ft. deep	None	Desert scrub vegetation
53. San Simon	Cochise N 32 15.50 W109 13.73	C3; C5; C24; C23	1919-20	Broad plain, normal, 1-2% slope	Deep gullies with piping, chimneys and blow-outs	None	Desert scrub vegetation
54. Bonita	Graham N 32 35.94 W109 58.52	G3; G1; G11; G5	1920-22	Alluvial toeslope, normal, 2-3% slope	Sheet erosion and gullies	None visible	Desert scrub vegetation
55. Ash Creek-Sunset	Graham N 32 30.79 W110 11.18	G12; G11;	1920-22	Alluvial toeslope, normal, 2-3%	Sheet erosion and gullies	None visible	Desert scrub vegetation

Table 5.1 (Cont.). Location and Condition of Living and Eradicated Prairie Dog Towns, 1996-1997

Colony Name	Location	Historic Record	Erad. Date	Terrain	Erosion Features	Burrow Features	Vegetation
56. Otero Bottoms	Otero N 32 24.981 W105 46.04	BLM records	Unkn.	Depression surrounded by 2-3% slopes	Sheet erosion, rills	Collapsed entrances and tunnels	Desert grassland
57. Mesa Horse Camp	Otero N 32 24.198 W 105 45.6	BLM records	Living colony	Bajada, normal, 3% slope	None	Intact mounds and entrances	Desert grassland
58. Mc Donald	Lincoln N 33 35.957 W106 05.49	BLM records	Living colony	Plain, normal, flat	Rills and sheet erosion	Active burrows with high mounds	Desert grassland
59. Asencion	Chihuahua N 31 08.43 W108 31.15	Ceballos, *et al.*, 1993	Unkn. (recent)	*Bajada*, normal, 1-2% slope	Rills and sheet erosion	Eroded mounds	Desert grassland
60. San Francisco	Chihuahua N31 14.03 W108 40.15	Ceballos, *et al.*, 1993	Living colony	Broad plain, normal, 0-1% slope	None	Active burrows with high mounds	Desert grassland
61. Buenos Aires	Chihuahua N 30 45.847 W108 23.47	Ceballos, *et al.*, 1993	Living Colony	Broad plain, normal, 1-2% slope	None	Active burrows with high mounds	Desert grassland

All sites but one showed evidence of concurrent use by livestock. Sites on Ted Turner Enterprises ranches, where resident cattle had been removed a few years earlier, showed evidence of either trespass cattle or horses being pastured there. Livestock had been removed from WSMR several decades earlier, but feral horses and exotic oryx were observed on the former dogtowns.

Desert grassland was the most common vegetation type found on eradicated and living dogtowns, but those colony sites poisoned in the 1920s were more often dominated by desert scrub vegetation. The particular species of woody shrubs seemed to be highly variable, with some sites being dominated by four-wing salt bush, others by mesquite, cat-claw acacia, or a mixture of woody species.

Qualitative examination of 56 extinct colonies reveals interesting evidence of a complex burrow erosion-and-decay processes. This erosion-and-decay process seems to be slow acting on most sites, presumably because of low rainfall on the desert grasslands. The rate of burrow decay is variable from site to site, possibly due to site-specific heavy rainfall events, variation in slope and soil characteristics. Some colonies contained thousands of pits and depressions from collapsed burrows that were heavily weathered and overgrown with grass. Sites such as these were very difficult to walk across. Other sites contained one or more very long troughs, 10-20 feet in length, where linear burrows had collapsed. In sites receiving more inflow than run-off, surface water collected in the collapsed burrow features for several weeks after rains. Cattle and livestock impacts at these water-filled depressions were apparent.

Two of the living prairie dog towns visited showed signs of collapsed burrows. Site 56, Otero Bottoms, contained a large area of dense and overgrown collapsed burrows, perhaps 100 acres in extent, with a few prairie dogs living at one edge. The active area showed collapsed burrows that had been cleaned out and were being used, as well as burrows with raised mounds. It appears that this site was eradicated several years earlier, then recolonized in the recent past. Site 58, McDonald, also had a large area adjacent to the active colony that was densely covered with pits and collapse features. No collapsed burrows were found on the active colony area, however. Records show that this site had previously been poisoned and the active colony area may represent a recolonization of land adjacent to the original poisoned colony.

Soils were analyzed for particle size distribution on 19 of the living and eradicated prairie dog towns. The particle size distribution and texture for each site is shown in Appendix B. The sites were highly variable in particle size distribution, with all soil textures represented except pure sand. Clay accounted for an average 25.6 % of the particle size distribution, sand for 41.8 %, and silt for 32.6 %. Loam was the primary soil descriptor at 14 sites. The primary descriptor at 3 sites was clay, and sand was the primary descriptor at only 2 sites. None of the sites contained a significant gravel component. Three of the soil samples showed the presence of high alkali components by the presence of crusts of white crystals. This indicates that prairie dogs in the desert grassland may be tolerant of various textures and chemical constituents, but be associated most frequently with loamy, well-sorted soils.

ECOLOGICAL STUDIES OF THE CONSEQUENCE OF PRAIRIE DOG ERADICATION

Ecological studies of a more quantitative nature were conducted on a subset of living and eradicated dogtowns to determine the physical consequences of removing this keystone rodent from the desert grassland ecosystem. Those sites with access, reasonably complete historic data and without evidence of land clearing were included in the ecological studies. A total of 21 eradicated and living dogtowns in the United States and Chihuahua, Mexico, were selected for further ecological study from among the 61 sites visited, as shown in Figure 5.1.

The living and eradicated colonies included in the study were free of plow agriculture and mechanical clearing, but showed evidence of recent or ongoing livestock grazing of variable levels of impact. The data are organized into general age groups related to time since eradication, since several eradication dates are only approximate.

No assumptions are made regarding uniformity of past or present environmental conditions at the sites, except that they lie within the desert grassland-Chihuahuan desert scrub mosaic. Rainfall quantity, intensity and periodicity may vary widely from site to site. The historic occurrence of wild fires is unknown.

Vegetation studies were conducted on the 21 sites, according to the methods described in Chapter 2. The relative vegetation cover, rounded to the nearest 0.5 %, is presented in Table 5.2 and detailed species lists are provided in Appendix C.

Table 5.2. Vegetation Structure On Living and Eradicated Prairie Dog Towns, 1997-98.

SITE NAME	AGE	COUNTY	GRASS (%)	FORB (%)	SHRUB (%)
Living Prairie Dog Towns					
58. McDonald	0	Lincoln	97	3	0
57. Mesa Horse Camp	0	Otero	72	28	0
60. San Francisco-MX	0	Chihuahua	98	2	0
61. Buenos Aires-MX	0	Chihuahua	56	44	0
Young Eradicated Colony Sites (22-35 Years Age)					
10. Salt Creek Draw	22	Sierra	99	0.5	0.5
46. Summit	23	Hidalgo	99	0	1
11. Rhoades Draw	23	Sierra	70	0	30
1. Lava Tank	35	Sierra	86	14	0
43. San Luis Draw	35	Hidalgo	65	32	3
Intermediate-Aged Eradicated Colony Sites (58-70 Years Age)					
15. Ladder Ranch	58	Sierra	78	6	16
41. George Wright	59	Hidalgo	71	6	23
50. Boss Ranch	63	Cochise	98	2	0
33. Stewart Well	63	Doña Ana	62	0	38
6. Deep Well	70	Sierra	89	1	10
Old Eradicated Colony Sites (>77 Years Age)					
49. Miller Ranch	78	Cochise	76	3	21
36. Corner Tank	79	Doña Ana	65	2	33
32. Middle Well	79	Doña Ana	54	0	46
35. Antelope	79	Doña Ana	41	8	51
34. Headquarters	79	Doña Ana	38	7	55
37. Big Sandy	79	Doña Ana	29	23	47
31. West Well	79	Doña Ana	10	3	87

Source: Author

I have previously identified three fundamental hypotheses of prairie dog succession: the Weed, Tall Grass and Brush-clipping Hypotheses. The study of living prairie dog towns tests the different hypotheses using the data from Table 5.2 and historic data from the JER.

Rapid transformation of sites from high grass cover to high forb cover is expected after prairie dog eradication according to the Weed Hypothesis, since most forbs can quickly colonize bare ground found on a prairie dog colony. An increase in grass cover and biomass is expected with the Tall Grass Hypothesis. Under the Brush-clipping hypothesis, woody species are expected to increase after eradication due to the latent seed bank and repressed seedlings on the site. All hypotheses would anticipate short-term vegetation change on eradicated prairie dog towns since the underlying cause of vegetation change is related to grazing and other surface activities of the prairie dog.

The ecological studies proceed in a step-wise fashion through five tests:

Test 1 establishes the characteristic vegetation structure of living prairie dog towns and the validity of using vegetation structure as an ecological baseline for measuring vegetation change on prairie dog colonies. This analysis also tests the assumption that other agents of ecological change, such as cattle grazing or climatic effects, do not have a significant influence on vegetation structure on active prairie dog towns.

Test 2 examines the possibility of long-term succession on a group of sites in a single geographic location for which detailed historical vegetation records are available, proving that vegetation structure has changed on these sites.

Test 3 examines the possibility of long-term succession across broader spatial and temporal scales by comparing vegetation structure on living prairie dog towns with that of colonies from a variety of locations eradicated between 58 and 80 years earlier.

Test 4 specifically tests for evidence of short-term vegetation change on eradicated prairie dog towns. In this test the vegetation structure of living prairie dog towns is compared with that of colonies from a variety of locations known to have been eradicated between 20 and 35 years earlier.

Test 5 compares the results of the ecological tests with qualitative data on the conditions of eradicated colonies, to determine if other factors might be influencing the observed pattern of vegetation change.

Test 1: Vegetation Structure on Living Prairie Dog Towns, Past and Present

The study of succession following prairie dog eradication requires some form of screening for the effects of the various ecological factors that have been suggested as causal agents producing ecological change in the region. Test 1 does not eliminate these effects but tests the hypothesis that they have not had a significant influence on the vegetation structure of active prairie dogtowns over the past 80 years. If this can be shown, then the removal of the effects of living prairie dogs becomes the single most significant factor to account for changes after eradication. Test 1 compares historic vegetation data on living dogtowns sampled in 1917 on the Jornada Range Reserve, now the JER, with vegetation structure on four living prairie dog colonies in the study area sampled in 1997.

The null hypothesis in Test 1 is that significant ecological change has occurred throughout the study area as a result of grazing, climatic variation and fire, producing significant differences in vegetation structure on living prairie dog colonies today compared with colonies living in the past. If significant climatic change has taken place, or if non-random effects from ecological factors related to human settlement and cattle ranching have occurred, significant differences will be exhibited in the comparison between vegetation structure on living dogtowns today and those living 80 years ago.

This is also a test of the validity of using vegetation structure on living prairie dogs towns as the assumed uniform baseline for ecological conditions on the average active prairie dog town in the past. If no significant difference exists between typical prairie dog town vegetation structure of the past and that of the present, this baseline of average vegetation structure will become the yardstick by which the long-term effects of prairie dog eradication can be measured. Since the study tests sites with great potential variability in time and space, a significance level of 99 % probability ($p<0.01$) is applied.

Data from maps produced in 1917 by Fred Quesenberry are evaluated to identify the vegetation structure characteristic of prairie dog colonies of the past. These maps show the boundaries of 17 individual prairie dog colonies on the JER along with detailed vegetation maps (Quesenberry, 1917). More than one vegetation type may occur within each colony boundary, as shown in Table 5.3. All of the prairie dog colony map sheets from the 1917 JER survey and some examples of associated vegetation data sheets are included in Appendix D.

Table 5.3. Vegetation Structure on Living Prairie Dog Colonies, JER, 1917.

Colony Name	Vegetation Type	Acres	% Grass	% Forbs	% Shrubs
Firing Range A	Burro grassland	8	67	1	32
Firing Range B	Burro grassland	34	95	2	3
Corner Tank A	Burro grassland	388	95	2	3
Corner Tank B	Grama grassland	83	80	8.3	11.7
Corner Tank C	Grama grassland	12	67	1	32
Middle Well A	Tobosa-Burro grassland	106	80	15.3	4.7
Middle Well B	Weeds	88	10	80.7	9.3
Middle Well C	Weedy grassland	7	60	30	10
Lucero Tank A	Tobosa-Burro grassland	28	80	15.3	4.7
Lucero Tank B	Grama grassland	16	70	12	18
Price A	Grama grassland	28	70	12	18
Powers A	Burro-Aristida grassland	10	75	1.6	23.4
Mud Tank A	Burro-Tobosa grassland	3	85	5	10
Mud Tank B	Burro-Sporobolus grassland	4	90	0	10
Little Sandy A	Grama grassland	35	90	7	3
Little Sandy B	Grama grassland	9	80	18	2
West Well A	Grama grassland	33	80	18	2
Big Sandy A	Grama grassland	335	85	4.8	10.2
Big Sandy B	Weedy Grama grassland	27	87	4.4	8.6
Big Sandy C	Yucca-Grama grassland	32	60	20	20
Brockway A	Burro grassland	20	90	9.5	0.5
Brockway B	Grama grassland	12	85	7.3	7.7
Warner I A	Grama grassland	18	65	27.6	7.4
Warner II A	Grama grassland	10	65	27.6	7.4
Little Pocket A	Tobosa grassland	10	55	35	10
Headquarters B	Grama grassland	90	90	10	0
Headquarters C	Tobosa grassland	18	95	5	0

Table 5.3. Vegetation Structure on Living Prairie Dog Colonies, JER, 1917 (Cont.).

Colony Name	Vegetation Type	Acres	% Grass	% Forbs	% Shrubs
Headquarters D	Aristida grassland	350	70	18.7	11.3
Headquarters E	Tobosa grassland	119	95	5	0
Headquarters F	Muhly grassland	9	95	5	0
Antelope Flat A	Aristida grassland	115	95	5	0
Antelope Flat B	Tobosa grassland	4.3	95	5	0
Antelope Flat C	Grama grassland	8.5	65	22	13
Antelope Flat D	Burro-Tobosa grassland	1.5	85	9.5	5.5
South Well A	Grama grassland	4	65	27.7	7.3
Unweighted Average		52.62	80.67%	14.66%	4.67%
Weighted Average			77.31%	14.23%	8.46%

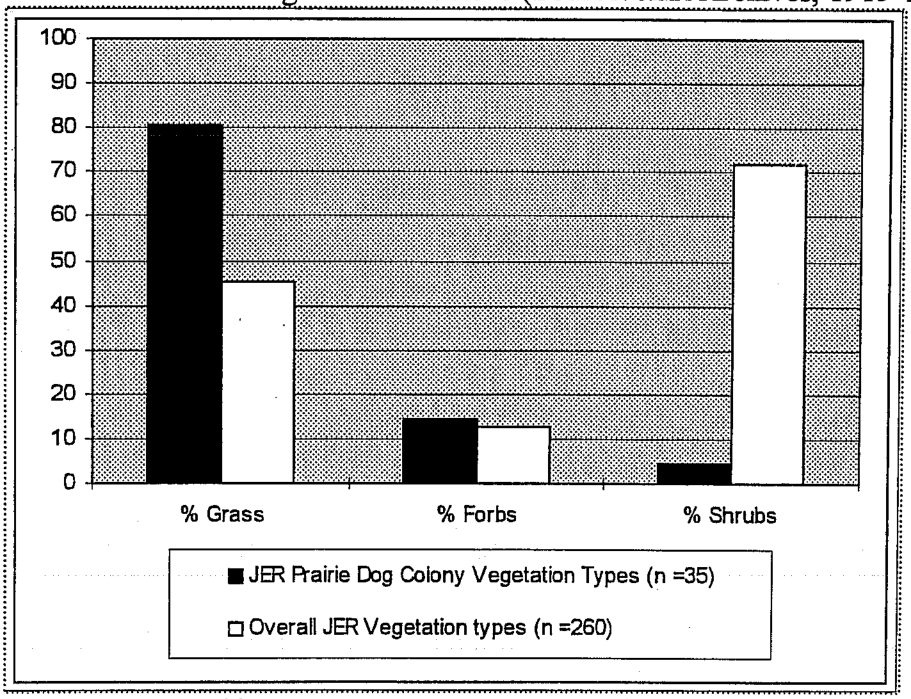
Sources: JER 1915 Vegetation Survey; Quesenberry, 1917.

The vegetation descriptions are coded on the original maps and the key to the codes is maintained in the JER archives. The 1917 survey shows the locations of 2,075 acres of prairie dog colonies on the Range Reserve, with 35 different vegetation types described on the prairie dog towns. Historic vegetation descriptions include information on species composition and relative cover of each vegetation structural class. The overall density of vegetation was also estimated, as well as the vegetation structure. At least 8,000 acres of prairie dog colonies had been poisoned on the JER during the two previous years, but their location and vegetation characteristics are unknown.

Colony size on the JER in 1917 ranged from a 4-acre colony to 586 acres. The vegetation type of each colony is listed, along with the area of occurrence for each vegetation type. More thorough descriptions of seven selected sites that were visited in the course of this study are provided in Table 5.1.

The vegetation structure of the entire JER was characterized in 1915 and is available in the JER archives. These data, listed in Appendix E, describe a total of 260 vegetation types according to relative cover of grasses, forbs and shrubs. The 1915 overall average vegetation structure is compared with the average vegetation structure of the 1917 JER prairie dog towns in Figure 5.2 and Table 5.4.

Figure 5.2 Comparison of Unweighted Averages of 1917 Prairie Dog Towns and Overall 1915 JER Vegetation Structure (Source: JER Archives, 1915-1917).



Source: JER Archives, 1915, 1917.

A statistical comparison of the average unweighted vegetation structure on 1917 JER prairie dog colonies and the overall average vegetation structure of the JER is possible. While this is not as satisfactory as a comparison of weighted averages, a full spatial analysis of the 1915 JER vegetation data is beyond the scope of this study. The comparison of unweighted averages provides a reasonable measure of the similarity of vegetation on prairie dog colonies with surrounding vegetation.

I used the Kolmogorov-Smirnov statistic to test hypothesis that vegetation structure on 1917 JER prairie dog colonies is significantly different from the overall average vegetation structure described in the 1915 vegetation survey. This is a non-parametric test for the analysis of similarity between frequency distributions (Miller and Kahn, 1962:464-467; Gregory, 1963:179-186). Summary statistics are shown in Table 5.4.

Table 5.4. Comparison of 1917 Prairie Dog Colony versus Overall JER Vegetation Structure, 1915

Sample Population	% Grass	% Forbs	% Shrubs
Observed 1917 JER Prairie Dog Colony Vegetation (n =35)	80.67	14.66	4.67
Overall 1915 JER Vegetation Types (n =260)	45.43	12.85	41.59
Difference	35.24	1.81	36.92
Significance	$p<0.001$	N/A	$p<0.001$
Conclusion	Different Populations	Same Populations	Different Populations

(Source: JER Archives, 1915-1917).

The tests shows that there is a significant and opposite difference between the overall cumulative distribution of grass and shrub density on the JER, and the observed distribution of these structural types on prairie dog colonies at a similar point in time.

No statistical difference occurs between the overall forb density on prairie dog colonies and the overall cumulative distribution of forb density on the JER, according to this test, leading to the conclusion that forb density is unrelated to the occurrence of prairie dog colonies and may be a random phenomenon on the desert grassland.

Modern living prairie dog colonies were sampled for vegetation structure and density. Colony locations were identified as those four colonies nearest to the JER: a colony at Mesa Horse Camp, Otero County, approximately 72 miles east of the JER, and McDonald Colony in southwest Lincoln County, approximately 87 miles northeast of the JER. Other living colonies are known from areas in northwestern Chihuahua. The two colonies located nearest to the US-Mexico boundary were selected for study: one is near the village of Monte Verde, Chihuahua, approximately 155 miles southwest of the JER. The second site is about five miles south of Antelope Wells border crossing. This last site is about 150 miles from the JER. There is absolutely no reason to think that these four living colony sites may be similar to the 1917 sites on the Jornada del Muerto, except that they all had active prairie dog towns when the vegetation was described.

The four modern colonies were sampled, as described in Chapter 2, and the percent cover (by basal area) of grass, shrubs and forbs determined. Care was taken to classify ambiguous species, such as snakeweed, according to the conventions used in the 1917 data. These were compared with the vegetation structure on 18 unique vegetation types from six of the largest undisturbed colonies in the JER 1917 data.

Significant deviation from the expected average vegetation structure of living prairie dog colonies is assumed to indicate change. If the factors producing post-eradication change consistently favor one structural class over another, directional change will be observed in which one structural class becomes dominant.

Since no assumptions of normality can be made about the sample populations, the non-parametric Mann-Whitney U Test was applied in the comparison of the ratios of vegetation structural classes. The historic vegetation data from the JER is provided only as a ratio of relative cover types, not as interval data. The Mann-Whitney U Test relies on the ranked order two data sets, which can be in the form of percentages without giving false results, unlike the Chi-square (Ebdon, 1985:67). The null hypothesis of the Mann-Whitney Test is that the two samples come from the same population and any observed differences in vegetation structure is due to chance in the sampling process. This hypothesis would, if true, result in a high critical U (Ui) statistic. The alternative hypothesis is that the two samples come from different populations, and is reflected in a low test statistic.

The results of the comparison of vegetation structure between the 1917 test group and 1997 test group are shown in Table 5.5. The modern living colonies showed no statistical difference from 1917 living colonies on the JER at $p<0.01$. This indicates that the presence of active prairie dog colonies is associated with a predictable vegetation structure that can be reliably used as a baseline from which to measure vegetation change. It also indicates that other environmental factors such as cattle grazing and wild fire occurrence, do not significantly effect vegetation on living prairie dog colonies.

The four living colonies in Mexico and the United States have no woody shrub vegetation on active colony areas (all areas within 50 feet of an active burrow), even though woody shrub vegetation was present in nearby surrounding areas without prairie dogs. Historic mapped data from the JER indicate that small inclusions of vegetation high in shrubs occurred within prairie dog colonies, and some small colony sites, 10 acres or less, had high shrub cover.

Table 5.5. Test 1: Comparison of Vegetation Structure on 18 Historic and 4 Modern Prairie Dog Towns on the JER.

Colony Name	Rank Grass	Rank Forbs	Rank Shrubs
1917 Prairie Dog Colony Vegetation			
Corner Tank A	5.5	20.5	11
Corner Tank B	14	11	4
Corner Tank C	18	22	1
Middle Well A	20.5	2	7
Middle Well B	14	9	10
West Well A	14	7	12
Big Sandy A	11.5	17	6
Big Sandy B	10	18	8
Big Sandy C	20.5	5	2
Headquarters A	9	8	17.5
Headquarters B	5.5	14	17.5
Headquarters C	17	6	5
Headquarters D	5.5	14	17.5
Headquarters E	5.5	14	17.5
Antelope Flat A	5.5	14	17.5
Antelope Flat B	5.5	14	17.5
Antelope Flat C	19	4	3
Antelope Flat D	11.5	10	9
1996-97 Prairie Dog Town Vegetation			
Mesa Horse Camp	16	3	17.5
McDonald	2	19	17.5
San Francisco	1	20.5	17.5
Buenos Aires	22	1	17.5
1917 Living Colonies Ui Statistic (n= 18)	31	33.5	60
1997 Living Colonies Ui Statistic (n= 4)	41	38.5	12
Critical Ui Statistic at p<0.01= 9	No Difference in Populations		

Source: JER 1915 Vegetation Survey; Quesenberry, 1917; Author

The cumulative average expected vegetation structure on living prairie dog towns in the desert grassland can be described as dominated by grass and forbs, with a low cover of woody shrubs. The average structural ratio is 82.6 % grass, 11.5 % forb and 6.0 % woody shrub, based on 39 sampled sites. The comparison also indicates that the relative cover of grasses, forbs and woody shrubs on dogtowns provides a valid baseline measurement from which vegetation change can be measured in other tests. Significant differences from the baseline averages for relative cover of grass, forb and shrub on other known former prairie dog towns will be assumed to indicate vegetation change, even when the original vegetation is not known.

It appears that prairie dog towns were associated with the best vegetation for cattle on the JER, except possibly for biomass. Other important qualitative information can be gleaned from the study of the known living prairie dog towns on the JER. Topographically, the living colonies are located in and around the lowest areas in the bottom of a non-draining basin. They do not occur in areas of the JER with surface or subsurface layers of caliche. And they do not occur on the gravely bajadas on the east side of the Range.

Large prairie dog towns occurred near Middle Well and in other depressions and low-lying areas of the JER prior to cattle ranching in the area, according to the original field notes of the Cadastral Survey of 1857-58 (General Land Office, 1857). As discussed in Chapter 3, the first successful well dug on the Jornada del Muerto in 1870, was intentionally located on a prairie dog town about 30 miles to the north of the JER. Early settlers believed that prairie dog colonies were associated with shallow groundwater (Mearns, 1907:344). The first successful wells on the JER were dug in 1903 at the site of Middle Well, Headquarters, and at Red Lake (Havsted, 1997). Both Middle Well and Headquarters had substantial prairie dogs towns in 1917 (Quesenberry, 1917). Seven of the 17 mapped prairie dog towns on the JER in 1917 had a well or stock tank within its boundaries. It seems likely that several wells on the JER were placed on prairie dog towns and that other ranch structures like corrals, barns and ranch houses, were located nearby, leading to direct conflict between prairie dogs and people. It also seems likely that the Red Lake well was the site of a large prairie dog town poisoned out prior to the creation of the 1917 prairie dog maps.

The sites of the prairie dog colonies on the JER shows prairie dog colonies in locations with many environmental characteristics desirable to cattle ranchers: loamy soils with high moisture retention, low-lying areas that concentrate the scant rainfall from a large watershed, and near playa lakes that fill with water in the summer rains. Conflict between human use and wildlife was inevitable over this scarce resource niche.

Test 2: Test of Site-specific Vegetation Change 80 Years After Eradication

Pre-eradication and Post-eradication data from six prairie dog towns on the JER were compared to test the hypothesis that site-specific directional vegetation change has occurred on prairie dog towns during the 80 years since their eradication.

The largest (1917) mapped dogtowns on the JER were screened as possible sites for current vegetation studies. One site, #1, Firing Range, was eliminated since it had been mechanically cleared and re-seeded in experimental studies (Haavsted, personal communication, 1997). Another site, #8, Little Sandy, was eliminated because the lack of proximal landmarks made location of the colony boundaries too unreliable in the field. This left seven mapped colonies greater than 30 acres in size to be included in the study. All sites were poisoned in 1917-18, and there is no archival evidence of later re-colonization by black-tailed prairie dogs.

A single vegetation type was selected at random from among the described vegetation types within each mapped colony. A single study plot was then selected from within the mapped vegetation unit and colony boundary based on the presence of clearly identifiable fences, tanks and other landmarks indicated on the original maps to help orient the plot within only one unique original vegetation type. Study plot locations were then verified by using Trimble GPS and the JER Geographic Information System (GIS).

Each plot was sampled for vegetation structure using methods outlined in Chapter 2. Percent cover of grass and shrubs for both population samples were ranked and then compared. Single-tailed test for directional difference was used with a rigorous confidence level of 0.001, since this test is for the same sites and the original vegetation was well described. The results of Test 2 are summarized in Table 5.6.

The test results indicate significant within-site post-eradication change in vegetation structure in the form of decreasing grass cover and increased shrub

Table 5.6. Test 2-- Vegetation Structure on Living Versus Eradicated Prairie Dog Towns, After 80 Years.

SITE/ date	% Grass	Rank Grass	% Forbs	Rank Forbs	%Shrubs	Rank Shrubs
West Well 1997	10	12	3	9	87	1
Big Sandy 1997	29	11	23	1	47	4
Antelope Flat 1997	41	9	6	6	51	3
Middle Well 1997	54	8	0	12	46	5
Headquarters Tank 1997	38	10	7	5	55	2
Corner Tank 1997	65	7	2	10.5	33	6
Antelope Flat 1917	75	6	12	4	13	7
West Well 1917	80	4.5	18	2	2	11
Middle Well 1917	80	4.5	15	3	5	9
Big Sandy 1917	85	3	5	7.5	10	8
Corner Tank 1917	95	1.5	2	10.5	3	10
Headquarters Tank 1917	95	1.5	5	7.5	0	12
1917 Ui statistic (n= 6)	36		13.5		0	
1997 Ui statistic (n= 6)	0		22.5		36	
Critical Ui Statistic at p<0.001 = 0	Significant Difference Between populations		Same population		Significant Difference Between populations	

Source: JER, 1915 Vegetation Survey; Quesenberry, 1917; Author cover after 80 years since eradication. Forb cover is inconsistent and shows no significant difference in populations at $p < 0.001$ (99.9 %) significance.

Test 2 does not support the Weed Hypothesis as a long-term outcome, since forb cover did not change significantly after eradication. The results are also inconsistent with the Tall Grass Hypothesis, since grass cover decreased significantly in the long-term. Test 2 supports the Brush-clipping Hypothesis of Weltzin, *et al.* (1997a; 1997b) by showing significant woody shrub increases after eradication.

Test 3: Long-term Succession on Eradicated Prairie Dog Towns from Other Locations

While the results of Test 2 are very tight in terms of known boundaries and original vegetation, they are confined to only one geographic location and are inconclusive of landscape-level change. Additional eradicated sites from other locations must be tested for directional change in order to rule out the possibility that the changes in vegetation observed on the JER dogtowns is unique to this location.

The third test of the hypothesis of succession on eradicated prairie dog towns compares the vegetation structure on living prairie dog towns (historic and modern) with 10 sites that were eradicated between 55 and 80 years earlier, shown in Table 5.7. The level of significance for Test 3 is $p<0.01$ since the sites are widely separated in both time and space.

The former dogtowns are located on both the JER and other locations and no assumptions are made about the grazing history of sites or other factors. Sampling methods and statistical tests were the same as those described for Tests

Table 5.7 Test 3--Comparison of Vegetation Structure on Living Versus 58-80 Year Eradicated Prairie Dog Colonies.

SITE/ date	Age	% Grass	Rank Grass	% Shrubs	Rank Shrubs
0-Aged Class					
Antelope Flat	0	75	12	13	10
West Well	0	80	8.5	2	16
Middle Well	0	80	8.5	5	14
Big Sandy	0	85	7	10	11.5
Corner Tank	0	95	4.5	3	15
Headquarter	0	95	4.5	0	19
Otero Horse Camp	0	72	14	0	19
McDonald	0	97	3	0	19
San Francisco	0	98	1.5	0	19
58-80-Year Aged Class					
Ladder	58	78	10	6	13
GW	58	71	15	23	8
Boss Ranch	63	98	1.5	0	19
Stewart Well	63	62	17	38	6
Deep Well	69	89	6	10	11.5
Miller Ranch	77	76	11	21	9
West Well	80	10	21	87	1
Big Sandy	80	29	19	47	4
Antelope Flat	80	41	19	51	3
Middle Well	80	54	18	46	5
Headquarters Tank	80	38	20	55	2
Corner Tank	80	65	16	33	7
Living Colony Ui statistic (n =9)			89.5		10.5
Extinct Colony Ui statistic (n=12)			12.5		97.5
Critical Ui Statistic at p<0.01 = 16			Significant difference between populations		

Source: JER, 1915 Vegetation Survey; Quesenberry, 1917; Author.

1 and 2, except that the Buenos Aires site is removed from the test since its exceptionally high forb cover may give spurious results in grass cover. The selected level of significance is lower in the face of the divergent environmental factors that may affect sites so distant from one another.

The site age is the approximate number of years between the time it was last occupied by prairie dogs and the date the vegetation was sampled. If the eradication date is only known within a range of years, the median age is given. Relative forb cover was shown in Tests 1and 2 to be an unreliable characteristic of prairie dog town vegetation and unrelated to any observed directional change after eradication, therefore, only grass and shrub cover were tested statistically.

Test 3 shows significant differences at $p<0.01$ (99 % probability) between vegetation structure on living dogtowns and those eradicated 55 to 80 years earlier. The observed differences in vegetation shows a directional increase in shrub cover, and decrease in grass cover with years since eradication. The results of Test 2 and 3 confirm a pattern of long-term succession on eradicated dogtowns and further suggest the plausibility of the Brush-clipping Hypothesis as an explanatory model. The test verifies that the pattern of long-term succession observed in Test 2 on eradicated prairie dog towns has also occurred in widely dispersed sites across the study area.

Test 4: Test of Short-term Succession on Eradicated Prairie Dog Towns

The Brush-clipping Hypothesis of Weltzin *et al.* states that woody species are kept in control on living prairie dog towns by the active clipping-down of woody seedlings as they begin to grow. A fairly rapid increase in woody species is expected under this hypothesis, certainly within 20 years (Weltzin et al., 1997b). The hypothesis of short-term succession is tested by comparing 0-aged colony vegetation structure with that on five dogtowns eradicated between 22 and 35 years earlier, as shown in Table 5.8.

Table 5.8. Test 4--Comparison of Living Versus 20-35 Year Eradicated Prairie Dog Towns.

SITE/ date	Age	% Grass	Rank Grass	% Shrubs	Rank Shrubs
1917 0-Aged Class					
Antelope Flat	0	75	11	13	2
West Well	0	80	9.5	2	7
Middle Well	0	80	9.5	5	4
Big Sandy	0	85	8	10	3
Corner Tank	0	95	5.5	3	5.5
Headquarter	0	95	5.5	0	12
1996-97 0-Aged Class					
Mesa Horse Camp	0	72	12	0	12
McDonald	0	97	4	0	12
San Francisco	0	98	3	0	12
23-35-Year Class					
Rhoades Draw	23	70	13	30	1
Summit	23	99	1.5	1	8
Salt Creek Draw	22	99	1.5	0.5	9
San Luis Draw	35	65	14	3	5.5
Lava Tank	35	86	7	0	12
Living Colony Ui Statistic (n = 9)			22		23.5
Extinct Colony Ui Statistic (n = 5)			23		21.5
Critical Ui at p<0.01 = 5			No difference between populations		

Score: JER, 1915 Vegetation Survey; Quesenberry, 1917; Author.

The test uses the Mann-Whitney U-Test with significance set at $p < 0.01$. Test 4 assumes that any significant differences between young eradicated colony vegetation and vegetation structure on living colonies are the result of the same processes of succession that caused the long-term change in vegetation structure observed on old eradicated colonies in Tests 2 and 3.

No significant differences were found between the vegetation structure on living colonies and that of colonies eradicated between 22 and 35 years earlier at 99 % probability. The results of Test 4 show that the process of vegetation change on eradicated dogtowns is not a short-term process such as that suggested by the Brush-clipping Hypothesis. The results suggest that the removal of the above-ground activity of prairie dogs (grazing and/or brush-clipping) is not the cause of the observed long-term change shown in Tests 2 and 3.

Test 4 does not support any of the suggested causes of vegetation change, but it may explain how ranchers and range managers might have been unaware of any negative effect from prairie dog removal, since the grass cover remains high on all the young eradicated sites.

Test 5: Comparison of Qualitative and Quantitative Data Related to Prairie Dog Succession

The statistical tests have so far shown that succession is taking place on eradicated prairie dog towns in the desert grasslands. The tests also demonstrate that succession results in a shift from grass dominance to shrub dominance in the long-term, but not in the short-term. The combined test results are not consistent with any current hypothesis of prairie dog succession.

A comparison between the qualitative and quantitative data is made in order to better understand the ecological processes taking place on eradicated prairie dog towns and to develop an explanatory model of the test results. eradicated sites. Sites on the JER appear to be in late stages of the processes of ecological succession. Therefore, data from the JER have been excluded from this analysis in order to focus on sites that are in earlier stages of succession. The analysis compares data on terrain, erosion, the condition of any remaining burrow features, soil texture, and vegetation structure. I have added additional descriptive information on the degree of weathering on collapsed burrow features in order to estimate the amount of time since the collapses occurred.

Table 5.9 combines data from five young eradicated colonies in different locations. Two sites among the young eradicated colonies, Salt Playa and Rhoades Draw, demonstrate that burrow decay, weathering and erosion processes affect sites differently. The two sites are within 30 miles of one another in the harsh environment on terraces around the Pleistocene bed of Lake Lucero in WSMR, with soils unusually high in gypsum. According to WSMR biological records, both sites were last occupied during the early 1970s. The grazing history is similar between the two sites, but the Rhoades Draw site occurs on a sloping swale leading from the San Andres Mountains to the lake bed. Salt Creek Playa is located out in the Tularosa Basin, away from the mountain slopes, and is flat by comparison.

Table 5.9. Comparison of Qualitative and Quantitative Data on Young (23-35 Years) Eradicated Prairie Dog Towns

Ref. #/ Colony Name	Age	Terrain/ slope	Erosion Features	Burrow Features	Weathering of Collapsed Burrow	Grass : Shrub Ratio	Soil Texture
10. Salt Playa	23	Terrace and swale, 0-1% slope	Sheet erosion, rills 10-18 in.	Intact burrow system, no collapses	Lightly weathered mounds and burrows	99: 0.5	Sandy loam
11. Rhoades Draw	23	Draw and *bajada*, 3-4% slope	Blow-outs, sheet erosion, deep gully erosion, 12-15 feet deep	Collapsed burrow entrances (18 in. X 3 ft.), tunnel blow-outs into gully	Weathered collapse features, no mounds	70: 30	Silty clay
46. Summit	23	Broad plain and *playa*, flat	Rills and sheet erosion	Collapsed burrow entrances (18 in. X 3 ft.)	Recent collapse features, mounds weathered away	99: 1	Clay loam
43. San Luis Draw	35	Alluvial toeslope, 1-2% slope	Gully, 3 ft. deep, sheet erosion	Collapsed burrow entrances and linear tunnel features (18 in. X 3 ft.)	Old and weathered collapse features, overgrown	65: 3	Clay
1. Lava Tank	35	Broad alluvial toeslope, flat	Rills, 8-10 in. , sheet erosion pans	Collapsed burrow entrances, linear tunnel collapses (18 in. X 2- 6 ft.)	Weathered collapse features, partly overgrown	86: 0	Clay

Source: Author

The most significant difference between the two sites is the deep, multi-branched gully that cuts through the former prairie dog town at Rhoades Draw. It is over 100 feet wide and 15 feet deep at its maximum. The arroyo began to form in the mid 1970s and continues to erode away the burrows in the main portion of the former colony site. Many badly eroded prairie dog burrows are still visible at the site along the up-hill and southern margins of the gully network. The original mounds around burrow entrances are completely obliterated, but water-worn burrow holes are visible that lead to wide blow-outs on the uphill side of the arroyo.

Burrows not immediately connected to the arroyo exhibit collapsed entrance chambers at the ground surface, approximately 12-24 inches deep and 2-3 feet across. These create a broken terrain with young shrubs growing in the collapsed burrow entrances and sometimes between the collapsed burrows. Grass amounts to 70% of the vegetation at the site and woody shrubs amount to 30% of the vegetation cover, even though it is one of the youngest eradicated colonies. Many shrubs are young and still small, so that their relative percentage will likely increase over the next decade.

By contrast, few signs of erosion were found on the Salt Creek Playa site. This flatter, less eroded site, with intact entrance mounds and burrows and little erosion taking place, has very high relative grass cover and very low shrub cover.

Since the young eradicated colonies as a group do no show significant differences in vegetation structure compared with living colonies, the process of vegetation change is assumed to just be beginning. Woody species, when found on sites were observed, but were at the seedling or young sapling stage.

Table 5.10 shows five old eradicated prairie dog colonies from different locations. One old site was found with very recently collapsed burrows and little erosion and a similar pattern of high grass cover. The colony on the Boss Ranch in Cochise County is known to have been poisoned in the early 1930s. It is on a slight slope and covered with dense Galleta grass (*Pleuraphis jamesii*). Very recent burrow collapses were observed on the site. The owners had never seen them before, and they were in the process of forming the summer that I conducted field studies on the site.

These collapsed areas were increasing in size and opened into subsurface burrows, allowing run-off from the summer rains to flow downward into the tunnel system. Large patches of grass were being uprooted by the subsequent erosion. The vegetation structure at the site showed 98% grass cover, very high compared to other sites of the same age.

The evidence from the comparison of complete site data indicates that burrow erosion-and-decay processes may be a compounding factor in the process of vegetation change after eradication. The weathering and erosion of the burrow system, being linked with edaphic conditions of the site, such as slope, soil and local rainfall amounts and intensity, may be producing variable rates of vegetation change over time.

Table 5.10. Comparison of Qualitative and Quantitative Data on Old (58-69 Years) Eradicated Prairie Dog Towns

Ref. #/ Colony Name	Age	Terrain/ slope	Erosion Features	Burrow Features	Weathering of Collapsed Burrow	Grass : Shrub Ratio	Soil Texture
41. George Wright	58	*Bajada*, 3-4% slope	Rills, 1ft. deep, sheet erosion	Collapsed linear tunnel features, entrances (18 in. X 2-3 ft.)	Old and weathered collapse features, overgrown	71: 23	Clay loam
15. Ladder	58	Shallow swale, 0-1% slope	Blowouts, discontinuous arroyos, 1-2 ft.	Collapsed burrows and linear tunnel features (18 in. X 4 ft.)	Old and weathered collapse features, overgrown	78: 16	NA
50. Boss Ranch	63	Bajada and swale, 2-3% slope	Rills and sheet erosion	Collapsed burrow entrances, some linear tunnel features (18 in. X 2-4 ft.)	Very recent collapses, mounds weathered away.	98: 0	Silty clay loam
33. Stewart Well	63	Terrace and *playa*, 0-3% slope	Rills, gullies 1 ft. deep and sheet erosion	Old collapsed linear tunnel features, entrances (18 in. X 3-6 ft.)	Old and weathered collapse features, overgrown	62: 38	Clay
6. Deep Well	69	Broad plain, flat	Rills, sheet erosion	Old collapsed burrow network (18 in.-3 ft. X 20 ft.)	Old and weathered collapse features, overgrown	89: 10	Clay

Source: Author

The timing and duration of these physical processes on the prairie dog town may be fore-shortened at any time by the occurrence of severe erosion on the colony site. Catastrophic erosion is frequently observed on empty prairie dog towns and therefore may play a significant role in the rate of succession. There are gullies present on 23 of the 57 eradicated prairie dog towns shown in Table 5.1, but no significant gullies present on the 5 living colonies observed.

The underlying cause of the erosion may be off-site human impacts in all these cases, either from timber-cutting, overgrazing, land disturbances from mining or plow agriculture in the upstream watershed or from downstream flow increases with subsequent head-cutting. But the presence of a prairie dog colony seems to broaden and deepen the erosion in a dendritic pattern as the burrows become conduits for the flow of water, and the resulting overburden collapses into the growing gully. Discontinuous gullies may be formed when tunnel systems become saturated and "blow-out" at the surface at a point downslope.

Some important trends can be seen when vegetative cover is viewed side-by-side with the qualitative data:

1. All ten eradicated dogtowns in this comparison have grass cover greater then 50%, regardless of age, erosion or stage of burrow decay.
2. The presence of gully erosion and collapsed burrows is associated with lower grass cover, regardless of the age of the eradicated site.
3. Uncollapsed burrow systems have the highest grass cover and lowest shrub cover, regardless of the age of the eradicated site.

An overall pattern of succession on eradicated prairie dog towns is confirmed by the study. Succession occurs slowly on most sites and may be triggered by burrow collapse and accelerated by catastrophic erosion. Eradicated colonies maintain relatively high grass cover for decades after eradication, usually long after residents have forgotten the earlier presence of prairie dogs on the site.

Chapter 6: Conclusions

THE CASE OF THE ARIZONA BLACK-TAILED PRAIRIE DOG AS ENVIRONMENTAL-HISTORICAL GEOGRAPHY

The eradication history of the Arizona black-tailed prairie dog has taken place against the backdrop of American settlement and adaptation to a new land. Environmental-historical geography has often considered the role of perception and agency in the transformation of newly settled environments (Dilsaver and Colten, 1993). In many respects this work is a continuation of a tradition of studies documenting the multitude of unintended landscape transformations brought about by Europeans in their settlement of North America. The environmental legacy of deforestation, erosion and siltation, soil depletion, improper irrigation, disease introductions, pesticide use and the introduction of exotic plants and animals have each been examined historically (Bahre, 1991; Turner *et al*, 1990; Goudie, 1986; Worster, 1979; Meinig, 1968; Crosby, 1972).

Like other studies of environmental history, this study shows that the forces of human agency were intentional and promulgated as utilitarian resource management, but proved to be neither. As in the case of pesticide impacts on wildlife, the case of the Arizona black-tailed prairie dog demonstrates that ecological consequences may be temporally separated from the human actions that produce them, and may be felt in entirely unexpected ways.

This study is unique in combining the methods of historical geography with those of ecology to uncover an important ecological interaction that would have otherwise remained invisible. Other studies in the tradition of environmental-historical geography have examined the nature of perception, public policy and human impact on wildlife populations in the United States (Hardin, 1992; Mighetto, 1991; Dunlap, 1988; Doughty, 1983). Such examples have relied on the methods of history alone to reveal the magnitude of our impact on other species. This study goes beyond the historical documentation of species loss to ask the question: what difference does it make ecologically if this animal is gone?

The case of the Arizona black-tailed prairie dog affirms the importance of utilizing a wide variety of historical sources in developing a full picture of the environmental past in a region. Textual and non-textual sources, as well as scientific and non-scientific sources were necessary to establish sufficient verifiable environmental data for ecological testing. The study shows that the historical-environmental resources available in the archives of federal agencies and institutions are a valuable and largely untapped source of information for regional studies.

CONSERVATION

Prairie Dog Control Programs Caused Extirpation

The study of the history and consequence of eradication of a keystone species gives new insight to conservation issues related to extirpation of species by a public institution. The first lesson to be gained from this case study is that it takes considerable resources to extirpate a species with a robust reproductive rate and generalized habitat requirements. Millions of dollars in public funds have been expended over nearly a century with the goal of eliminating the prairie dog pest.

The study shows that prairie dog eradication programs were very successful in all parts of the range of black-tailed prairie dogs and could have resulted in the extinction of all black-tailed prairie dogs on the desert grasslands of Arizona, New Mexico and Texas if full public funding had continued.

This research shows that the original mandate of the BBS rodent control programs in Arizona and New Mexico were based on the goal of complete eradication of prairie dogs. This goal was based on the premise that prairie dogs reduce the grasses available for cattle. During BBS management of the federally-subsidized rodent control programs, from 1915 through 1938, most of their efforts were directed towards the goal of complete extermination of prairie dogs rather than other pest species. Under BBS management, the Arizona black-tailed prairie dog was virtually extirpated from Arizona, with the exception of remnant colony of only a few animals in the Peloncillo Mountains. During this time the animals were still numerous in parts of southern New Mexico, but had been eliminated from Doña Ana County.

Transfer of federal rodent control programs in 1939 from the BBS in USDA to PARC in the Department of Interior did not change the function and mandate of prairie dog eradication. Both agencies kept detailed statistics on the number of acres poisoned each year and were well aware of the extent of population reductions. In the years that followed, PARC demonstrated the same goal of total elimination of prairie dogs. The agency continued to devote most of its funding to prairie dog eradication, despite dwindling prairie dog populations in most areas and the presence of other rodent pests.

Prairie dog population inventories conducted by the rodent control agencies in 1921, 1961 and 1971 indicate that federal agencies were well aware of the severely diminished numbers of all prairie dogs, and the near extirpation of the Arizona sub-species from the state of New Mexico after its final demise in Arizona. Impacts on the Arizona back-tailed prairie dog from government-sponsored poisoning programs in Arizona and New Mexico were transparent and similar impacts were occurring in other states.

The Arizona black-tailed prairie dog is the only case in the range of prairie dogs in the United States where total extermination was nearly achieved. This sub-species may have been ecologically more vulnerable than prairie dogs on the Great Plains by virtue of their concentration in basins and valleys that were widely separated by unsuitable habitat. This gave an advantage in the implementation of rodent poisoning operations more effectively in the desert grasslands. Had the poisoning of prairie dogs been left to individual resources and initiative, the population of Arizona black-tailed prairie dogs in southern Arizona and New Mexico would probably be similar to that of Chihuahua: reduced but still viable in several localities.

Using BBS statistics, I have estimated the population of Arizona black-tailed prairie dogs to have occupied approximately 6 million acres in Arizona and New Mexico in 1916. Additional populations of the sub-species also occurred in west Texas. By 1961, rodent control programs had poisoned all colonies of the animals in the study area at least once, and *arizonensis* had been reduced to 4,830 acres, 0.8% of the original population. The 1971-74 population inventory for *arizonensis* indicated that between 85 and 2,000 acres remained. Comprehensive inventories of Arizona black-tailed prairie dogs have not been conducted since that time.

This study demonstrates that the philosophy of total extermination of prairie dogs has always guided prairie dog policy, regardless of the most fundamental principles of genetic, ecological and species conservation. The prairie dog has declined in New Mexico as a direct result of government-sponsored "rodent control" programs, not plague, sport hunting or habitat destruction.

Federal Agencies Forced Participation in Prairie Dog Eradication Programs

A second significant finding of this study regarding conservation is that from the inception of rodent control programs, the BBS and PARC openly used political power and funding to coerce participation in their programs. They accomplished this by using propaganda campaigns and political lobbying to manipulate public opinion, discrediting non-cooperative land owners, passing legislation coercing landowner participation, and politically blocking initiatives to stop their funding and protect prairie dogs.

The historical study show that Arizona black-tailed prairie dogs were considered friendly companions by immigrants, bringing a measure of entertainment and interest to early settlers in the Southwest. It was only after 1870s, when settled agriculture and cattle ranching developed in the region, that the animals began to be considered a pest species.

Prairie dogs occupied the same areas that were favored by American settlers: the fertile river valleys and the broad internally-draining basins of the Southwest. Conflict between settlers and prairie dogs over the best agricultural lands was probably inevitable. Private initiatives for prairie dog control greatly reduced prairie dog populations in many settled areas before organized government programs began in 1916. These areas include the Babocomari, San Pedro, Upper San Simon, Middle Gila, and Mangas/Duck Creek floodplains.

But prairie dog colonies also occurred on rangelands that were far from the fertile agricultural valleys and other centers of human settlement. Apparently there was little public interest in spending money to eliminate these colonies, because from 1901, the BBS employed sophisticated propaganda campaigns to "educate" ranchers about the importance eliminating prairie dogs, and intensely lobbied the state governments to impose mandatory rodent control laws.

According to BBS records, many ranchers opposed poisoning, either because they did not believe it worth the expense, because they were concerned about the effects of widespread poison application, or, in the case of Native Americans, because prairie dogs were considered a valuable food. The BBS reports that 20% of the land owners in New Mexico refused to support government-sponsored prairie dog poisoning in 1918.

The cooperative agreements between the BBS and Arizona and New Mexico in 1918 included the important post of publicity manager to continue propaganda campaigns. Anti-German slogans were featured in the publicity for prairie dog poisoning for many years. The BBS labeled all opinions counter to their program of complete eradication as "non-cooperative" and secured legislation requiring mandatory poisoning on private lands in Arizona and New Mexico. There is evidence that landowners were coerced or tricked into poisoning prairie dogs, even during the New Deal.

The war on prairie dogs required constant publicity and active federal involvement to sustain it. Indian Reservations, particularly Navajo and Apache, were very resistant to poisoning and succeeded in keeping programs out of many areas until after 1961. Opposition to poisoning may have been high in parts of the study area, particularly Grant, Hidalgo, Luna, Otero and Sierra counties, New Mexico. Large portions of these counties were not poisoned until after 1937.

Rodent Control Agencies Avoided Public and Scientific Accountability

The BBS and PARC had forged strong relationships with the cattlemen's and woolgrower's associations of each state, organizations that dominated state politics. Together, they lobbied for increasing federal subsidies for livestock owners and increasing predator and rodent control budgets each year. The scientific community, however, first began to voice concerns over the effects of widespread poisoning in the 1930s.

The American Society of Mammalogists condemned the BBS in 1931 for its role in exterminating wildlife and scientists testified before Congress regarding the excesses of the Bureau. Since 1923, the BBS had been openly claiming complete extermination of the Arizona black-tailed prairie dog. Reports appeared in the scientific journals that federal poisoning programs had nearly eliminated the Arizona black-tailed prairie dog in the United States. The case of the Arizona black-tailed prairie dog was important evidence of the potential effect of systematic rodent poisoning on wildlife.

The BBS was able to use their power and funding to rally the support of the powerful ranching interests before Congress and secure huge budgets for continued wildlife eradication. Another wave of opposition to eradication programs developed in the 1960s from the ranks of scientific organizations like the American Society of Mammalogists and several emerging conservation organizations. Congress again conceded to the powerful livestock interests that supported eradication and continued program funding. At no time did the BBS make their detailed records of prairie dog eradication available to the scientific community, although their annual reports estimated the number of acres of prairie dogs remaining in each county of each state. A comprehensive survey of prairie dog populations was not conducted by the agency until 1961.

Failure of PARC to publish the results of the 1961 prairie dog inventory in the public record demonstrates a failure of the public trust. Even more so, it shows that the agency had permanently divorced itself from the scientific tradition from which all natural resource programs draw their validity. Lack of institutional action after the 1961 inventory also shows that the mandate of total eradication of prairie dogs was held at the highest levels in the USFWS and continued to guide prairie dog policy into the late 20th century.

The New Mexico prairie dog inventory of 1971, and the following year's activities within PARC demonstrate a similar pattern of withholding and manipulating the release of scientific information unfavorable to their objectives.

ECOLOGICAL CONCLUSIONS AND IMPLICATIONS

Historic Distribution of Arizona Black-tailed Prairie Dogs on the Desert Grasslands

Arizona black-tailed prairie dogs clearly predate permanent livestock herds in the study area. Major areas of original occupation in New Mexico were the Jornada del Muerto, the Animas, Playas, and Hachita valleys, and tributaries of the Gila in the vicinity of Silver City and Cliff, most notably Duck and Mangas creeks. In Arizona, the animals were common in the San Pedro, Sulphur Springs and San Simon valleys.

Prairie dogs did not occur randomly in the landscape, but were present in low-lying alluvial basins and river terraces, swales and draws where soils are deep and with large watersheds to collect the limited rainfall of the semi-arid region. Arizona black-tailed prairie dog colonies historically occupied only a small proportion of the land in the study area: approximately 687,000 acres (7%) of southeastern Arizona and 5,360,000 acres (10%) of southwestern New Mexico. Data from the BBS 1921 inventory and map of New Mexico prairie dog colonies shows that the study area had the lightest prairie dog occupation rate in the state.

The last record confirmed record I was able to find for Arizona black-tailed prairie dogs in Arizona was from 1960. The last confirmed record of Arizona black-tailed prairie dogs in southwestern New Mexico came from 1972 in Hidalgo County and on WSMR. A few colonies of black-tailed prairie dogs persist today in isolated areas of Otero and Lincoln counties, on sites recolonized after being poisoned in the 1970s by PARC. These occupy approximately 750 acres.

Major centers for Arizona black-tailed prairie dogs in Mexico include the area around Sierra en Medio, large colonies around Casa de Janos and Monte Verde (Llano Carretas). These colonies were reported to occupy approximately 55,000 hectares (103,905 acres) in 1991 (Ceballos *et al.*, 1993). In the past, the animals also occurred in large colonies in the agricultural areas around Casas Grandes and possibly in small colonies on the plains around Samalayuca.

Prairie Dog Succession in the Desert Grassland Ecosystem

I conducted studies of ecological succession on eradicated prairie dog colonies. These studies consisted of qualitative and quantitative data gathered from over 61 living and eradicated Arizona black-tailed prairie dog towns in the study area. These sites were located using historical records of the location and eradication history of prairie dogs in the study area.

Qualitative data were gathered for the 61 sites. These data indicate that many former colony locations have been greatly affected by erosion. Comparisons with living prairie dog towns shows that similar erosion patterns do not occur where a colony is active. Most eradicated sites also evidenced some degree of burrow decay and/or collapse related to the weathering and erosion of subsurface voids. These observations of distinctive erosional processes on former colonies is believed to be a significant consequence of eradication, contributing to further ecological change.

I obtained historic data on the original vegetation associated with living prairie dog towns in 1917 from archival records of the JER. Historic vegetation data from the entire JER was available, as well. Prairie dog colonies on the JER were associated with 35 different vegetation types of the total of 260 types identified on the JER. Vegetation on prairie dog colonies showed an unweighted average of approximately 81% grass, 15% forbs and 5% woody shrubs, significantly different from the average structure found overall on the JER.

I tested the hypothesis of vegetation change on 21 of the 61 prairie dog towns sites identified in the study. Tests were conducted to determine if current conditions are comparable to past conditions on living dogtowns, if succession has occurred on eradicated colonies, and to test different hypotheses of vegetation change on eradicated prairie dog towns. A summary of the test results is shown in Table 6.1.

Test 1 shows that living colonies are associated with the same vegetation structure today as they were in the past. Living prairie dog colonies are shown to be predominantly grass and have a low percentage of woody shrubs, even when surrounded by vegetation high in shrub species. This statistical test is constrained by the small number of living colonies available in the United States today. Although the sites were few in this test, the results are confirmed by numerous previous descriptions and floristic studies of living black-tailed prairie dog colonies that show that active colonies have little or no woody shrub vegetation (Mearns, 1907; Bailey, 1932; Whicker and Detling, 1988; Weltzin *et al.*, 1997a, 1997b).

This similarity of vegetation structure on living colonies across time and space suggests that other causal factors (e.g. climate change, fire suppression, cattle grazing and cattle seed dispersal) are not interfering with prairie dog effects on active colonies. The test also shows the reliability of vegetation structure as an ecological baseline against which post-eradication change can be measured.

Table 6.1 Summary of Statistical Tests

Test #	Test Category Y (n)	Test Category X (n)	Test Result
1	1917 Living Colonies (18)	1997 Living Colonies (4)	Ui= 12 (Not Significant at p< 0.01) Past and present living colonies associated with high grass cover, low shrub cover.
2	JER 1917 Living colonies (6)	JER Colonies 80 years after eradication (6)	Ui= 0 (Significant at p<0.001) Directional long-term change occurs within the same sites after eradication
3	Past and present living colonies (9)	Colonies 58-80 years after eradication (9)	Ui=10.5 (Significant at p<0.01) Directional long-term change occurs on different sites after eradication.
4	Past and present living colonies (9)	Colonies 23-35 years after eradication (5)	Ui=21.5 (Not Significant at p< 0.01) No significant change occurs on colonies within 35 years after eradication.

Test 2 shows, in contrast, that prairie dog towns poisoned 80 years ago have experienced significant vegetation change, from grass dominance toward shrub dominance. This test is based on detailed maps of the exact boundaries of prairie dog towns and vegetation types on the JER in 1917. Test 3 demonstrates that directional change in vegetation structure has occurred on a variety of different sites poisoned between 58 and 80 years earlier. Together, Tests 2 and 3 evaluate the theory of long-term vegetation change on a total of 12 different eradicated sites, providing evidence that long-term vegetation change is occurring. These tests support the Brush-clipping Hypothesis as the process of prairie dog succession. In the long-term, grass cover decreased significantly, shrub cover increased, while forb cover did not significantly change.

Test 4 is a direct test of the short-term succession hypothesized by Weltzin *et. al.* (1997a; 1997b) in the Brush-clipping Hypothesis. The test shows that the process of vegetation change is slow acting, taking more than 35 years. This result contradicts the Brush-clipping Hypothesis, which postulates that removal of prairie dog grazing and clipping effects is the ultimate cause of succession.

While this study expands the research on vegetation change on single prairie dog colonies conducted by Weltzin and others (1990, 1997a and b), the statistical tests are constrained by small sample size, limited time interval data and lack of precise dates of eradication for some sites. A high degree of confidence can be placed on the results of tests for long-term vegetation change presented in this study because of the detailed historical data available on the JER and larger sample size. These data were not fully tapped in this study, however, since only six out of 35 possible dogtown vegetation types were sampled for long-term change.

Far greater discriminatory power could have been achieved, for example, with a complete time series of eradicated sites from within each of two limited geographic areas, providing opportunities for both correlational and comparative studies. In addition, a larger sample of colonies eradicated since 1960 would have allowed a more discriminating statistical analysis to examine the factors influencing vegetation on eradicated colonies in the short-term. Unfortunately, very few colonies remained in the United States portion of the study area after 1960 and PARC did not maintain records of their locations or eradication dates.

Review of descriptive information on the eradicated colony sites along with the data on vegetation structure showed that the pattern of succession on prairie dog towns might be controlled by physical rather than biological processes. The two related processes observed on most of the eradicated colonies, erosion and burrow decay, are shown to be acting as a trigger to the biological process of vegetation change. These specific observations, coupled with the large number of eroded sites found in the initial site visits and the literature review, lead me to advance a new model to explain the observed pattern of succession.

The Burrow-decay Model of Prairie Dog Succession

I suggest that post-eradication vegetative succession is caused by the loss of the ground-modifying activities of prairie dogs: both mound-building and below-ground burrow maintenance. I call this the Burrow-Decay Model. In this model, succession after prairie dog removal is not related to the age of a site in a linear manner, but is a process triggered by the physical degradation and collapse of the burrow network and accelerated by specific erosion on the site, particularly gully erosion.

The Burrow-decay Model is depicted schematically in Figure 6.1 and Figure 6.2. The model postulates that an active prairie dog colony is a highly modified environment that acts as a depositional sink for silt from the constant supply of subsurface soils being carried to the surface during burrow maintenance and mound-building, and from storm run-off through the site.

Figure 6.1 A depicts a complex burrow typical of the black-tailed prairie dog (adapted from Hoogland, 1995). Mound building prevents water from entering the burrows and flooding the nesting chambers (Hoogland, 1995: 31; Costello, 1970), but also slows run-off across the colony surface, increasing the deposition of silt and water infiltration on the colony. What is created over time is a subsurface honeycombed with tunnels with an overburden of loose soil, frequently high in erodable silt.

Black-tailed prairie dog burrows usually have one or two entrance chambers within one meter of the surface, and sometimes have a connector tunnel to a second, or even a third entrance some distance away. The connector tunnels are also near the surface. Burrows are reported to between 5 and 33 meters in length, two to three meters deep, and from ten to 30 centimeters in diameter at the entrance.

After eradication, the extinct burrow no longer receives the continual maintenance required to keep the structural modifications in place, and the burrow decay process begins, as shown in Figure 6.1 B. The first step in burrow decay is the erosion and disappearance of the mound around the burrow entrance. This allows run-off to enter the burrows, rather than flowing across the colony. Silt is carried by run-off into the burrows and water pools in the underground nesting chambers. This stage can be accelerated by the practice of killing prairie dogs by manually digging down their mounds and flooding the burrow system. Silt fills the deeper levels of the burrow complex, eventually plugging it up.

Figure 6.1. The Burrow-decay Model, Stages A and B.
A. Living Burrow System (adapted from Hoogland, 1995:27); B. Extinct Burrow System

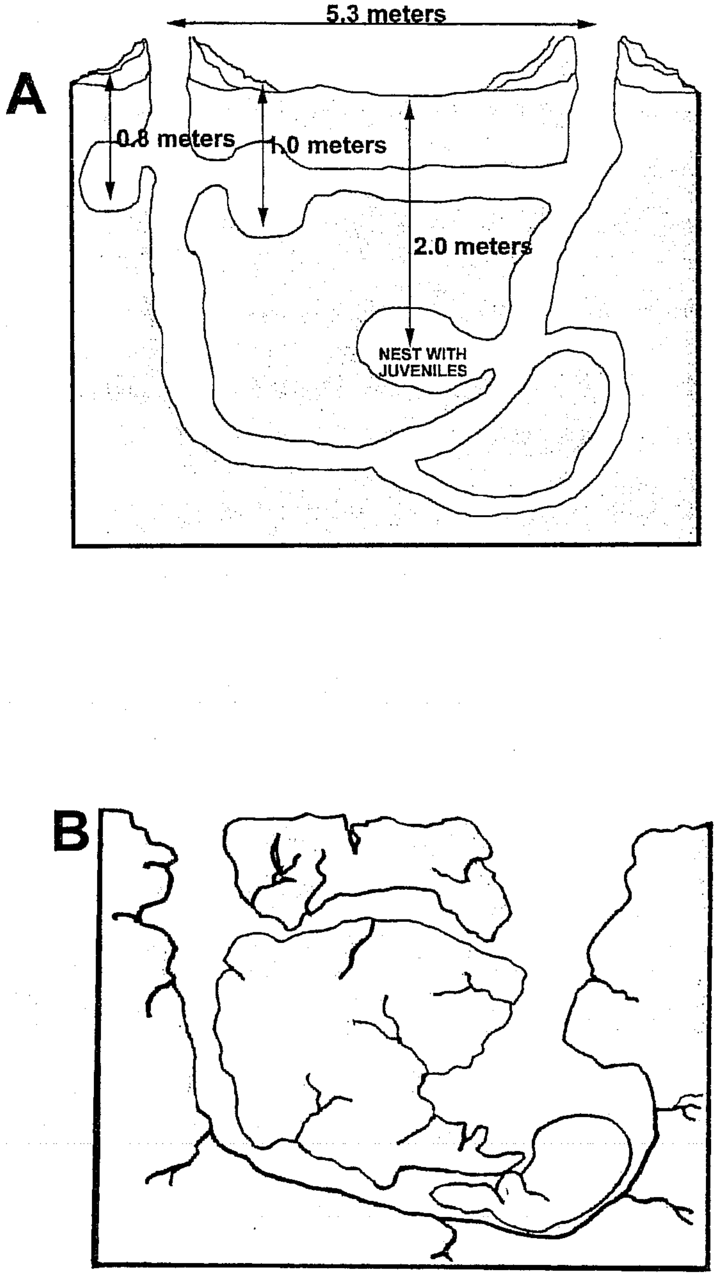
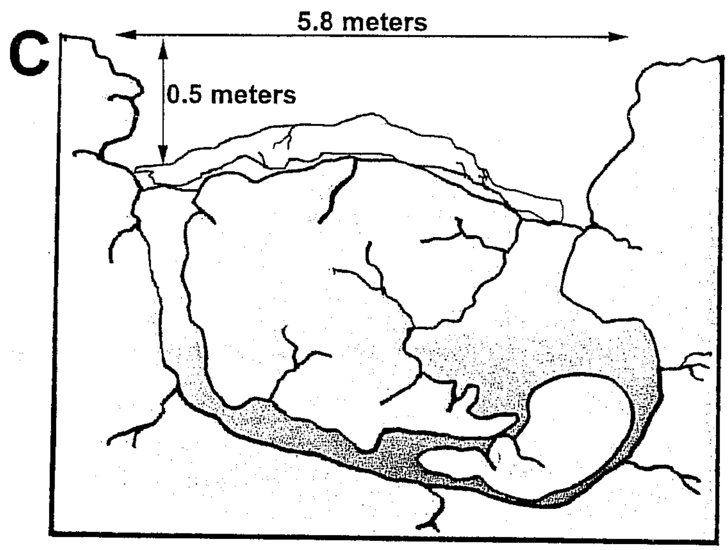


Figure 6.2. The Burrow Decay Model, Stages C and D.
C. Burrow In-fill and Collapse; D. Microterrain Development and Succession



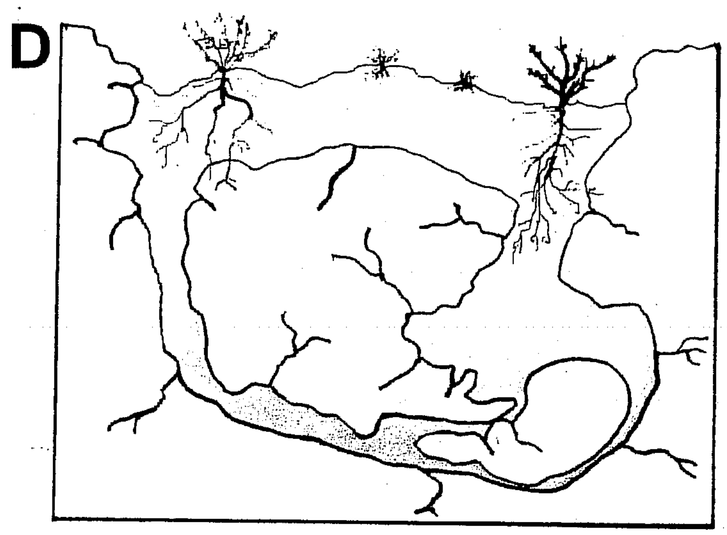


Figure 6.2 C depicts the phase of burrow in-fill and collapse. During a ground-saturating rain, the connector tunnels and entrance chambers collapse from the weight of the overburden.. This process is variable in time and site-specific since it is dependent on slope, soil type and rainfall. It may also be affected by the presence of cattle. Burrow collapses may be linear if the connector tunnels collapse, or circular or dumb-bell shaped if chambers cave in. At this stage, the lower tunnels are at risk of filling with run-off and acting as pipes or conduits that "blow-out" at the end of the tunnel

In the semi-desert environment of the study area, the process is normally slow and uneven from site to site. One "gully-washer" can occur within a few years of the death of a colony, such as at Rhoades Draw, and greatly accelerate the burrow decay process as well as the underlying hydrology of a site. On other sites, it may take 50 years or more before burrows begin to collapse.

The collapsed burrows act as a trigger for vegetation change in that they alter the nutrient profile and surface micro-terrain. Collapsed burrows create varied micro-habitats where water can flow and pool after rains, rather than penetrating the soil evenly across uniform surface, as shown in Figure 6.2 D. The collapsed burrows become depositional sinks for incoming silt and nutrients, rather than between-burrow areas. The collapsed microterrain may also shelter seedlings from the sun and wind and favor the germination of a different suite of grasses and woody shrubs than occurred on the original site.

The between-burrow spaces of the newly formed microterrain become drier and more susceptible to wind and water erosion and less favorable to the original grass, as moisture and nutrients are increasingly diverted into the collapsed burrows. Over time, collapsed burrows become completely filled with sediment and shrubs and clumps of grass that are surrounded by areas of bare, deflated soil.

Burrow collapse and blow-outs may not occur at all if the soils are high in clay or if the site is at the bottom of a *playa*. In these cases, burrows continue to fill with silt until the surface is level. These areas are gradually colonized by woody shrubs, as well, judging from sites on the JER and other locations.

In addition to being influenced by rainfall, slope and soils on each site, the burrow decay process may be greatly accelerated by catastrophic erosion events, particularly when prairie dog tunnels act as conduit for run-off, causing piping and blowouts that release into a downstream gully. The heavy use of the empty and eroding colony site by cattle during the rainy season could also accelerate the process of burrow decay by trampling down the collapsing tunnels to form trenches where connector tunnels once existed.

The Burrow-decay Model explains the observations of uneven timing and the generally slow rate of vegetation change observed in this study. Sites where burrow collapse has not yet begun or is just beginning would be ideal locations to test this model.

Implications of Prairie Dog Succession

It is important to distinguish between processes of vegetation change occurring on known prairie dog towns (colonized areas) and the processes occurring on desert grasslands that are free of prairie dog disturbances (uncolonized areas). The complex factors of livestock introduction, overgrazing, wildfire suppression and climate change are shown in this study to be less important on colonized areas than the effects of the living prairie dog colony. This does not imply that these other factors are not significant on uncolonized desert grassland sites. Furthermore, each of these factors may have important interactive effects on the rate of succession on colonized areas. Future studies investigating causal factors in vegetation change should compare ecological effects on uncolonized versus colonized areas in order to evaluate the significance and independence of each factor relative to prairie dog succession.

Previous studies investigating vegetation change on the desert grassland-desert scrub ecotone should be reexamined for possible confusing results arising from the unforeseen effects of prairie dog succession. For example, prairie dog succession may explain some of the inconsistencies in observations on experimental cattle exclosures. Cattle exclosures located on the JER and in the San Simon Valley near Rodeo and Portal are very likely to be compromised by prairie dog succession. Exclosure data from the Santa Rita Experimental Range is probably not compromised, since no records of prairie dog colonies were found for this area.

The direct and indirect implications of the historical and ecological evidence of this research is that prairie dogs are significant keystone organisms on the desert grasslands and "prairie dog succession" may be changing vegetation structure on eradicated colonies. More than 4 million acres of prairie dogs where poisoned before 1943 in southeastern Arizona and southern New Mexico. Arizona black-tailed prairie dogs formerly occupied approximately 417,452 acres of

Cochise County, 270,535 acres of Graham County, and 95,090 acres of Doña Ana County and the animals are believed to have been eradicated in these counties over 60 years ago.

The majority of prairie dog colonies in Cochise, Graham and Doña Ana counties were eradicated between 1918-1935. Authors have documented widespread long-term vegetation change in these three counties similar to that observed prairie dog colonies in this study. Furthermore, vegetation change has been reported in these counties from the same general locations where prairie dog colonies are shown to have been located: the San Pedro, Babocomari, Sulphur Springs and San Simon valleys in Arizona, and on the Jornada del Muerto in Doña Ana County, New Mexico.

Most of the scientific evidence for vegetation change in southern New Mexico comes from the Jornada del Muerto, and the locations given for vegetation change there is entirely consistent with the locations of former prairie dog colonies there (Buffington and Herbel, 1965; Dick-Peddie, 1965).

Bahre (1991) evaluated multiple sources of historical data on vegetation change in southeastern Arizona. He summed up his findings on the historic decline of grasslands with a list of areas for which there was clear evidence of conversion from grassland to desert scrub vegetation. His list includes the primary locations of prairie dog colonies in the region: the Aravaipa Valley, the east side of the San Pedro Valley near the international boundary [Hereford District], the Croton Springs region southwest of Willcox, alluvial fans east of the Huachuca and Whetstone Mountains, the plains east and west of the Dragoon and Chirachuahua

Mountains [Sulphur Springs Valley], and large sections of the San Simon Valley (Bahre, 1991: 179-180). The only area listed by Bahre for which I found no historic evidence of prairie dog colonies is on the lower slopes of the Santa Rita Mountains. All other areas are part of the described occurrence of Arizona black-tailed prairie dog towns poisoned by 1922.

It is uncertain if all sites eradicated between 1916 and 1938 have already reached a climax or if further change can be anticipated. Judging from the variable vegetation structure found on colonies poisoned in the 1930s, these sites are probably still undergoing succession and further shrub increases can be expected.

The areas with extensive prairie dog colonies in Cochise and Graham counties have also reported severe erosion that may have greatly accelerated the succession being experienced on former dogtowns, or may have obliterated the sites altogether, such as at Hereford, San Simon and Benson. Identification of prairie dog colonies may be difficult after succession has begun because the distinguishing burrow systems are no longer visible.

Other portions of the study area have experienced more recent eradication, dating from 1937 to 1960. Former dogtowns in Luna, Grant, Hidalgo, Sierra, Otero, and Lincoln demonstrate a variety of physical levels of decay, depending on the date of eradication and the edaphic conditions of the sites. Even the living colony that was sampled in Otero County had been partially poisoned in the 1970s and showed, in locations away from the active colony area, evidence of burrow decay and collapse. Most, if not all, of the former colony locations poisoned since the New Deal are probably still undergoing succession.

Regardless of the ability of burrow decay to explain the slow and variable rate of vegetation change, the study shows that significant increases in woody shrubs can be expected in the long-term on all eradicated prairie dog towns in the desert grassland, including areas in Texas and Mexico. Transformation to desert scrub vegetation on these colonized areas may be irreversible. The processes of erosion and establishment of mature desert scrub communities forever alters the ability of the land to support desert grasslands, even when woody shrubs are mechanically removed.

For the approximately two million acres of prairie dog towns poisoned since 1943, understanding and stopping the process of prairie dog succession may still be possible. Healthy desert grassland ecosystems may be preserved on these more recently exterminated dogtowns if their exact locations can be determined and new range management options implemented, including prairie dog reintroduction. For that reason, the experimental prairie dog reintroductions on the Pedro Armendaris, Ladder and Gray ranches bear watching for signs of grassland improvement.

Landscape transformation by human agency is most often assumed to be an obvious thing: in this case it is not. This study is shows that unfounded prejudice against a simple animal has made a mockery of our best efforts at land management in a newly settled environment. Elimination of a small rodent from the broad grassy plains and valleys of the Southwest did not seem like a high price to pay for greater economic productivity. Arizona black-tailed prairie dogs were considered so inconsequential to the study area as to have been nearly forgotten.

The potential transformation of millions of acres of an ecologically unique grassland into vast tracts of desertscrub is a powerful legacy of human agency that will forever alter the productivity and biotic diversity of the region. Transformation in this case has been so slow, and the possibility of assigning importance to the "despicable little prairie dog" so remote, as to obscure human perception. Cultural perception of the status of animals may be playing itself out in the most ironic manner in the Southwest: removal of the "prairie dog pest" has destroyed rather than improved the desert grassland ecosystem, making it less fit for cattle every year.

Appendix A

Interviews

Johnny Anglin

Former Animal Damage Control supervisor, New Mexico

Interview conducted on 7/26/96 in Cuchillo, New Mexico

How long have you lived in the area, and where? I worked down in Hidalgo and Grant county for the Animal Damage Control from 1977 to 1980, then worked up in Sierra County. I was raised in this country.

Where do you remember seeing prairie dogs? When did you see them in this location? In Sierra, Hidalgo and Grant County I never did see a prairie dog in all my years. They have been gone since the CCC boys took care of them in the 1930s, I guess. But there have been prairie dogs up in Socorro County. There is a colony by Silver Creek. Go 9 miles north of Winston, then at the fork to Beaverhead, head across Roberts Ranch past a new powerline. There is another dogtown up in the forest by Beaverhead, too.

Do you know if they were black-tailed prairie dogs? Not really.

Do you remember seeing prairie dogs along Willow Creek or on the HOK? No. I would have known if there were any because I was poisoning kangaroo rats in there.

Do you recall any rodent control programs in your area? When was that? The CCC did work up in this area around Cuchillo and on the HOK back in the 1930s.

Gene Barksdale

Retired Air Force and former cowboy on the Ladder Ranch, Sierra County, New Mexico

Interview conducted by telephone on 7/10/96 from Amarillo, Texas

How do you know about Sierra County and when were you here? I was raised in Sierra County and when I was a teenager I worked for four years on the Ladder Ranch. That was from 1944 to 1948.

Do you remember seeing prairie dogs on the Ladder Ranch? I worked all over the Ladder Ranch during those years, but never saw a prairie dog out there. I never saw one in all of Sierra County during those years. I guess they were all killed off.

Roy Boss

Cattle Rancher, Boss Ranch, Cochise County, Arizona

Interviews conducted 5/16/97 and 7/13/97 in Cochise County, Arizona

How long have you lived in the area, and where? I'm 86 years old and I moved out here with my family when I was a little boy. My father bought the ranch in 1910 and I've lived here all my life.

Where do you remember seeing prairie dogs? When did you see them in this location? There was a prairie dog town right here (near Boss Ranch corrals) when I was a boy. This was a dogtown about 300 acres, about ½ mile across. One day my dad came in and said that the County agents had been out here and had poisoned this dogtown without asking his permission. Maybe it was a good thing, but my dad was not pleased because they hadn't asked permission. He had bought this piece of land from Mr. Claunch in 1920. Claunch refused to let the agents on here to poison the prairie dogs. They poisoned it a long time ago when I was still in high school. It was shortly before the gas pipeline came through.[Documents that Mrs. Boss provided showed the gas company purchased right-of-way in 1931].

Do you remember seeing prairie dogs along the road to Douglas or up toward Rodeo? No. I never saw any prairie dogs except the ones on our ranch.

After the prairie dogs had been poisoned here how has this area been compared to the ranch? Well, they came through with a gas pipeline shortly after it was poisoned. The water used to spread out real even through here over the dogtown, now it has two diversions. We have always had this pasture fenced off and use it for a temporary holding pasture for branding and round-up. We don't keep cattle down here for more than two weeks in the spring and again in the fall.

Do you notice anything different here on the old dogtown? This is the only area where I have big Galleta grass. Before it used to be real bare from the dogs eating off all the grass. Now it has some of our tallest grass. Its been real good with sacaton and tobosa grass. But the cattle can't eat it when we hold them in here because it gets real tough when its tall like this.

What did people think of prairie dogs? They were a nuisance. They could bring down a horse, I hear.

Have you noticed these sink-holes and collapsed areas before?[Mrs Boss] No. I never did see those before. They look like they just formed after the rain.

Lewis Cain

Cattle rancher, Sierra County, New Mexico

Interview conducted on 10/97 in Aleman, New Mexico

How long have you lived in the area, and where? I grew up on a ranch over in the Tularosa Basin in what's now White Sands Missile Range. That was called the Buckhorn Ranch. I was a young man there when the government came in and moved my family out. That was in 1944. We were on that ranch from 1941 to 1944. We moved over here [Aleman] in 1954 to ranch on the Jornada del Muerto and I've been here ever since. I'm 82 years old.

Where do you remember seeing prairie dogs? When did you see them in this location? The only living prairie dogs I remember ever seeing were on our ranch on White Sands. Used to herd the cattle out of the hills by Rhodes Canyon where we had land along both sides of the road to Tularosa. I'd bring them down from the hills and east across the Basin to Tularosa. There was a colony of prairie dogs in the draw on the north side of the road up to Rhodes Canyon. That was a little past Tip Top Tank [indicated on map to be northwest of the Rhodes Range Center]. It was about ½ mile from east to west and about ¼ mi. wide along the draw. The were there when I left in 1944.

Do you remember seeing prairie dogs around the dry lake bed west of Salt Creek? No. The cattle didn't spend much time down there because of all the salt. I'd just drive them through along the road. And since I've been out here on the Jornada [del Muerto] I haven't seen any.

Do you recall any rodent control programs in your area? When was that? There was a CCC camp down here at Aleman, right where my brother's place is. That was before we came in 1954. That camp was right across from where the first well on the Jornada del Muerto was drilled. That was in 1870 and the building there was a stage stop. The CCC camp there did a lot of poisoning around here.

What did people think of prairie dogs? Mostly that they weren't much good for anything.

Did you ever eat them? No.

Tom Day

Ranch hand, Gray Ranch, Hidalgo County, New Mexico

Interviewed by telephone on 3/1/96 in Lordsburg, New Mexico

How long have you lived in the area, and where? I've lived in southern New Mexico and worked out on the Gray Ranch since 1963.

Where do you remember seeing prairie dogs? When did you see them in this location? I never saw any prairie dogs on the Gray Ranch. When I came in 1963, there weren't any. Bill Cowen, the neighboring rancher at Cloverdale told me about prairie dogs out there. He said that ranch was owned by Diamond A Cattle Co. back in the 1920s and 30s and they did their own poisoning. Then the CCC came into the area in the late 1930s and poisoned everything that was left...kangaroo rats and prairie dogs. But when I got there in 1963 there weren't any left.

Frank Drummond

Interviews conducted by telephone on 2/15/96 and 3/1/96 in Buckhorn, New Mexico

How long have you lived in the area, and where? I've lived in Buckhorn since 1943. I was raised in Oklahoma. Before the war I worked for CCC camps up near Valecitas, New Mexico doing prairie dog eradication.

Where do you remember seeing prairie dogs? When did you see them in this location? Prairie dogs used to still be scattered along the valley of Duck Creek and through Buckhorn when I first come out here in 1943. They were over across the Creek in Buckhorn where there are trailers now. They went up Duck Creek north to about Cactus Flat, but didn't have any in Glenwood. Then even further north in Reserve. I did prairie dog poisoning during the 30s and so I know prairie dogs pretty well.

Do you know if they were black-tailed prairie dogs? Yes they were here.

Do you know if there was ever any plague in the dogtowns? No. I didn't hear of any down here.

Did you ever visit any prairie dog towns after they had been poisoned? Yes. I used to run the road plow and I could see many prairie dog mounds up on Sacaton Mesa on Roland Rice's ranch up there. There were many colonies on the mesa but they had been poisoned out. I could see the mounds where they had dug up the caliche, but these weren't kangaroo rat mounds. I heard that they were poisoned by the CCC back in the 30s. I never saw any living colonies up there.

I did see prairie dogs up around Horse Springs in Catron County and toward Magdelena on the north side of the highway. That wasn't too many years ago, either.

Myra Drummond

Home-maker, Buckhorn, New Mexico

Interviewed on 7/7/97 in Buckhorn, New Mexico

How long have you lived in the area, and where? I'm 87 and have lived here in Buckhorn all my life.

Where do you remember seeing prairie dogs? When did you see them in this location? There was a prairie dog town next to my home here in Buckhorn on the north side of Duck Creek. I used to have to lead the milk cow across that dogtown to my grandmother's house and I had to be very careful. Then later when I got married and Frank and I lived out here in 1943, we could watch the prairie dogs from the house.

What happened to the prairie dogs on your land? We tried to poison them sometimes. But then in about 1950 there was a program for raising castor beans and the County helped with seeds and plowing up the field where the animals were. I guess they got rid of them for good when they plowed up the fields.

Do you remember seeing prairie dogs further up Duck Creek or up on Sacaton Mesa? Yes, at Duck Creek. When they set up the CCC camp up there, they killed them all. I never did go up on Sacaton Mesa much.

What did people think of prairie dogs? Seems like folks didn't like them because of the cattle and horses stepping in the holes. We had to watch out around them.

Tom Emanual

Retired Game Warden and Wildlife Manager, White Sands Missile Range, New Mexico

Telephone interview conducted 4/11/97 in Las Cruces, New Mexico.

How long have you lived in the area, and where? I started work out at White Sands Missile Range in 1962. I worked out there until 1982.

Where do you remember seeing prairie dogs? When did you see them in this location? I've done a lot of work all around WSMR, first as a game warden and later in wildlife management. When I first came out there in 1962, there might have been a few animals out by Cottonwood Canyon but, to tell the truth, I don't remember ever seeing a live prairie dog. We had lots of other problems then. There were still trespass cattle and there were hundreds of wild horses. We just didn't pay much attention to rodents. Then we had the Oryx introduction in the '70s.

Do you remember seeing prairie dogs at Salt Creek or near Rhodes Range Center? No. I don't remember seeing any there.

Do you know if there was ever any plague in WSMR? We had plague surveillance out there for several years after plague showed up by Tularosa. We would sample different rodents. Some plague showed up in rock squirrels but that was all. No prairie dogs showed up in the traps, either.

Do you recall any rodent control programs in your area? When was that? No. WSMR didn't poison rodents. They trapped coyotes, though.

Art Evans

Retired Ranch Foreman, Ladder Ranch, Sierra County, New Mexico

Interviewed on 7/10/96 at Ladder Ranch Headquarters, New Mexico

How long have you lived in the area, and where? I live in Cuchillo and I first came to work out on the Ladder Ranch as Foreman in 1953. They mostly raised horses here back then, for the movies.

Where do you remember seeing prairie dogs? When did you see them in this location? I never saw living prairie dogs on the Ladder Ranch or in Cuchillo. I worked all over this country in the 1950s and never saw any. I saw them up in Socorro County, though.

Alton Ford

Government Trapper, Hidalgo and Grant Counties, New Mexico

Interview conducted on 3/2/96 in Red Rock, New Mexico

How long have you lived in the area, and where? I've lived and worked as a government trapper in Grant and Hidalgo Counties all my life.

Where do you remember seeing prairie dogs? When did you see them in this location? Yes. I never thought much about prairie dogs. I was trapping for USF&WS in the Silver City/ White Signal area in Grant County from 1952. There were just four prairie dogs towns that I knew about that were left in the area southeast of the Burro Mountains. These were about 20 acres each and were in the triangle from White Signal to Gage to Silver City. Some were out west of the Silver City airport in Whitewater Draw and in Cow Springs Draw.

Did you ever see any prairie dogs in Hidalgo County? I worked down in the Big Hatchet area from 1948-1952. There were no prairie dogs left in the area, but the ranchers talked about them a lot.

Do you recall any rodent control programs in your area? When was that? In 1958 the District agent for PARC came out and was interviewing everybody about prairie dogs. They wanted to know where any dogtowns were located. I felt pretty sorry for the critters and didn't tell, but others did. In 1958-59 the agents came out and poisoned them with 1080 grain but it rained real hard just after the poisoning and some animals survived. In 1960, they came back out and poisoned them again and I guess that finished them off.

John Ford

Retired Animal Damage Control Supervisor, Socorro County, New Mexico.

Interview Conducted March 2, 1997 in Magdelena, New Mexico

How long have you lived here? Since 1963 ...36 years. Lived in Socorro County most of my life.

Where do you remember seeing prairie dogs? When did you see them in this location?

This county had the worst prairie dog problem in the state when I first came here. There were thousands of acres of prairie dogs and my job was with rodent control. Each year we would get our budget and submit our plans for where we would treat the prairie dogs.

The only prairie dogs I know about now are over by the Kelly Ranch area…about 1,000 acres. There is another colony down by Water Canyon, just north of the water tanks by the highway. Most of the other prairie dogs are gone now. They started poisoning prairie dogs here when the CCC had a camp out here on the Plains of San Augustin in the 1930s.

I remember a colony out by North Lake by Alamo and a huge colony south of Acoma on the old Red Lake Ranch that we were working on in the 60s and 70s.

There used to be a large colony out by Silver Creek west of Dusty, I'm not sure when I last saw them there. Between Bernardo and Riley there was a colony of about 3,000 acres and there were more colonies on the terraces north on the Puerco River.

The Sevilleta used to have about 5000 acres on the east side of the Rio Grande. We treated that area several times in the 1960s. Three times. West of Bernardo there were more. [McKinsey?] had over 1,000 acres.

Between 1958 and 1969 we poisoned the area between the Pedro Armanderis Land Grant and the Bosque del Apache…thousands of acres.

I didn't work any in Sierra County, but Manny Holden, Red Potter and Jim Arnold did. They're all dead now. John Anglin may know about prairie dogs there.

Do you recall any rodent control programs in your area? When was that?

A lot of times we just couldn't get a good kill and the prairie dogs would just come back, especially in the center of a dense colony. Plague may have helped reduce their numbers a lot, but we poisoned many areas more than once. In the 1970s there was an outbreak of plague. I was asked to take folks out to collect fleas from burrows where the animals had died from plague. They tested the fleas and found plague in them.

Do you remember seeing any black-tailed prairie dogs in the area?

There used to be black-tailed prairie dogs around here. Both species (Gunnison's and black-tailed) used to be on the Plains of San Augustin, living near each other. I think they both still live here. Sometimes you'd be in the same big colony with some Gunnison's here and black-tailed prairie dogs over there.

Did they live together out on the plains at low elevations?

Yes they did. But black-tailed prairie dogs were higher up, too. I even saw a few up the road to South Baldy near to the top.

Did you ever visit any prairie dog towns after they had been poisoned?

We also worked on kangaroo rat eradication. It seemed like the kangaroo rats got real thick here in the 1960s and 1970s. Occasionally you'd see a kangaroo rat mound in the prairie dog town, if it was scattered out a lot, but never in a dense colony. Sometimes they would just use a prairie dog burrow, but usually they'd dig their own. Also, there used to be a lot of pack rats, but not now.

What did people think of prairie dogs?

Well, the ranchers always wanted our help. Nobody liked a prairie dog...they were pests. What good are they?

Did you ever eat them?

Yes, I tried them before. The Indians out here like to cook them up. They would wrap them up in burlap and roast them in the fire. The meat tastes good too.

Margaret Glenn

Cattle rancher, Leslie Canyon, Cochise County Arizona

Interview conducted on 2/8/97 in Cochise County

How long have you lived in the area, and where? I met and married Marvin Glenn and moved up here to the Glenn Ranch in Leslie Canyon in 1930 and I've been here ever since.

Where do you remember seeing prairie dogs? When did you see them in this location? When I first came up here in 1932 there was a colony of prairie dogs out on the Leslie Canyon Road where the Hunt Canyon road forks off. We used to ride horseback through that colony and it was treacherous. There were all in the valley, right up to the ridge. I'm not sure when they were killed off. I don't remember, but it seems like they weren't there many years after I came.

Do you remember seeing prairie dogs anywhere else in Cochise County? I never saw any prairie dogs after that, but I didn't get out from the canyon here very much in those years. But we heard about prairie dogs out on Ben Snure's place in the Pelloncillos. Its now the Taylor Ranch.

Alden Hayes

Former Rancher and long-time resident of Cochise County, Arizona

Interview conducted by telephone, 10/12/97 in Portal, Arizona

How long have you lived in the area, and where? I came into the area in 1940.

Where do you remember seeing prairie dogs? When did you see them in this location? When I first came here to the Portal area, I bought some land in the San Simon Valley at the mouth of Antelope Pass. The CCC had poisoned prairie dogs there and they were doing flood control on the land to keep it from eroding away. Blackie Sturdham told me about the prairie dogs in the Valley here. But they were gone from the Valley when I first got here. They were still poisoning them up in the hills though and in Hidalgo County.

Do you recall any rodent control programs in your area? When was that? The CCC was camped up on Cienega and Cave Creek and they were doing lots of flood control on the alluvial fans and poisoning the prairie dogs and kangaroo rats. They worked there in '41 and '42.

Bruce Hayward

Biology Professor, Western New Mexico State University, Silver City, New Mexico

Interviewed on 10/9/95 in Silver City, New Mexico

How long have you lived in the area, and where? I came out here to teach in Silver City in the late 1950s.

Where do you remember seeing prairie dogs? When did you see them in this location? There were Gunnison's prairie dogs located 30-35 miles north of Silver City in the community pasture adjacent to the East Fork of the Gila by Tom Moore Canyon when I first came out here. Also there were black-tailed prairie dogs southwest of White Water and south of Red Rock in the late 1950s [these were marked on a map]. Both of these areas were poisoned in the early 1960s.

Do you know if they were black-tailed prairie dogs? The colonies around Silver City were black-tailed prairie dogs, up north, they were Gunnison's.

Do you recall any rodent control programs in your area? When was that? New Mexico State University in Las Cruces had the extension programs and they conducted the poisoning campaigns. The last campaigns in Grant County were in early 1960s.

V. W. Howard

Professor, Department of Wildlife Biology, New Mexico State University

Interview conducted 4/10/97 in Las Cruces, New Mexico

How long have worked in the area as a wildlife biologist?

I have been working in the area as a biologist since the mid-1960s. I've worked between Las Cruces and Socorro County and over in White Sands and Otero County.

Where and when do you remember seeing prairie dogs?

When I first went out on White Sands Missile Range with Tom Emmanuel I saw prairie dogs. That was in 1965-66 and I went out a few times. I saw prairie dogs south of Rhodes Range Center and out by Salt Creek in '65-66. The colony by Rhodes Range Center was small.

Then in 1975 I worked with Dr. Piper to conduct a wildlife inventory of WSMR. In that study we surveyed those areas but found that the black-tailed prairie dogs had been extirpated from WSMR.

In Socorro County I had a project near Dusty up until the 80s. There was a colony there of prairie dogs in 1978-79. By the 1980s that colony had become real small—just a few animals. A large gully appeared through the colony.

There is a colony out on Otero Mesa on the McGreggor Range. I've been out there before. Jim Lackey of BLM (now retired) brought the animals in from Ft Bliss. The colony plagued twice and was empty. In '78-79 I went out there and there was about 20 acres of prairie dogs.

What did people think of prairie dogs?

We used to hunt them a lot, right up until the '80s in Dusty. Now there aren't any out at Otero Mesa. I think they make great target practice.

Did you ever eat them?

No.

Do you know any one else that might know about prairie dogs in the area?

R.O. Anderson used to own the Ladder Ranch for a long time. He lives outside Roswell. Also, Tom Emanuel still lives in Las Cruces. He used to be a wildlife manager at WSMR.

Dustin Hunt

Former rancher and Jack-of-all-trades, Grant County, New Mexico

Interviewed on 2/15/96 in Cliff, New Mexico

How long have you lived in the area, and where? I came out to Grant County when I was a teenager in the late 1940s.

Where do you remember seeing prairie dogs? When did you see them in this location? Between 1950 and 1955 I tried ranching. I had a small spread out between White Signal and White Stock Tank, near the Timmer mine. There was a small prairie dog town on my place out there, about 40 burrows. There was a terrible drought, no rain for those five years and all the cattle died or were sold off of nothing. But the prairie dogs were still there when I went bust on the ranch. There was another colony out there during the 1950s also near the big windmill.

Do you recall any rodent control programs in your area? When was that? Well both those colonies out along White Water Rd. were poisoned by ADC in 1960. They were small colonies and they were the last I ever saw in these parts.

What did people think of prairie dogs? They didn't bother me any. But most ranchers didn't like them.

Did you ever eat them? Yes. When I first came out and was just a young boy, me and a friend went out for a week of hunting and didn't get anything. One day we got a prairie dog and skinned it out and roasted it. It was OK, but it was covered with fleas and not much meat for two hungry boys.

John Hubbard

Retired head of New Mexico Game & Fish Department and resident of Grant County

Interviewed on 2/14/96 and 9/15/96 in Pleasanton, New Mexico

How long have you lived in the area, and where? I've worked and lived in Grant County for many years. I started doing biological work in Hidalgo and Grant Counties late in the 1950s.

Where do you remember seeing prairie dogs? When did you see them in this location? Yes. There were a few colonies of prairie dogs in Grant and Hidalgo County when I first came here. There were a couple of small colonies near White Signal off of Separ Rd.. These were poisoned in 1960. There was also a colony on the Gray Ranch when I was down there for a mammal survey in 1960. That colony was just west of San Luis Pass and near the big old juniper tree on the dike north of Lake Cloverdale. A third colony was near Summit north of Lordsburg. There may have been black-footed ferrets in this colony.

Do you know if they were black-tailed prairie dogs? Yes. The colonies in southern Grant county and in Hidalgo County were black-tailed. There were some colonies in Jewett and Quemado, but these were Gunnison's.

Chuck Lawson

Retired, Soil Conservation Agent, Cochise County, Arizona

Telephone interview conducted on 3/28/96 and 2/7/97, Willcox, Arizona

How long have you lived in the area, and where? I've lived here all my life and I'm 87 years old. I grew up out on the Muleshoe Ranch where my dad worked and moved to Willcox in 1926. I worked for the SCS for 40 years in Cochise County and know this area pretty well.

Where and when do you remember seeing prairie dogs? When did you see them in this location? When I was a boy out on the Muleshoe Ranch we used to ride into town on a wagon across Allen Flats. There were lots of prairie dogs out there, a big town. They were about 2 miles west of Muleshoe Ranch road north of the turn off for Cascabel Rd.. When I moved to Willcox in 1926, I didn't go up there any more. But they were there before that.

Do you know if they were black-tailed prairie dogs? No. I wouldn't know. I was just 9 or 10 years old then and never saw one after that.

Do you remember seeing prairie dogs around Willcox or Dos Cabesas after that? No.

What did people think of prairie dogs back then? I never really thought much about them. They have been gone nearly all my life.

Bill Miller, Sr.

Interviews conducted 3/25/96 in Post Office Canyon, Cochise County, Arizona

How long have you lived in the area, and where? I've been out here all my life. My family settled this country and I'm 86 now.

Where do you remember seeing prairie dogs? When did you see them in this location? When I was a young boy, we lived down in the Valley [San Simon] and there were big prairie dogs towns all along down there. We had a big colony right there on the road as you come in through the gate down there, by the corrals. They were just down in the valley, not up against the hills or in the canyons here.

Us boys had to go out after the heavy summer rains with shovels. The valley floor would hold the water several inches deep around the prairie dog mounds, and we would dig a hole in the mound and the water would go in and flood them out. Then we'd smack them with the shovel as they came out. That would only kill a few though.

Then there was a colony up on the Darter Place. That was the last prairie dogs in this area. It was small, just 40-50 animals. I used to go up there to shoot them between 1935 and 1938. I believe that I shot the last prairie dog in all of Cochise County there in 1938. That ranch is now owned by Bill Camditch.

Did you ever visit any prairie dog towns after they had been poisoned? Well, the one by the corral down there. Its been poisoned a long time now.

What did the old dogtown look like? It used to be just bare most of the year or with real short grass and all the bore dirt on the mounds. There mounds were real high, like a cone. Now its just full of cat-claw and weeds mostly.

Do you recall any rodent control programs in your area? When was that? When I was about 10 they came in here with wagons of poisoned grain and everybody around would gather and spread the grain to kill the prairie dogs. I helped with that and we poisoned colonies all up and down the valley here and got rid of them that year. That must have been before 1920. They have been gone from around Rodeo and through this part of the valley ever since.

What did people think of prairie dogs? They were pests and we hated them. Good to shoot, though. I take my boys up to Nebraska to shoot them.

Did you ever eat them? No, but I've heard of people eating them.

Roland Rice

Cattle Rancher, Cliff, New Mexico

How long have you lived in the area, and where? I've been up here in Cliff for all of my life…nearly 65 years. My mother is 85 and still living here, too.

Where do you remember seeing prairie dogs? When did you see them in this location? There used to be prairie dog town up on our property on Sacaton Mesa. They were on the first terrace above the Gila River up Bell Canyon. There is a jeep road out there and you can still see signs of the animals. They were poisoned in the mid-1940s.

Do you remember seeing prairie dogs at the entrance to the Shelly Ranch up on the Mesa? No. They must have been poisoned before I could remember.

Do you know anybody else that would know about prairie dogs in the area? You should call Otho Woodrow. He's been here all his life and is in his eighties. He rode with the Shelly boys in the early days out here and he would know. Also you might talk to my mother.

Joe Turner

Retired cowboy, Jornada del Muerto, New Mexico

Interviewed on 9/6/97 and 10/97 in Cutter, New Mexico

How long have you lived in the area, and where? I first came out here in 1930 to work for the Diamond A Cattle Co.. They had land all over the Pedro Armenderis Land Grant and over on the Gray Ranch. I only worked for them one year before the Kern County Land & Cattle Co. bought them out and laid everybody off. That was the start of the Depression. I went back to Texas until 1935, then came back here and I've been out here ever since. I'm 85 years old. My wife and I kept the little store and bar at Engle until she passed away and I've been a cowboy out here all these years.

Where do you remember seeing prairie dogs? When did you see them in this location? There were prairie dogs out here when I first came in 1930. They were mostly all along by the ranch at Lava Camp, between there and the railroad tracks, and from there south along the bottom of the valley all around Red Lake. They were still real thick through there and it was real bare ground with their mounds sticking up everywhere. The ranch kept working on that area with poison every year it seemed like and finally killed them off. The last little patches of them were there in 1960 between Red Lake and Lava Camp, where I showed Tom

Wadell. I'll be darned if he didn't come bring some prairie dogs back into those same spots. Why would he want to do that?

I also saw prairie dogs out at the Pankey ranch where I worked for awhile in 1936. We were building fences, fencing in the range because of the Taylor Grazing Act. There were prairie dogs in Nogal Canyon and in the draws across the Pankey ranch.

Do you remember seeing prairie dogs by Tucson Springs or over on the eastern edge of the ranch? In 1930 I lived for awhile over at Mesa Well by Black Mesa on the north end of the ranch. I had to ride over the Lava to work in the area around Tucson Springs and never did see any prairie dogs out there.

Do you know if there was ever any plague in the dogtowns? I don't remember any mention of it.

Did you ever visit any prairie dog towns after they had been poisoned? I lived for awhile in 1930 at Deep Well Camp and we had to be real careful to guide our horses through an old empty dogtown the valley just north of the camp. It was real treacherous with sunken burrows all hidden in the grass.

That area around Red Lake and up to Lava Camp, that all used to be prairie dog towns and they were real bare and without much brush. Now the grass is real tall in there since they took the cattle off, but there is a lot of mesquite and creosote coming in. It use to be thick with side oats grama and other grasses. There used to be so many antelope around Red Lake.

Do you recall any rodent control programs in your area? When was that? The Diamond A had a crew that did their poisoning and so did the Kern County

Land & Cattle. I heard about the CCC Camps down in Aleman, but they never worked up here that I know of. The ranches bought their own grain and cyanide and mixed it up and dispensed it. It was a separate crew, so I never worked with them, just heard about it. In the 1950s they came out with cyanide bombs. Johnny Anglin and Walter Duds came out to poison coyotes here.

What did people think of prairie dogs? Nobody liked them.

Did you ever eat them? No, I didn't.

Tom Wadell

Ranch manager and wildlife biologist, Pedro Armanderis Ranch, New Mexico

Interviewed conducted on 10/3/97 at the Pedro Armanderis Ranch Headquarters, New Mexico

How long have you lived in the area, and where? I worked for Arizona Fish & Wildlife in the 1970s then came over here to run the Pedro Armanderis Ranch for Turner in 1984.

Where do you remember seeing prairie dogs? When did you see them in this location? We just reintroduced black-tailed prairie dogs here on the ranch last year and they are doing well. Prairie dogs are just about gone from this country and we had to search all over to kind a colony to get our animals from. We finally got animals from over in Lincoln County.

There weren't any of the Arizona black-tailed prairie dogs left in Arizona when I worked for Arizona Fish & Wildlife Department in the early 70s. David Brown was very interested in getting some back and he worked out a deal with a ranch in Cochise County, the Appletons, I think, to accept some Arizona black-tailed prairie dogs from New Mexico. I got sent over to watch the collection of the animals and that was the only time I saw Arizona black-tailed prairie dogs.

The ADC was about to poison a colony on the Day Ranch, just over the New Mexico state line, south of Summit Hills on the north end of the Lordsburg Lake area. They (ADC) agreed to let us help them capture some animals before they poisoned the colony. That was in 1972. We came in and worked all morning capturing the prairie dogs and putting them in the truck. All the animals they couldn't catch they poisoned with 1080, then sent the truck off to Arizona in the heat of the afternoon...no shade or water. I guess the prairie dogs never made it in Arizona, because I hear they just dumped them out on the ground without pens or shelter. I don't think the ADC "rat stranglers" had any intention of succeeding in that operation.

W.D. Wear

Cattle Rancher, Sunset area, Graham County, Arizona

Conducted telephone interviews on 5/17/97

How long have you lived in the area, and where? I grew up out here on the ranch. I'm 88 and I've been out here all my life.

Where do you remember seeing prairie dogs? When did you see them in this location? When I was a boy there were lots of prairie dogs out here. There was a small colony on our ranch along Ash Creek. There were lots of prairie dogs on the Sierra Bonita Ranch and there was a big colony along Oak Creek by Sunset. That was when I was little. They were poisoned in about 1920 by all the men.

Also out on the Sierra Bonita Ranch we used to drive our cattle through a big dogtown there. That dogtown was poisoned out in about 1920. Those colonies on the Sierra Bonita Ranch really were the biggest in the whole area.

Do you know if they were black-tailed prairie dogs? No.

Did you ever visit any prairie dog towns after they had been poisoned? Oh yes. That one on our ranch got to be real treacherous after the war. It was full of sink holes and I had to fence it off so the cattle wouldn't get mired in it. Its been fenced off ever since. There used to be lots of old prairie dog sign out at Oak Creek. That colony was real big and was on three ranches out there.

What did the old dogtown look like? Full of sunken burrows and holes, but with lots of grass.

Do you recall any rodent control programs in your area? When was that? Yes. That was what finally killed them off. First they killed off that big colony on the Sierra Bonita, then they came up the valley here a few years later. I remember that all the men got out one year, sometime between 1920 and 1925 to poison them out with grain.

What did people think of prairie dogs?

Well, I reckon they didn't like them much. Those sunken holes sure messed up my pasture.

Otho Woodrow

Cattle rancher, Grant County, New Mexico

Interview conducted on 7/12/97 in Cliff, New Mexico

How long have you lived in the area, and where? I was born in Grant County in 1916 and I've lived all my life at this ranch on the Gila River.

Where do you remember seeing prairie dogs? When did you see them in this location? I first saw prairie dogs when I was 12. We didn't have any on our ranch and I was working up on Sacaton Mesa in 1928 and coming down the mesa when we came through a colony of prairie dogs. There was quite a lot of them, on both sides of the road [Rd. 916]. This is on the Roland Rice Ranch. Then I went up into the forest to work for the Diamond Bar Ranch until I was about 19. When I came back down to the ranch here, those prairie dogs were gone. Up in the mountains, there was a colony of prairie dogs at the mouth of Tom Moore Canyon and the East Fork of the Gila. That was on the community pasture there.

And not too many years back there was a prairie dog town across from the rest stop on Hwy. 180, about 8 miles north of Deming. I'm not sure if its still there or not.

What did the old dogtown look like after awhile? The grass on that old dogtown on Rice's Ranch was real good. Rice never did graze his land down like some ranches.

What did people think of prairie dogs? People hated them. They could snap a horse's leg.

Did you ever eat them? No I never did. I didn't eat ground squirrels either, but I did eat tree squirrels. I'm not sure why.

Do you know anybody else that might know about prairie dogs? Yes. Wort Youngblood used to work out on the Moon Ranch. He did a lot of poisoning for the CCC and knows a lot about them. He lives in T or C now.

Wort Youngblood

Retired cowboy and camp cook, Moon Ranch, Grant County, New Mexico

Interviewed on 7/12/97 and 9/7/97 in Truth or Consequences, New Mexico

How long have you lived in the area, and where? I came out to New Mexico in the Great Depression. I was a boy and I've been working out here ever since, except when I left for World War II. I was born in Texas.

I worked in 1933. I worked in Williams, Arizona. Then in 1935 I worked a summer job for U.S. Biological Survey on rodent control, then again in 1937 as a foreman until 1942, when the war broke out. For all those years I worked to poison prairie dogs. People just lined up to get the work poisoning prairie dogs in those days. Then when I came back from the war and took a job on the Moon Ranch (Grant County), it looked like all the prairie dogs had been poisoned out of the country down there. I worked for the Moon Ranch for 42 years and lived in Buckhorn.

Where do you remember seeing prairie dogs? When did you see them in this location?

I worked in Vermejo Park and Maxwell in 1936, and saw lots of prairie dogs up there. We poisoned them out of La Belle, around Castillo Lake, Dawson, and all over the C.S. Ranch.

Then I came down to Sierra, Socorro and Catron Counties in '37-39. In the Monticello and Dusty area there were many prairie dogs. Also over the divide at Horse Springs in the Plains of San Augustin (right up the road from the old post office on the road that goes over to Greens Gap). At Greens Gap there were so many prairie dogs one old timer told me that when they started the campaigns the whole country around there smelled like something dead.

There were big colonies at Apache Creek and Mangas. In Apache Creek they were in the sandy terraces above Apache Creek. In Aragon they were out by the graveyard. We poisoned that in 1939. There were lots in Datil and Reserve, too. Catron County was just about as thick as anywhere. Patterson Lake, where the Very Large Array is now, had a big colony. We also worked out on the Pankey Ranch and at Nogal Canyon in 1937-38. That area was thick with prairie dogs and kangaroo rats. Up in those parts there came a big flood (Dusty, Monticello, Nogal) in 1941. It cut gullys out real bad. Then another flood came in 1947-48 that was even worse.

In Sierra County, I worked around Winston and Chloride and on the HOK, but I didn't do any work on the Ladder Ranch. In Cuchillo there were prairie dogs all along the canyon. In northern Sierra County they had been poisoned already so in 37-38 we just did clean-up work in Cuchillo Canyon, Willow Creek

We worked as far down as Earl Colson's Ranch on Hillsboro Creek. There was a CCC Camp in Kingston.

In Luna County there weren't many prairie dogs, just a few at Lake Valley and by the Uvas Mountains. And there were a few colonies down by Columbus and Deming, but I never worked there. In Nutt and Deming there were a few prairie dogs but mostly kangaroo rats that we poisoned in 1940-41.

Did ranchers cooperate? Many ranchers said no and did not want the crews to come out on their land. We had to get a release to go in after the prairie dogs on private land. One time a homesteader refused to let us on.. he wouldn't sign a release. We waited until he left for town, then we went in anyhow and poisoned the colony. We felt we had to or else they would re-infest all the surrounding land. Also the Navajos didn't want us to poison them at all. They would eat them and they hated to see us coming. Up in the area around Cuba I worked with a crew all day putting out poison grain. The next morning we went back out and the Navajo ladies were out sweeping up all the grain and throwing it away. They kept on like that and we could never get a good kill out there. They hated the program. The Indian Service had given permission for us to go out on the Reservations, but the people weren't in favor of it at all.

Was it difficult to poison them? How did you do it?

We would drag a chain to keep from missing an area, and the boys would go back and forth and put the grain mixed with cyanide down each mound. Sometimes we used HiLife, which was a gas. We'd dip a rag into it and stuff it in the hole then cover it with dirt to keep the gas down.

There were 22 crews in New Mexico between 1935 and 1937. Some of these were trappers, but mostly rodent control. Of those crews, 3 of the biggest worked out of Horse Springs, that's how bad the prairie dogs were up there. I worked on one of those crews and on one in Beaverhead and up in Cuba, and at Maxwell.

Do you know if they were black-tailed prairie dogs? Well, the ones out on the Plains of San Augustin were mostly Zuni prairie dogs. Some White-tail [Gunnison's] were out there too. Down at Monticello they were mostly black-tailed but with some white-tails.

How could the prairie dogs survive with so much poisoning, and what about the other animals? If there were 2 or 3 left that didn't die, they would move to a different town and it seemed like you could never kill them all. Especially the Zuni prairie dogs. They were hard to kill off. They'd move 1-2 miles away and set up a new colony. Sometimes they would scatter out to make small new colonies and sometimes they would come back to the center of the main colony. We'd have to go back the next year and find them.

One time I was out in Colfax County working on the CS Ranch. We were heading out across a flat with our horses and poison grain, when my buddy and I came upon a herd of about 100 to 125 prairie dogs loping along like rabbits. They hopped along in a crowd, all going in the same direction. We tried to run our horses through them and break them up, but they would just come back together and keep on going. It was real peculiar because they all seemed to know where they were heading. This was the summer of 1936 out near Maxwell. I've never seen such a big bunch of them moving before. I still don't know where they was headed or if they made it. We scattered the poisoned grain, but they weren't interested in anything but moving.

Out in the Northeast corner of the state, they made the mistake of giving poisoned grain out to the ranchers directly and letting them do the work. They wouldn't use grain to pre-bait the colonies, just to save some grain, then when they put the poisoned grain out they would only get a partial kill and the colony would then know to avoid any grain you put out after that. They were real smart and would even teach the pups. I've seen mama prairie dogs go out and whip their pups for going near the grain we put out.

Lots of other animals would eat that grain and die, too. We tried to keep the poisoned grain down in the hole and hoped that the animals would die below ground. But sometimes they would come running out and have a stroke and die and lie all over the country for hawks and eagles to eat. We used cyanide and strychnine and that would kill most other animals if they got into it.

After a colony was poisoned, what changes did you notice? It would take about 3 winters to "hair out"...that is for the grass to grow back good. The prairie dogs would keep the grass eaten down to the roots. You had to be real careful with livestock at that stage because you can't see the burrows and they might break a leg.

What did people think of prairie dogs? They were pests and ate up all the best grass. They would multiply so fast that a rancher didn't have a chance. They would lay waste to the land without a blade of grass left. And the burrows could bring down a horse.

Did you ever eat them? No. I never could eat them, but the Indians ate them all the time. I could never eat anything called a dog.

Appendix B

Soil Texture Data

SITE NAME	% SAND (>60µ)	% SILT (2-60µ)	% CLAY (<2 µ)	SOIL TEXTURE
San Francisco, MX	51.0	41.3	7.7	sandy loam
Lava Tank	20.0	33.1	46.9	clay
Deep Well	10.6	45.4	44.0	clay
Stewart Gauge	35.0	29.3	35.7	clay loam
Rhoades Draw	12.0	53.6	34.4	silty clay loam
Big Sandy	79.0	10.9	10.1	loamy sand
Middle Well	21.0	45.8	33.2	silty clay loam
Headquarters	60.2	21.3	18.5	sandy loam
George Wright	34.7	33.1	32.2	clay loam
Salt Creek Draw	61.6	28.2	10.2	sandy loam
Miller Ranch	19.8	53.3	26.9	silty loam
Summit	38.8	27.0	34.2	clay loam
Otero Horse Camp	44.0	32.4	23.6	loam
San Luis Draw	27.2	19.1	53.7	clay
Buenos Aires	52.7	23.7	23.5	sandy clay loam
West Well	78.1	13.4	8.6	loamy sand
Boss Ranch	18.4	60.3	21.3	silty loam
Antelope Flat	68.8	17.0	14.2	sandy loam
Corner Tank	61.9	32.2	5.9	sandy loam
Average particle size distribution	41.8	32.6	25.6	loam

Source: Textures based on USDA, 1951

Appendix C

Plant Species Lists

Buenos Aires Colony, Chihuahua, Mexico		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (56 %)	*Muhlenbergia arenacae.*	Ear Muhly
	Panicum obtusum	Vine mesquite
	Scleropogon brevifolia	Burro grass
	Aristida sp.	Threeawn
FORB (44 %)	*Pseudographallium canescens*	Gay everlasting
	Cassia bauhinia	Cassia
	Croton sp.	Croton
	Conyza sp.	Horseweed
	Unknown forb	Seedling
	Unknown Portulaceae	Unkn.
Mesa Horse Camp, Otero County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (72 %)	*Muhlenbergia torreyi*	Ring muhly
	Muhlenbergia porteri	Bush muhly
	Dasyochloa pulchella	Fluffgrass
	Panicum obtusum	Vine mesquite
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
	Aristida adscensionis	Sixweeks Threeawn
	Aristida purpurea.	Red Threeawn
	Bouteloua barbata	Sixweeks grama
	Bouteloua gracilis	Blue grama
FORB (27.9%)	*Acourtia nana*	Desert holly
	Chamaesyce sp.	Rattlesnake weed
	Sphaeralcea sp.	Globemallow species
	Solanum elaeagnifolium	Sliver-leaf

	Eschscholtzia californica	Mexican poppy
	Cirsium neomexicanum	New Mexico thistle
SHRUB (0.1 %)	*Ephedra trifurca.*	Mormon tea
McDonald Colony, Lincoln County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (96.8%)	*Muhlenbergia arenacea.*	Ear Muhly
	Scleropogon brevifolia	Burro grass
FORB (3 %)	*Solanum elaeagnifolium*	Silverleaf nightshade
	Amaranthus powellii	Careless weed
	Salsola kali	Tumbleweed
	Chamaesyce sp.	Rattlesnake weed
	Unknown forb	Unkn.
SHRUB (0.2 %)	*Gutierrezia sarothrae*	Snakeweed
San Francisco Colony, Chihuahua, Mexico		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (97.8 %)	*Bouteloua hirsuta*	Hairy grama
	Aristida adscensionis	Sixweeks threeawn
FORB (2 %)	*Eurotia lanata*	Winterfat
	Portulaca pilosa	Rose purslane
	Sphaeralcea sp.	Globemallow species
	Malvella sp.	Mallow
	Unknown forb	Unkn.
	Unknown forb	Seedling
	Tribulus terrestris	Goathead
	Unknown forb	Unkn.
	Unknown forb	Unkn.
	Astragalus sp.	Astragalus
SHRUB (0.2 %)	*Gutierrezia sp.*	Snakeweed

Rhoades Draw, White Sands Missile Range, Sierra County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (70 %)	*Muhlenbergia torreyii*	Ring muhly
FORB (0)	*Sphaeralcea sp.*	Globemallow species
SHRUB (30 %)	*Prosopis glandulosa*	Mesquite
	Atriplex canescens	Four-winged salt
	Gutierrezia sarothrae	Snakeweed
San Luis Draw, Hidalgo County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (65 %)	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa
	Hordeum glaucum	Barley
	Aristida sp.	Three Awn
	Buchloë dactyloides	Buffalo grass
	Eragrostis sp.	Lovegrass
	Chloris sp.	Windmill grass
FORB (32 %)	*Sphaeralcea sp.*	Globemallow species
	Solanum elaeagnifolium	Silverleaf nightshade
	Marrubium vulgare	Horehound
	Salsola kali	Tumbleweed
	Ipomoea barbatisepala	Bristle-cup morning
	Physalis hederifolia	Heartleaf
	Solanum jamesii	Wild potato
	Amaranthus powellii	Careless weed
SHRUBS (3 %)	*Prosopis glandulosa*	Mesquite
Salt Creek Draw, Sierra County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (99 %)	*Pleuraphis mutica*	Tobosa
FORB (0.5 %)	*Zinnia grandiflora*	Wild zinnia
	Lepidium montanum	Peppergrass
SHRUB (0.5 %)	*Artemisia filifolia*	Sand sage

Summit Draw, Hidalgo County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (99 %)	*Pleuraphis mutica*	Tobosa
FORB (0)	*Sphaeralcea sp.*	Globemallow species
	Unknown. Composite	Composite
SHRUB (1 %)	*Yucca baccata*	Banana-leaf yucca
	Prosopis glandulosa	Mesquite
Lava Tank, Sierra County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (86 %)	*Muhlenbergia porteri*	Bush muhly
	Panicum obtusum	Vine mesquite
	Muhlenbergia arenacea	Ear muhly
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
	Aristida adscensionis	Sixweeks Threeawn
	Eragostis sp.	Lovegrass
FORB (14.8 %)	*Amaranthus powellii*	Careless weed
	Mirabilis sp.	Four o'clock
	Chamaesyce albomarginata.	Rattlesnake weed
	Chamaesyce lata	Spurge
	Salsola kali	Tumbleweed
	Sphaeralcea sp.	Globemallow species
	Solanum elaeagnifolium	Sliver-leaf
	Chenopodium sp.	Goosefoot
	Unknown composite	Unknown
	Unknown buckwheat	Buckwheat
	Unknown forb	Unkn.
	Convolvulus equitanus	Dagger bindweed
SHRUB (0.2 %)	*Gutierrezia sarothae*	Snakeweed
George Wright, Hidalgo County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (71 %)	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa

	Chloris sp.	Windmill grass
	Schizachyrium scoparium	Little blue-stem
	Bouteloua barbata	Sixweeks grama
	Eragrostis sp.	Lovegrass
	Scleropogon brevifolia	Burro grass
FORB (6 %)	*Sphaeralcea sp.*	Globemallow
	Solanum elaeagnifolium	Silverleaf nightshade
	Croton sp.	Croton
	Salsola kali	Tumbleweed
	Amaranthus powellii	Careless weed
	Eriogoium sp.	Buckwheat
	Kochia scoparia	Kochia
	Acourtia nana	Desert holly
	Unkn.	Unknown composite
	Sphaeralcea sp.	Prostrate mallow
SHRUB (23 %)	*Gutierrezia sarothrae*	Snakeweed
	Prosopis glandulosa	Mesquite

Stewart Gauge, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (62 %)	*Aristida harvardii*	Sixweeks threeawn
	Scleropogon brevifolia	Burro grass
FORB (0)	*Sphaeralcea sp.*	Globemallow species
	Unknown. Composite	Composite
SHRUB (38 %)	*Flourensia cernua*	Tarbush
	Prosopis glandulosa	Mesquite

Stewart Gauge, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (62 %)	*Aristida harvardii*	Sixweeks threeawn
	Scleropogon brevifolia	Burro grass
FORB (0)	*Sphaeralcea sp.*	Globemallow species
	Unknown. Composite	Composite
SHRUB (38 %)	*Flourensia cernua*	Tarbush
	Prosopis glandulosa	Mesquite

Ladder Ranch, Sierra County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (78 %)	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa
	Bouteloua gracilis	Blue grama
	Bouteloua curtipendula	Side oats grama
	Aristida sp.	Three Awn
	Scleropogon brevifolia	Burro grass
	Muhlenbergia arenacea	Ear muhly
	Chloris sp.	Windmill grass
	Unknown grass	Unknown
FORB (6 %)	*Sphaeralcea sp.*	Globe mallow
	Mirabilis linearis	Narrow-leaf desert four o'clock
	Dimorphocarpa wislizenii	Spectaclepod
	Acourtia nana	Desert holly
	Kochia scoparia	Kochia
	Salsola kali	Tumbleweed
	Solanum elaeagnifolium	Silverleaf nightshade
	Chenopodium neomexicanum	Chenopodium
	Talinum angustissimum	Talinum
	Drymaria effusum	Low drymary
	Convolvulus equitanus	Dagger bindweed
	Viguiera stenoloba	Goldeneye
	Amaranthus powellii	Powell amaranth
	Senecio flaccidium	Threadleaf groundsel
	Chamaesyce sp.	Rattlesnake weed
	Berlandia lyrata	Greeneyes
SHRUB (16 %)	*Prosopis glandulosa*	Mesquite
	Flourensia cernua	Tarbush

Deep Well, Pedro Armenderis Ranch, Sierra County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (89 %)		Mesa dropseed
	Bouteloua curtipendula	Side-oats grama
	Scleropogon brevifolia	Burro grass
FORB (1 %)	*Solanum elaeagnifolium*	Silver-leaf
	Portulaca pilosa	Rose purslane
	Unknown	Unknown
	Pericome caudata	Taperleaf
SHRUB (10 %)	*Prosopis glandulosa*	Mesquite
	Atriplex canescens	Four-winged salt
Miller Ranch, Cochise County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (76 %)	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa
	Bouteloua hirsuta	Hairy grama
	Bouteloua barbata	Sixweeks grama
	Eragrostis sp.	Lovegrass
	Bothriochloa sp.	Beardgrass
	Muhlenbergia porteri.	Bush muhly
	Aristida ternipes var. *gentilis.*	Hook Threeawn
FORB (3 %)	*Solanum elaeagnifolium*	Silverleaf nightshade
	Amaranthus powellii	Careless weed
	Astragalus sp.	Locoweed
	Unknown composite	Unkn.
	Unknown forb	Unkn.
	Chenopodium leptophyllum	Narrow-leafed
	Hymenothrix wrightii	Wright's
	Acacia sp.	Catclaw acacia
	Sphaeracae sp.	Globemallow species
SHRUB (21 %)	*Prosopis glandulosa*	Mesquite
	Gutierrezia sarothrae	Snakeweed

Boss Ranch, Cochise County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASSES	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa
	Pleuraphis jamesii	Galleta
	Bouteloua sp.	Unknown grama
	Aristida sp.	Threeawn
FORBS	*Solanum elaeagnifolium*	Silverleaf nightshade
	Amaranthus powellii	Careless weed
SHRUBS	*Prosopis glandulosa*	Mesquite
Middle Well, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (54 %)	*Pleuraphis mutica*	Tobosa
	Bouteloua barbata	Sixweeks grama
	Scleropogon brevifolia	Burro grass
FORB (0)	*Chamaesyce micromera*	Spurge
	Cassia bauhinia	Two-leaf senna
SHRUBS (46 %)	*Prosopis glandulosa*	Mesquite
Corner Tank, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (64 %)	*Aristida harvardii*	Sixweeks threeawn
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
FORB (2 %)	*Chamaesyce albomarginata*	Rattlesnake weed
	Sphaeralcea emoryii	Emory's
	Echinocerus sp.	Echinocerus cactus
	Acourtia nana	Desert holly
	Croton potsii	Croton
	Lepidium montanum	Peppergrass
SHRUB (33 %)	*Gutierrezia sarothrae*	Snakeweed
	Flourensia cernua	Tarbush

West Well, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (10 %)	*Panicum obtusum*	Vine mesquite
	Setaria leucopila	Plains bristlegrass
	Sporobolus flexuosus	Sand drop seed
	Aristida adscensionis	Sixweeks threeawn
	Dasyochloa pulchella	Fluffgrass
FORB (3 %)	*Sphaeralcea sp.*	Globe mallow
	Solanum elaeagnifolium	Silverleaf nightshade
	Croton sp.	Croton
	Salsola kali	Tumbleweed
	Eriogonum sp.	Buckwheat
	Cassia bauhinoides	Two-leaf senna
	Acourtia nana	Desert holly
	Unkn.	Unknown composite
	Sphaeralcea sp.	Prostrate mallow
SHRUB (87 %)	*Gutierrezia sarothrae*	Snakeweed
	Prosopis glandulosa	Mesquite
	Yucca baccata	Banana-leaf yucca
Headquarters, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (38 %)	*Panicum obtusum*	Vine mesquite
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
	Sporobolus flexuosus	Sand drop seed
	Muhlenbergia aarenacea	Ear muhly
FORB (7 %)	*Sphaeralcea sp.*	Globemallow species
	Sphaeralcea fenderli	Fendler's
	Chamaesyce sp.	Rattlesnake weed
	Portulaca oleracea	Portulaca
	Astragalus sp.	Locoweed
SHRUB (55 %)	*Prosopis glandulosa*	Mesquite

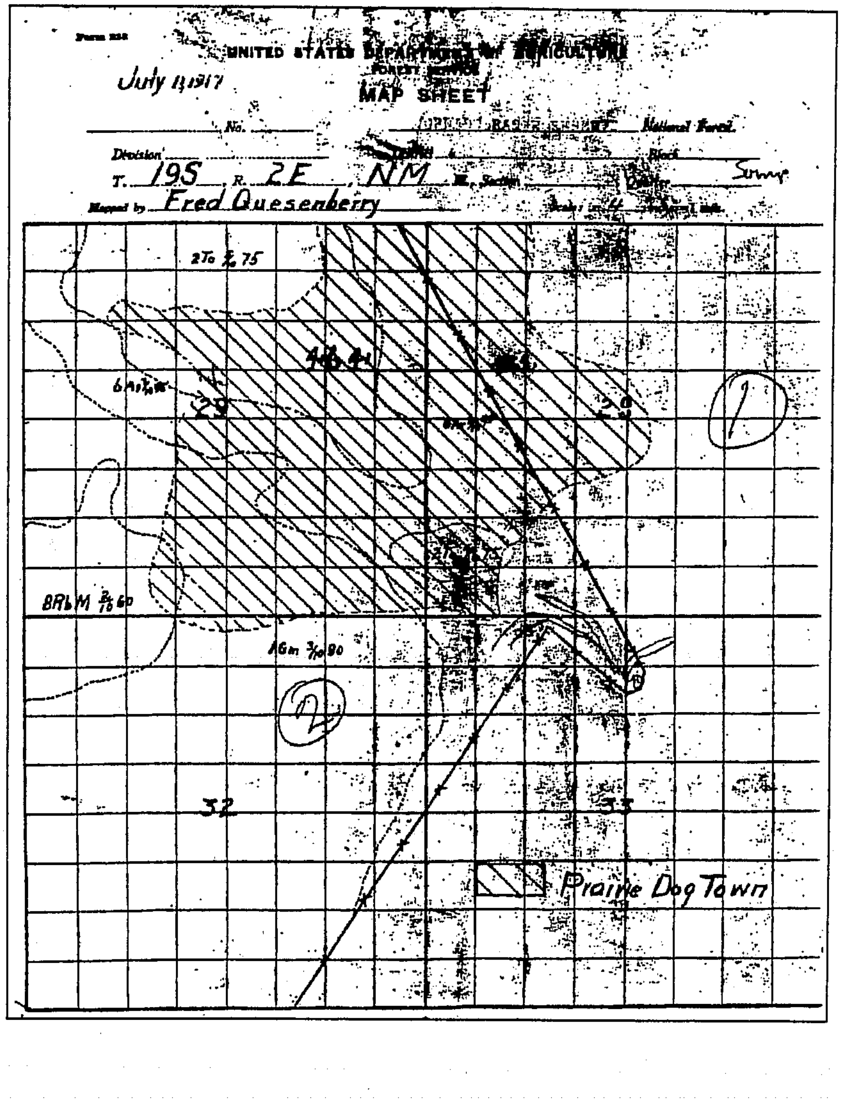
Antelope Flat, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (41 %)	*Panicum obtusum*	Vine mesquite
	Aristida adscensionis	Sixweeks threeawn
	Dasyochloa pulchella	Fluffgrass
	Aristida purpurea	Purple threeawn
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
	Sporobolus flexuosus	Sand drop seed
	Bouteloua barbata	Sixweeks grama
	Muhlenbergia porteri	Bush muhly
FORB (8 %)	*Sphaeralcea sp.*	Globe mallow
	Bahia absinthifolia	Hairyseed bahia
	Solanum elaeagnifolium	Silverleaf nightshade
	Psilostrophe tagetina	Paperflower
	Eriogonum sp.	Buckwheat
	Cassia bauhinoides	Two-leaf senna
	Unkn.	Unknown composite
SHRUB (51 %)	*Gutierrezia sarothrae*	Snakeweed
	Atriplex canescens	Four-wing saltbush
	Acacia constricta	Western whitethorn
	Prosopis glandulosa	Mesquite
Big Sandy, Jornada Experimental Range, Doña Ana County		
CLASS (Relative Cover)	SCIENTIFIC NAME	PLANT NAME
GRASS (29 %)	*Panicum obtusum*	Vine mesquite
	Dasyochloa pulchella	Fluffgrass
	Aristida purpurea	Purple threeawn
	Pleuraphis mutica	Tobosa
	Scleropogon brevifolia	Burro grass
	Sporobolus flexuosus	Sand drop seed
	Bouteloua barbata	Sixweeks grama
	Muhlenbergia porteri	Bush muhly
FORB (23 %)	*Aphanotlephus ramosissimus*	Burr ragweed

	Bahia absinthifolia	Hairyseed bahia
	Solanum elaeagnifolium	Silverleaf nightshade
	Dimorphocarpum wislizenii	Spectaclepod
	Caesalpinia jamesii	Caesalpinia
	Zinnia grandiflora	Wild zinnia
	Croton potsii	Croton
	Chamaesyce prostrata	Prostrate spurge
	Cassia bauhinoides	Two-leaf senna
SHRUB (47 %)	*Gutierrezia sarothrae*	Snakeweed
	Prosopis glandulosa	Mesquite

Appendix D

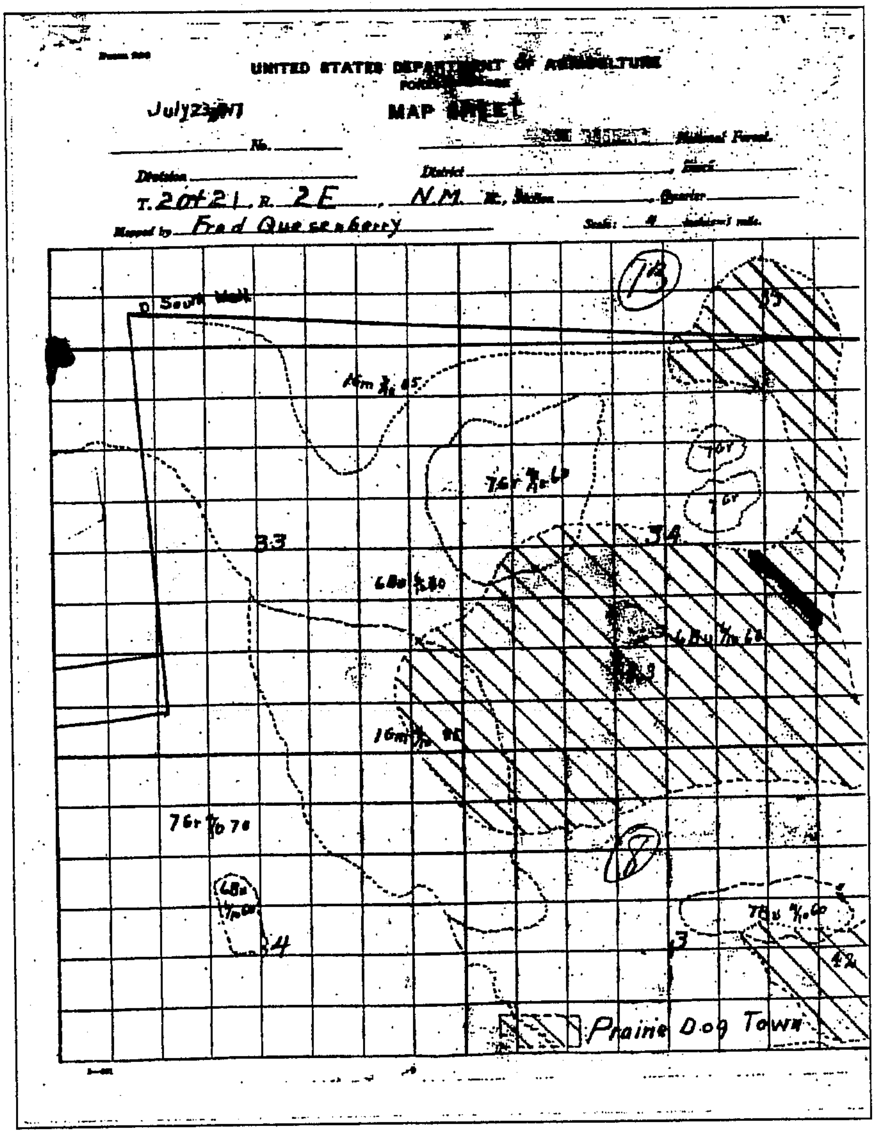
1917 Maps of Prairie Dog Towns and Vegetation on the Jornada Experimental Range

MAP SHEET 1



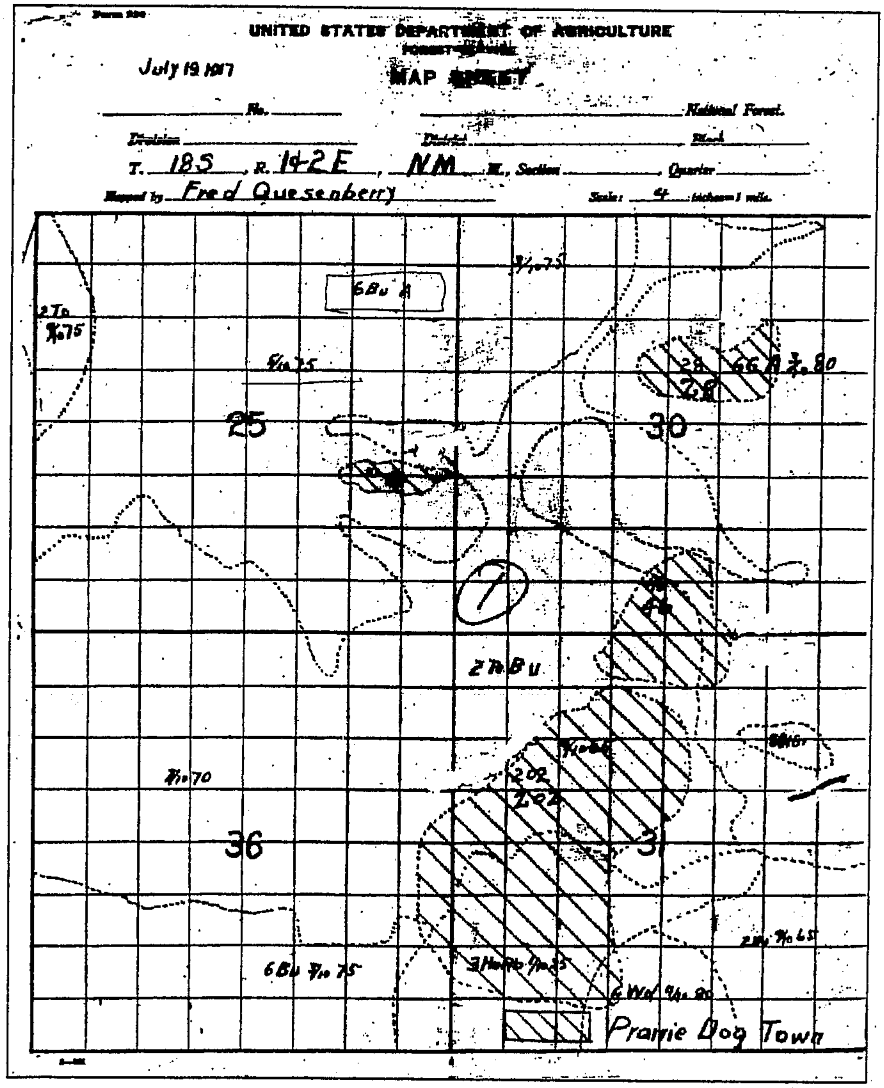
Source: Quesenberry, F. 1917.

MAP SHEET 2



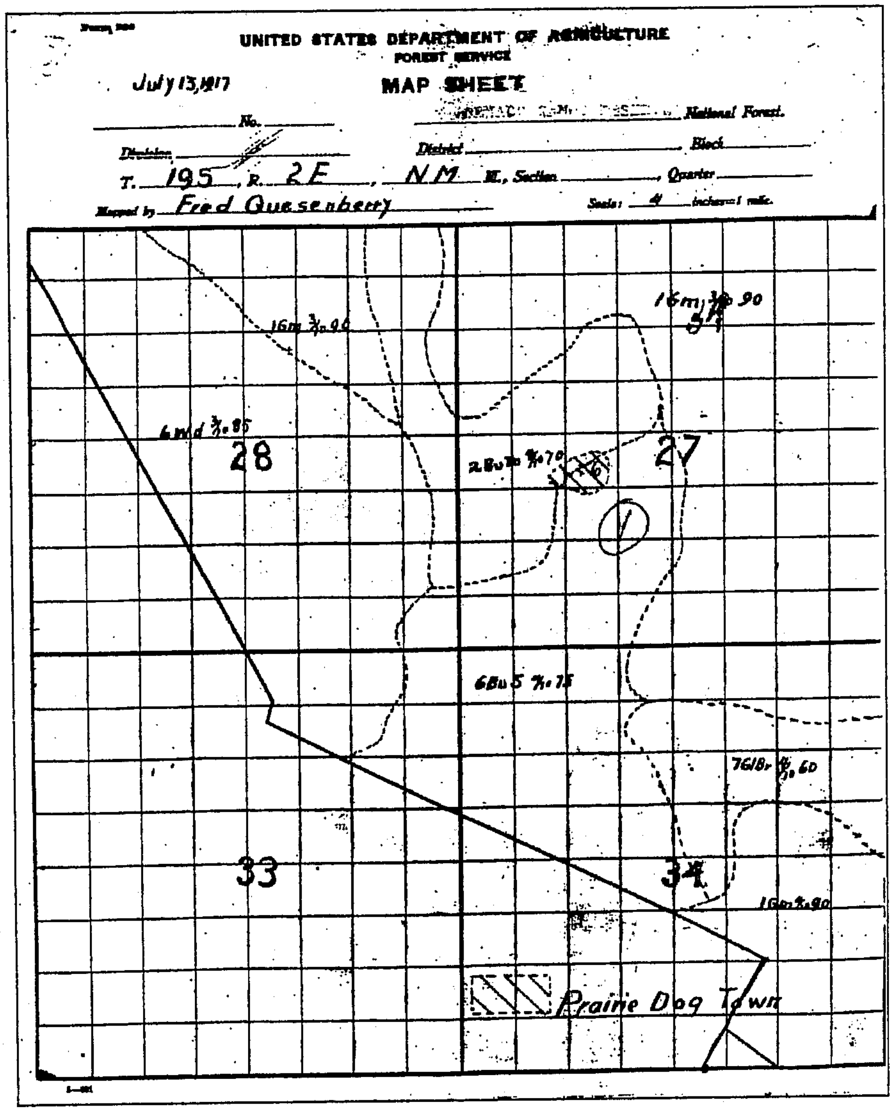
Source: Quesenberry, F. 1917.

MAP SHEET 3



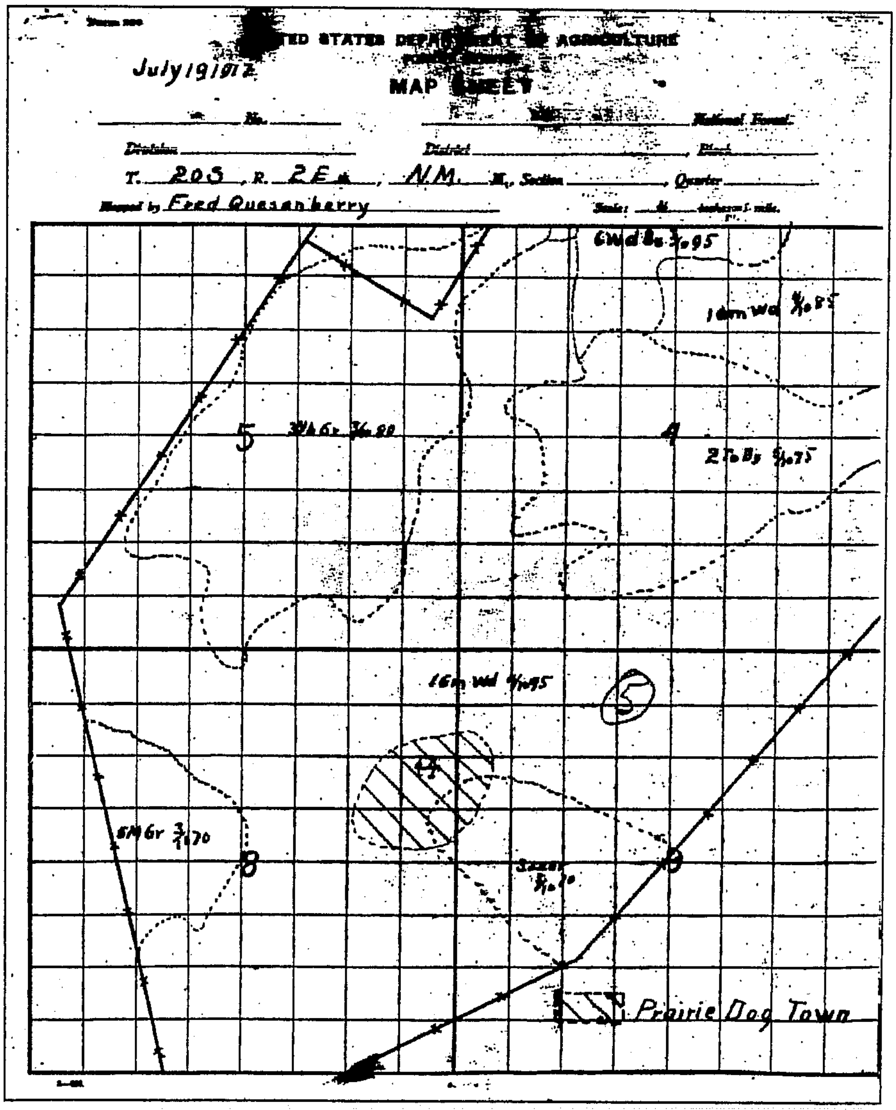
Source: Quesenberry, F. 1917.

MAP SHEET 4



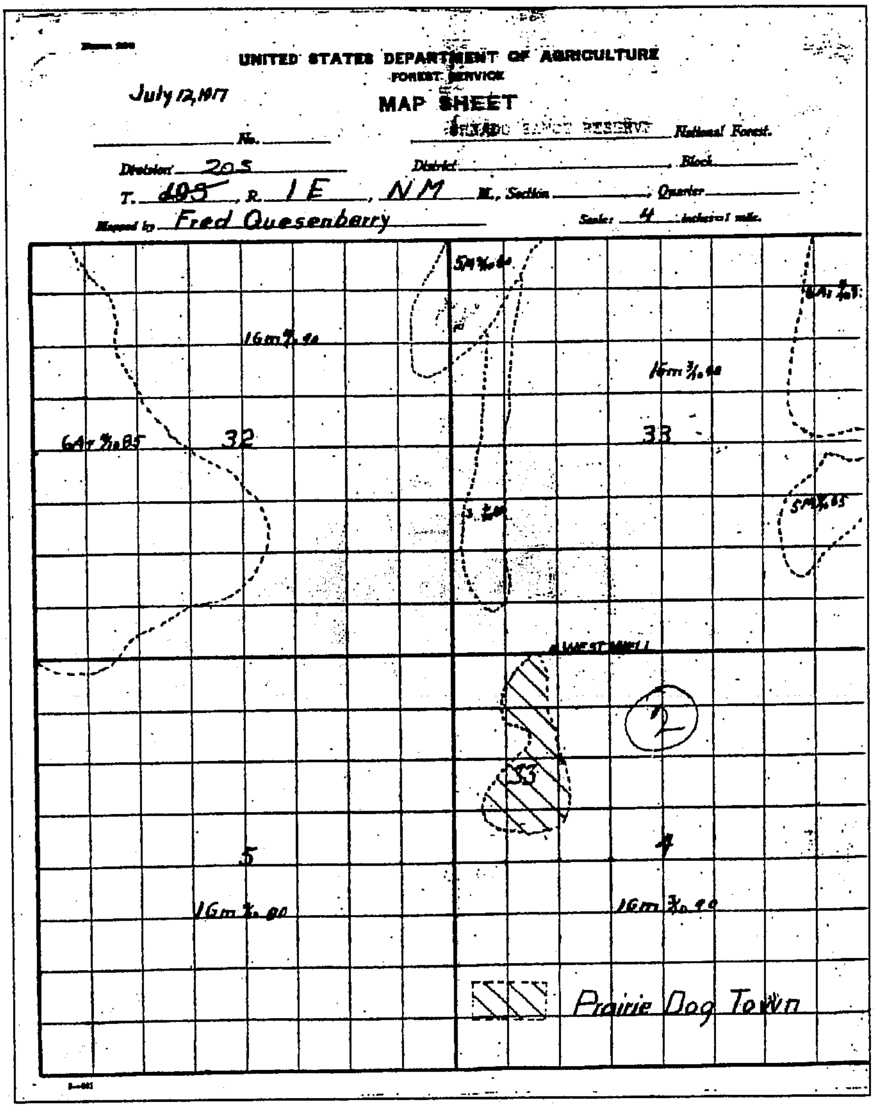
Source: Quesenberry, F. 1917.

MAP SHEET 5



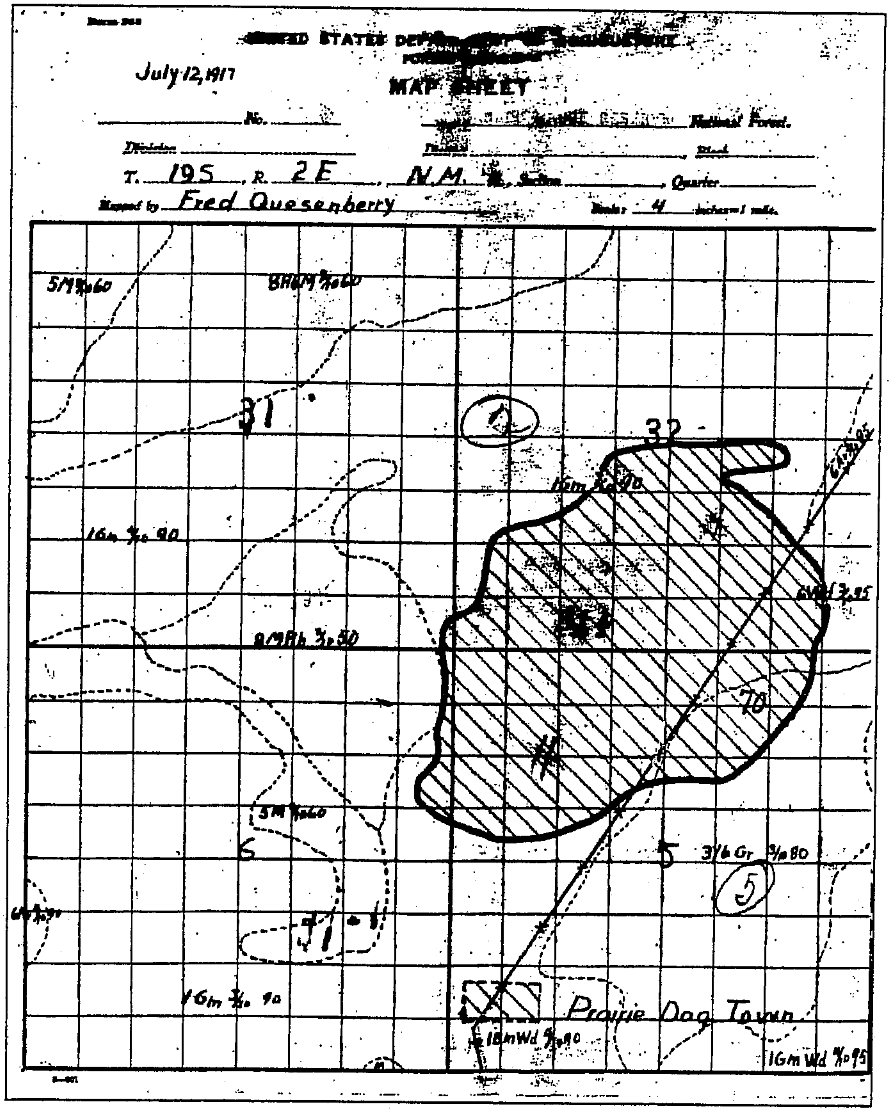
Source: Quesenberry, F. 1917.

MAP SHEET 6



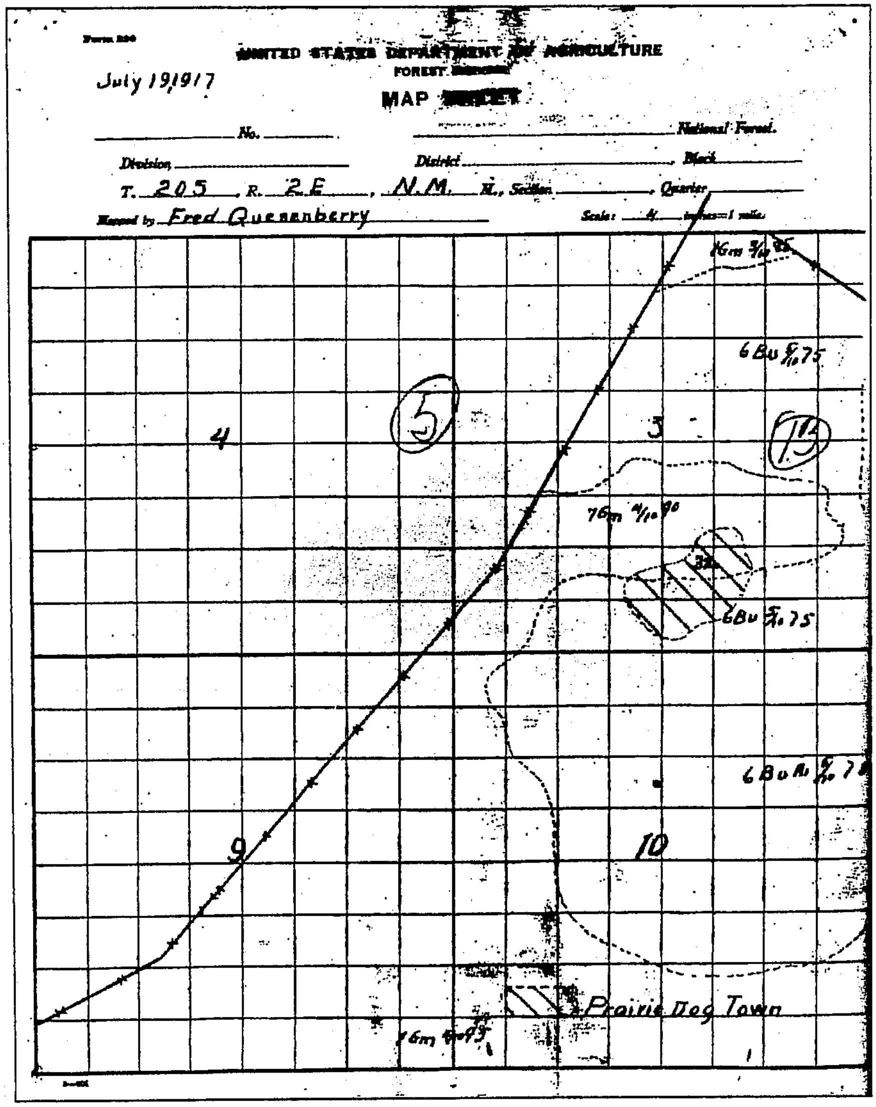
Source: Quesenberry, F. 1917.

MAP SHEET 7



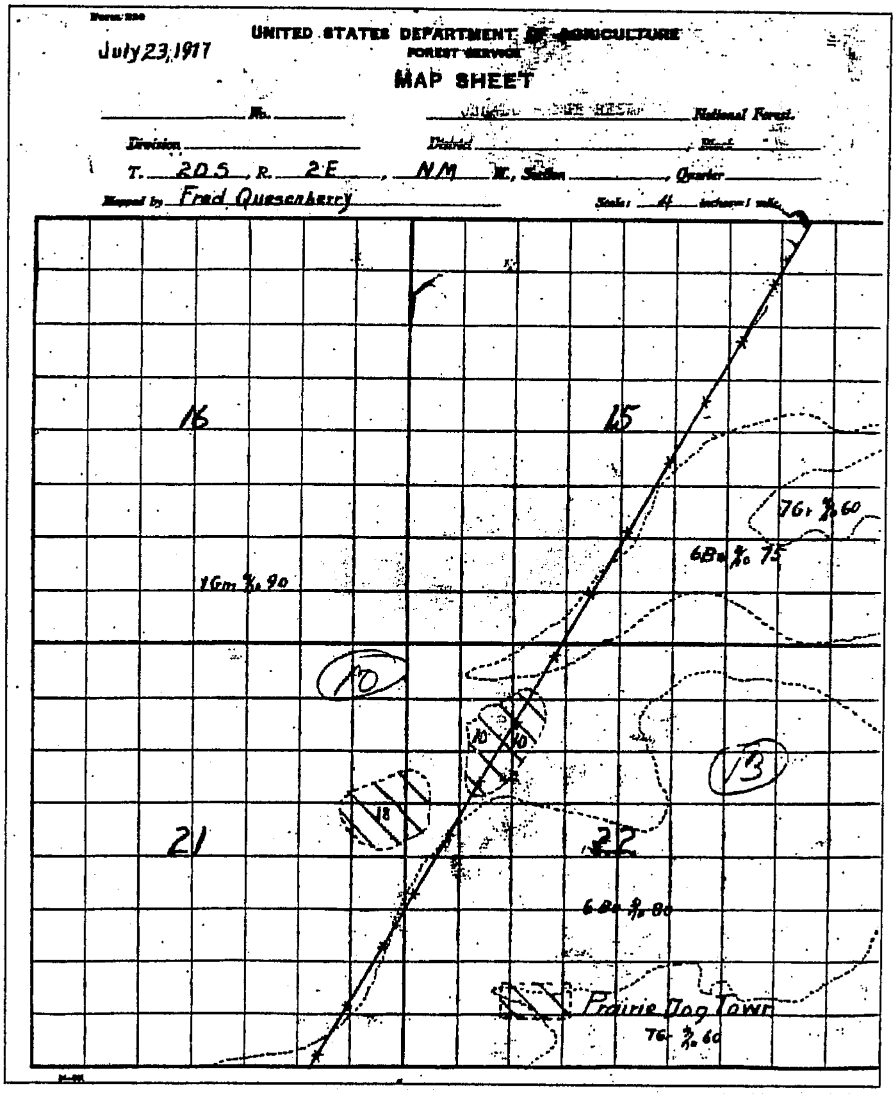
Source: Quesenberry, F. 1917.

MAP SHEET 8



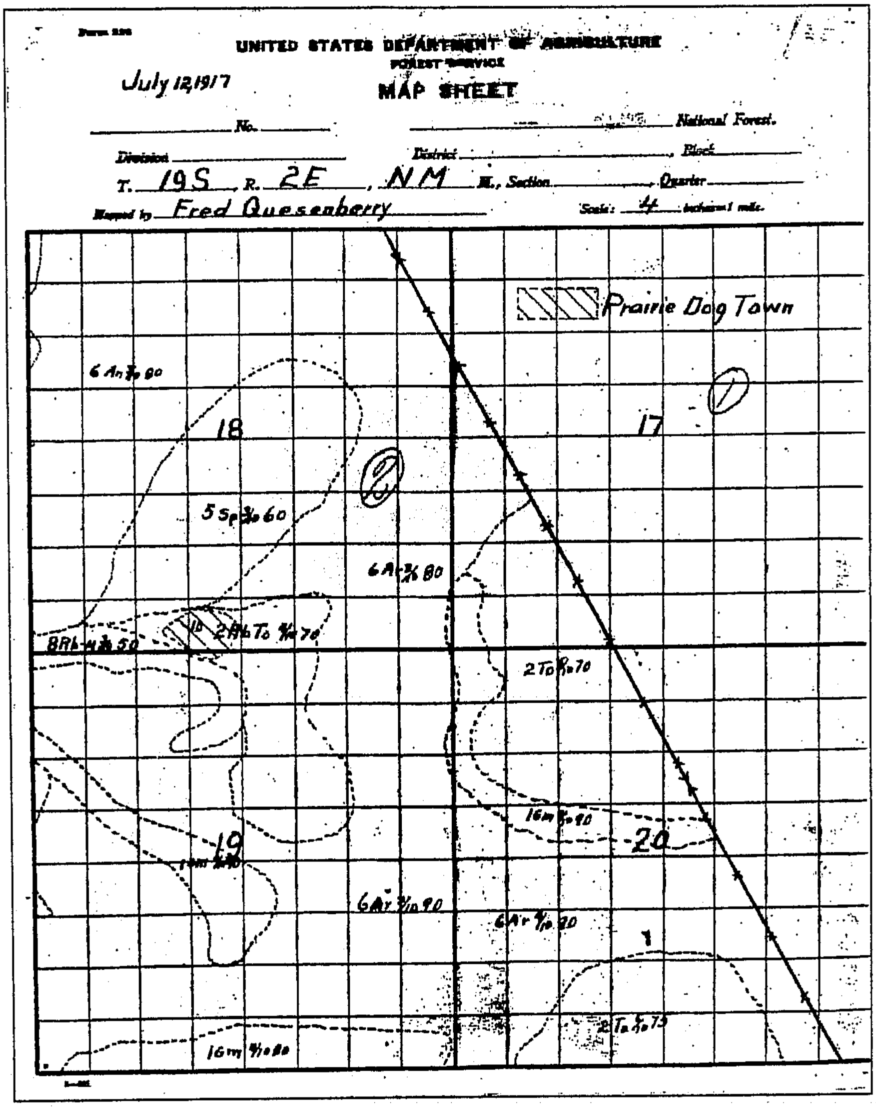
Source: Quesenberry, F. 1917.

MAP SHEET 9



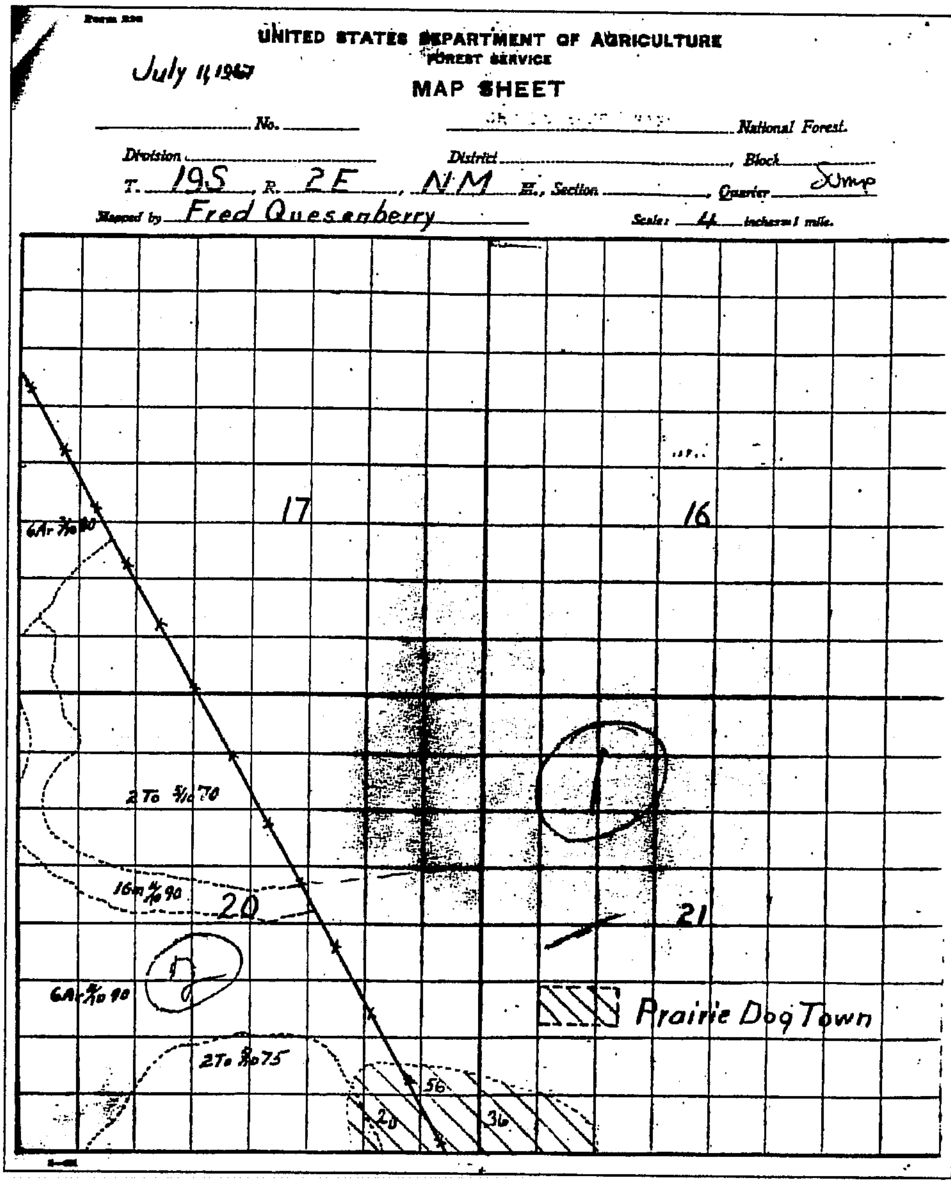
Source: Quesenberry, F. 1917.

MAP SHEET 10



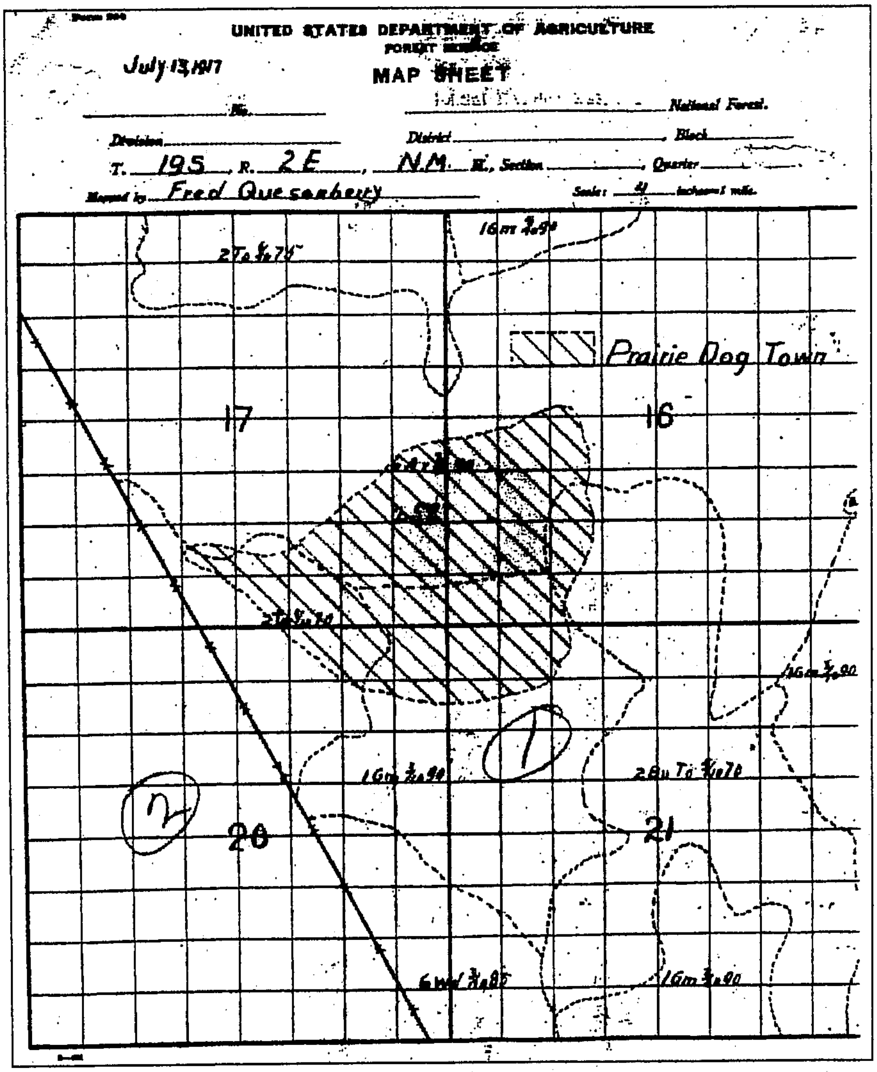
Source: Quesenberry, F. 1917.

MAP SHEET 11



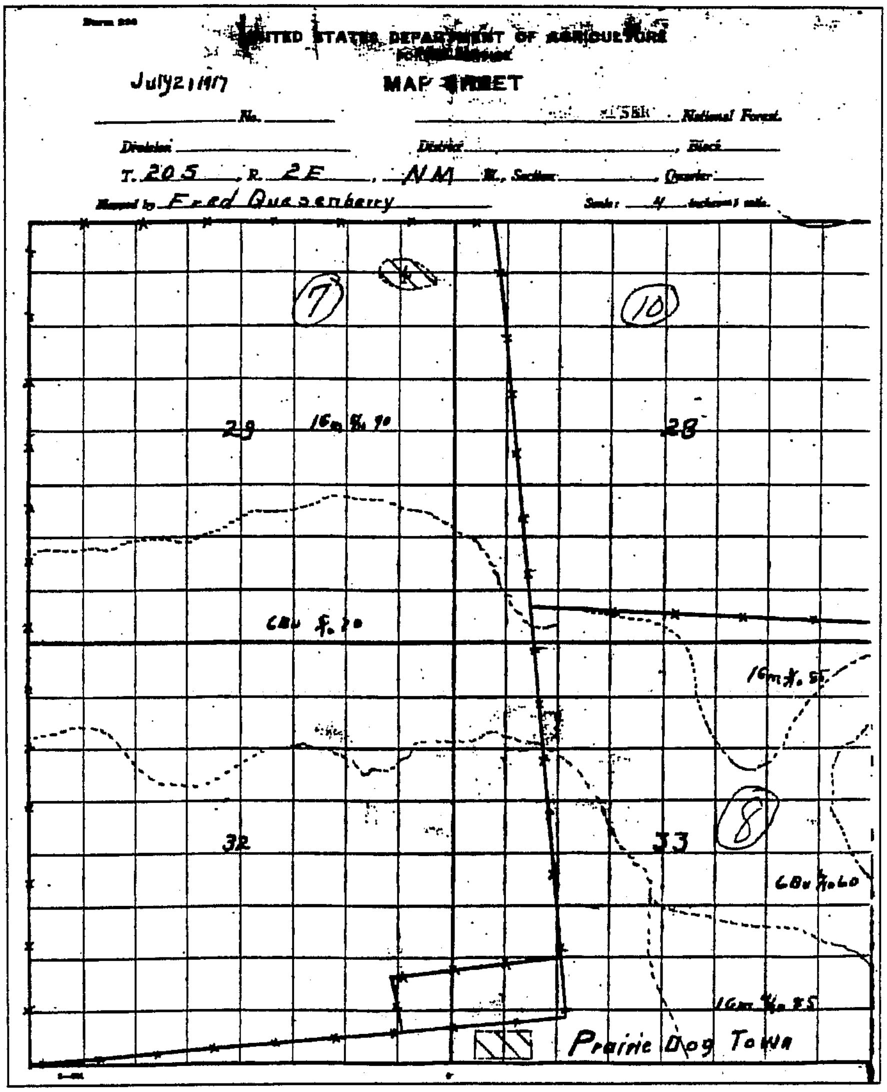
Source: Quesenberry, F. 1917.

MAP SHEET 12



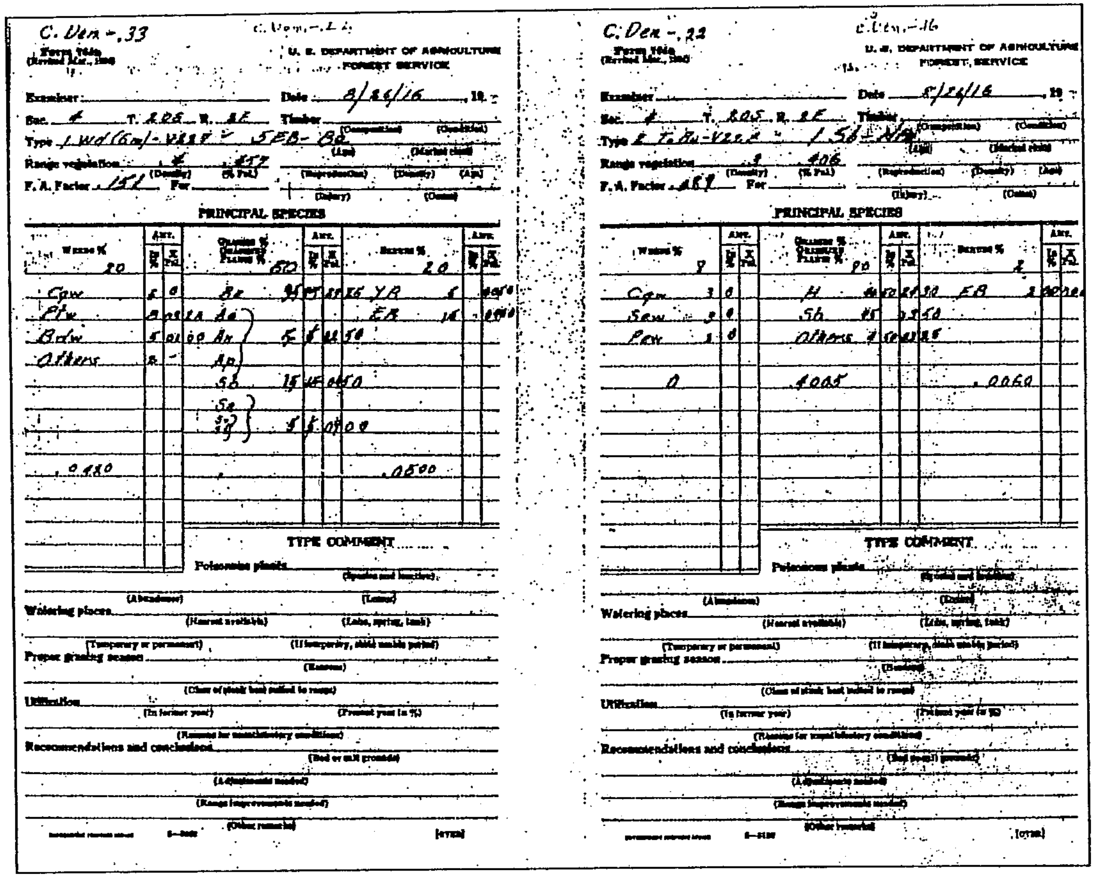
Source: Quesenberry, F. 1917.

MAP SHEET 13



Source: Quesenberry, F. 1917.

EXAMPLE VEGETATION DATA SHEET



Source: Jornada Experimental Range, 1915.

Appendix E

Jornada Experimental Range 1915 Vegetation Data

Overall JER Vegetation Types, 1915 (n=260)

GRASS %	FORB %	SHRUB %
30	6	64
55	3	42
40	6	54
80	3	17
50	6	44
50	5	45
40	7.5	52.5
30	8	62
30	2	68
10	15	75
40	7.5	52.5
40	6	54
10	2	88
30	1.5	63.5
25	15	55
30	7.5	67.5
30	0	70
45	10	60
60	2.5	52.5
40	5	35
30	0	60
50	5	65
50	6	44
85	5	45
40	5	10
40	3	57
15	6	54
35	7.5	77.5
45	12	53
15	4	51
10	12	73
5	7	83
10	5	90

Overall JER Vegetation Types, 1915 (Cont.)

10	9	81
20	5	85
55	12	68
50	5	40
45	7.5	42.5
40	6	49
45	3.75	56.25
45	3.95	51.05
20	3.75	51.25
45	4.5	75.5
55	3.5	51.5
80	4	41
35	10	10
15	4	61
35	16.6	68.5
35	16.5	48.5
45	15	50
30	26	49
30	5	50
25	17.5	52.5
30	19.5	50.5
15	14	61
15	16	54
10	10.5	74.5
10	15	70
10	11.25	78.75
10	12	78
15	8.75	81.25
5	15	70
5	6.25	88.75
70	0	30
5	10.5	89.5
30	12	58
5	21	74
5	8.75	86.25
10	32	58
10	34	56
10	7.5	82.5
5	30	65
15	0	85
10	27	63

Overall JER Vegetation Types, 1915 (Cont.)

5	28	67
70	0	30
15	13.5	71.5
10	22.5	67.5
85	4	11
85	0	15
60	33.25	6.75
15	5	80
25	9.75	65.25
50	15.75	34.25
80	2.4	17.6
90	1.4	8.6
80	12.75	7.25
10	15	75
30	13.5	56.5
50	16	34
10	15.4	74.6
65	35	0
80	5.1	14.9
85	4	11
70	10.95	19.05
65	20	15
10	12	78
20	12.5	67.5
80	2.5	17.5
15	12.25	72.75
35	10	55
10	8.75	81.25
90	2.5	7.5
75	5	20
10	66.4	23.6
70	11.25	18.75
65	13.5	21.5
40	22.5	37.5
10	20	70
15	18	67
30	12	58
30	18	52
15	8	77
15	9.25	75.5
85	5.5	9.5
60	26	14

Overall JER Vegetation Types, 1915 (Cont.)

30	9	61
40	2	58
35	4.5	60.5
30	6	64
40	3	57
65	9	26
50	4	46
80	5	15
0	100	0
70	20	10
70	12	18
10	10	80
60	35	5
90	10	0
70	24	6
15	58.8	26.2
10	24.6	65.4
30	13	57
60	16.45	23.55
60	16.25	23.75
80	4.6	15.4
15	20	65
65	15.6	19.4
10	10.5	79.5
5	15	80
10	30	60
10	1	89
0	31.7	68.3
5	64.5	30.5
0	7.2	92.8
0	5.5	94.5
60	18	22
10	13.35	76.65
10	15	75
10	20	70
5	8.5	86.5
10	30	60
5	15	80
85	8.5	6.5
5	15	80
15	18.5	66.4
85	12	3

Overall JER Vegetation Types, 1915 (Cont.)

5	15	80
75	6.8	18.2
5	8.4	86.6
10	11.25	78.75
15	5	80
70	16.2	13.8
50	37.2	12.8
85	6.8	8.2
60	25.2	14.8
10	18	72
20	12.9	67.1
85	9.9	5.1
15	18	67
20	10	70
47.25	14.75	40.75
37	12	51
40	9.2	55.8
25	12	63
83	10.2	6.8
65	22.5	12.5
87	4.5	8.5
85	10.5	4.5
85	10	5
87	4.4	8.6
80	12.45	7.55
65	10	25
80	5	15
80	6.75	13.25
95	4.5	0.5
90	9	1
90	7.2	2.8
50	2.5	47.5
95	4.75	0.25
55	15	30
15	5	80
75	5	20
30	2.8	67.2
20	8.5	71.5
60	0	40
30	15	55
40	1.05	58.95
25	3.5	71.5

Overall JER Vegetation Types, 1915 (Cont.)

40	56.4	3.6
70	30	0
45	55	0
25	4	71
95	2.7	2.3
35	5	60
95	2.7	2.3
95	2.7	2.3
50	4.78	45.25
50	4.75	45.25
50	8.6	41.4
45	8	47
50	10	40
50	10	40
60	10	30
50	4.1	45.9
75	1.5	23.5
60	26.4	13.6
70	3.5	26.5
50	4.1	45
25	9.75	65.25
20	80	0
45	3.75	51.25
20	30	50
10	10.5	79.5
67	1	32
95	2	3
95	2	3
80	8.3	11.7
67	1	32
10	80.7	9.3
60	30	10
80	15.3	4.7
80	15.3	4.7
70	12	18
70	12	18
85	5	10
90	0	10
90	7	3
90	7	3
80	18	2
85	4.8	10.2

Overall JER Vegetation Types, 1915 (Cont.)

87	4.4	8.6
60	20	20
90	9.5	0.5
85	7.3	7.7
65	27.6	7.4
65	27.6	7.4
55	35	10
90	10	0
95	5	0
95	5	0
70	18.7	11.3
95	5	0
95	5	0
65	22	13
85	9.5	5.5
65	27.7	7.3
85	9.5	5.5
65	27.7	7.4

Overall 1915 JER Unweighted Vegetation Structural Averages:

45.43 % Grass　　12.85 % Forb　　41.59 % Shrub

Glossary

Alluvial toeslope:	The base of the long slope of an alluvial fan where the slope flattens to 0-4°. Alluvial deposition and subsurface water movement are common.
Arroyo:	A channel or wash of an ephemeral or intermittent stream with banks of unconsolidated material, often vertical.
Bajada:	Long slope of an alluvial fan in which processes of mass movement, surface wash and redeposition take place, with typical slopes of 4-25°. Also known as the mid-slope and colluvial footslope.
BBS	Bureau of Biological Survey
Bench:	A narrow strip of relatively level land, usually parallel to and higher than a valley bottom, with a steeply ascending slope on the side away from the valley bottom.
Blow-out:	A hollow depression and gully formed from the collapse of soil overlying a subsurface pipe transporting water and solutes, creating an abrupt connection into the surface drainage.
CCC:	Civilian Conservation Corps
Chimney:	Ephemeral vertical pipes surrounded by standing

columns of unconsolidated sediment that form along actively eroding gully walls.

Clay: Fine soil particle <2 μ in diameter.

Coppice dune: A mound of windblown sand usually stabilized by deeply rooted woody vegetation.

Draw: Broad, open and gently sloping valley surrounded by low hills.

Discontinuous gully: Recently-formed wash or channel with a blow-out or steep up-slope face, and steep walls tapering at the down-slope end to the level of the original channel bed.

Edaphic: Site conditions of soil, nutrient levels and water retention that affect vegetation.

Erosion: The natural or accelerated mass movement of sediment by wind or water.

Gully: Recently-formed wash or channel with steep, unconsolidated banks.

Hill slope: The sloping side of a well-defined natural elevation that is smaller than a mountain.

JER: Jornada Experimental Range

Loam: Nomenclature for intermediate soil textures with relatively high silt content, usually greater than 65 %.

Low rise: A minor but distinct elevation of the ground above the surrounding terrain.

Normal drainage:	Inflow approximately equals the run-off at a site.
Microterrain:	The variation in minor surface topography and edaphic conditions , usually composed of elevational differences of less than one meter.
PARC:	Predator and Rodent Control
Pan:	Denuded smooth soil surface that is relatively impervious to water, across which sheetflow occurs.
Plain:	An area of some extent, generally uniform in slope and unbroken by marked elevations or depressions.
Physiognomic structure:	Descriptive vegetation categories based on a combination of growth form and functional (e.g. perennial grasses, evergreen shrubs).
Pipe:	Major subsurface pathways for concentrated lateral subsurface water movement. Soil thickness, slope, burrow networks or macropores.
Playa:	A shallow drainage basin with little or no outlet, that holds ephemeral or seasonal water accumulations until they evaporate.
Receiving drainage:	Inflow of surface water exceeds the run-off at a site.
Ridge:	A relatively narrow, steep sided elevation, often occurring between drainages.
Rill:	Small ephemeral channel in which surface run-off is

concentrated, particularly on silty or clayey soils.

Saddle: A low point on a ridge or the shoulder of a mountain, usually dividing streams flowing in opposite directions.

Sand: A coarse mineral particle, >60μ in diameter.

Shedding drainage: Run-off from the site is greater than the inflow at a site.

Sheet erosion: Mass transport of sediments from unconcentrated flow of run-off across a relatively smooth surface. Can be recognized by the exposure of roots, pebbles, or B-horizons at the surface.

Sheetflow: The unconcentrated flow of run-off across a relatively smooth land surface.

Silt: Intermediate-sized soil particle, 2-60μ in diameter.

Slope The angle of vertical displacement from the horizontal in the lay of the land.

Swale: Gentle drainage without a defined channel, usually found in an open plain.

Terrace: A narrow strip of level land perched between an upslope and downslope leading to a drainage or playa.

Topoedaphic: The combination of edaphic conditions and topography of a site that affect vegetation.

Trough: Non-draining narrow depression formed by collapse of overburden into a subsurface pipe or burrow.

USDA: United States Department of Agriculture

USF&WS:	United States Fish and Wildlife Service
Valley:	A low-lying area bounded by hills, mesas, interfluvials, or mountain ranges and usually traversed by drainages.
Vegetation structure:	Descriptive vegetation categories based on growth form.
WSMR:	White Sands Missile Range

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Vita

Claudia Lea Oakes was born in Long Beach, California on September 21, 1949, daughter of Claude B. Oakes and Shirley L. Oakes. Claudia enrolled in the University of California at Riverside after graduating from Yucaipa High School, Yucaipa California in 1967. She transferred to the University of California at Berkeley in 1968 and Northern Arizona University in 1970, where she pursued undergraduate studies in Anthropology. In 1971, Claudia left the university to raise a family and pursue a career as an environmental technician.

In 1980, Claudia received a Bachelor of Science degree in zoology from the University of Texas at Austin. From 1981 through 1987, Claudia taught chemistry and biology in high schools in Bloomington and Austin, Texas. In 1987, she moved to Bangkok Thailand, where she taught science at the International School of Bangkok. In 1990, she received a Masters of Science degree from Mahidol University in Thailand for her ecological studies on white-handed gibbons. Articles on her research have been published in the *American Journal of Primatology* and the *Natural History Bulletin of the Siam Society*. She entered the Graduate School of the University of Texas in September, 1991. Since 1994, Claudia has been employed as an environmental and natural resource consultant.

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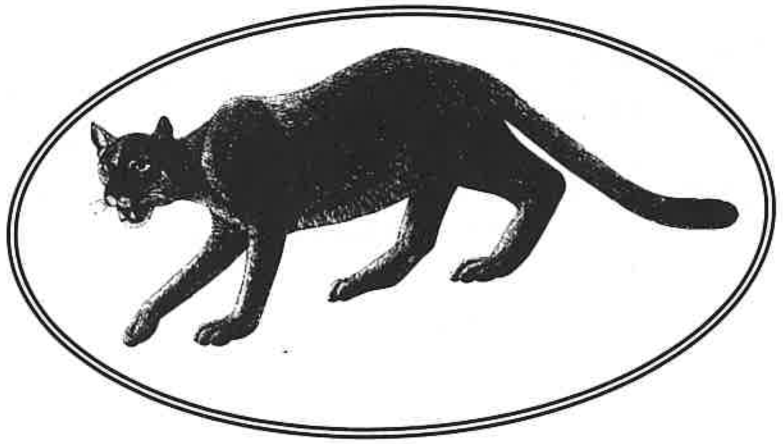

Conservation Genetics of the Felidae

Stephen J. O'Brien and Collaborators *

Introduction

The Felidae family comprises 38 living species that have fascinated naturalists, biologists, artists, children, and nearly everyone else for thousands of years (Guggisberg, 1975; Nowak, 1991; Seidensticker and Lumpkin, 1991). Because of their agility, speed, and efficient specialization as killer-carnivores, felids occupy the top of the trophic food chain in most habitats on all continents. Yet their ferociousness and predatory elegance have also instilled fear in humans, and persecution of felids has been an integral component of human civilizations, particularly agrarian societies. Even today, many of the big cats are central targets of "problem animal" control programs throughout the world—from Missoula, Montana (pumas), to Windhoek, Namibia (cheetahs), to Sasan-Gir, India (lions), to Fos du Iguazu, Brazil (jaguars). Man's antagonism toward large predators and the constant pressures on natural habitats have led to the situation in which 37

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Box 3.1. Taxonomic and Conservation Status in the Family Felidae

Species (number of subspecies)	U.S. Fish and Wildlife Service listing	IUCN listing
Pantherine lineage		
Cheetah, *Acinonyx jubatus* (5)	Endangered	Vulnerable (1 subsp. Endangered)
Lion, *Panthera leo* (8)	Endangered (1 subsp. only)	Endangered (1 subsp. only)
Tiger, *Panthera tigris* (5)	Endangered	Endangered
Leopard, *Panthera pardus* (27)	Endangered	Vulnerable (2 subsp. Endangered)
Jaguar, *Panthera onca* (8)	Endangered	Vulnerable
Snow leopard, *Panthera uncia* (0)	Endangered	Endangered
Clouded leopard, *Neofelis nebulosa* (4)	Endangered	Vulnerable
Marbled cat, *Pardofelis marmorata* (2)	Endangered	
North American lynx, *Lynx canadensis* (2)	Threatened	
Bobcat, *Lynx rufus* (12)	Endangered (1 subsp. only)	
Eurasian lynx, *Lynx lynx* (7)	Threatened	
Spanish lynx, *Lynx pardina* (0)	Endangered	Vulnerable
Caracal, *Caracal caracal* (9)	Threatened	
Serval, *Leptailurus serval* (15)	Endangered (1 subsp. only)	
African golden cat, *Profelis aurata* (2)	Threatened	
Asian golden cat, *Profelis temmincki* (3)	Endangered	
Leopard cat, *Prionailurus bengalensis* (11)	Endangered (1 subsp. only)	
Fishing cat, *Prionailurus viverrina* (2)	Threatened	
Flat-headed cat, *Ictailurus planiceps* (0)	Endangered	
Rusty-spotted cat, *Prionailurus rubiginosa* (2)	Threatened	
Bay cat or Bornean red cat, *Profelis badia* (0)	Threatened	Rare
Iriomote cat, *Mayailurus iriomotensis* (0)	Endangered	Endangered
Jaguarundi, *Herpailurus yagouaroundi* (8)	Endangered (4 subsp. only)	
Puma, *Puma concolor* (30)	Endangered (3 subsp. only)	Endangered (2 subsp. only)

Box 3.1. *(cont.)*

Species (number of subspecies)	U.S. Fish and Wildlife Service listing	IUCN listing
Ocelot lineage		
Ocelot, *Leopardus pardalis* (11)	Endangered	Vulnerable
Margay, *Leopardus wiedii* (11)	Endangered	Vulnerable
Tigrina, *Leopardus tigrina* (4)	Endangered	Vulnerable
Kodkod, *Oncifelis guigna* (2)	Threatened	
Geoffroy's cat, *Oncifelis geoffroyi* (4)	Threatened	
Andean mountain cat, *Oreailurus jacobita* (2)	Endangered	Rare
Pampas cat, *Lynchailurus colocolo* (7)	Threatened	
Domestic cat lineage		
Wild cat, *Felis silvestris* (36) (includes *F.s. libyca*)	Threatened	Vulnerable
Pallas cat, *Otocolobus manul* (3)	Threatened	
Jungle cat, *Felis chaus* (10)	Threatened	
Black-footed cat, *Felis nigripes* (2)	Endangered	
Sand cat, *Felis margarita* (4)	Endangered (1 subsp. only)	Endangered (1 subsp. only)
Chinese desert cat, *Felis bieti* (3)	Threatened	

of the 38 species of extant felids are listed as either endangered or threatened by the international monitors of endangered species (Box 3.1). The only non-endangered felid is the one we do not fear, the domestic cat *Felis catus*, which numbers in the hundreds of millions of individuals worldwide and, ironically, has become a pest and threat to native wildlife in many areas.

Humankind's fascination with cats has led to countless scientific and non-scientific descriptions of their appearance, behavior, and relationships with man. They have been the subject of mythology, art, and even theology. Furthermore, both big and small cats have been captured and trained for hunting or circus performance, as well as displayed in zoos and bred in captivity. These experiences have given insights into the biology and behavior of cats, and have provided empirical opportunities for study of their reproduction, clinical health, and nutrition. This rich informational background, from rigorous science to mythical anecdote, provides a substantial assemblage of explanations and hypotheses about the intrinsic and extrinsic threats faced by felids. Unfortunately, much of what has been written of

felid natural history is also unsubstantiated. The advent of molecular genetic technologies has begun to change this situation, in part, by providing the means of examining patterns of genomic variation in the cat family and in particular cat species. The data are revealing phylogenetic relationships of relevance to taxonomy, as well as elucidating characteristics of population structure that may directly affect species survival. By highlighting examples from particular species of Felidae, this chapter summarizes findings that relate to conservation of a group of organisms that some consider among evolution's most charismatic creations.

The methods of analysis will be familiar to readers of this book, since they have been applied to many endangered species (Schonewald–Cox et al., 1983; Avise, 1994; Li and Graur, 1991; O'Brien, 1994a, 1994b). The molecular methods are the tools of molecular biology: a variety of procedures for assessing the extent and character of genomic variation in DNA sequences of individuals. Technologies from human, mouse, *Drosophila*, and bacterial and plant genetics have been used to track DNA differences in the felids, and various phylogenetic algorithms that reflect different philosophies for relating gene characters in an evolutionary or systematics sense have been applied (Weir, 1990; Li and Graur, 1991; Avise, 1994). Genetic partitions, evidence of inbreeding, and historical migration events have been interpreted against a framework of population genetic theory applied to free-ranging populations (O'Brien, 1994a, 1994b). Finally, in a synthesis of species characteristics that assess the present and future disposition of felids, medical and ecological disciplines have been recruited to better describe population status on topics ranging from prey base to infectious disease to reproductive fitness.

Because many of the felid populations studied are endangered (e.g., African cheetah, Asiatic lion, Sumatran tiger), we do not have the scientific luxury of designing explicit experiments to test hypotheses. Rather, correlation and multidisciplinary inference are relied upon to draw conclusions. This approach is reminiscent of human genetic analysis, which is restrained from direct experimentation by ethical considerations. Despite these limitations, much has been (and remains to be) learned from descriptive applications of molecular methods to the ecological and evolutionary genetics of felids.

PHYLOGENY AS A BASIS FOR SPECIES RECOGNITION AND PROTECTION

Taxonomy, the systematic classification of plants and animals, had little relevance beyond academic institutions before the mid-1970s. Species were grouped according to morphological types into genera, genera into families, families into orders, and so on. Systematic uncertainties had little relevance to everyday life, and taxonomic resolution was limited. When taxonomic distinctions became the basis for legal protection afforded by the Endangered Species Act of 1973, this innocence was lost forever (U.S. Fish and Wildlife Service, 1973). Disagreements over taxonomic status fueled legal assaults on the Act, and misclassifications led to inappropriate conservation measures resulting in losses of some species. Errors of "oversplitting" and "overlumping" based on guesswork have led to mistaken legal judgments retrospectively revealed by molecular approaches (Avise and Nelson, 1989; Daugherty et al., 1990; O'Brien and Mayr, 1991; Wayne and Jenks, 1991; Geist, 1992). Even today, with vastly improved molecular methods for discriminating taxonomic groups, there remains considerable confusion about the units of conservation that the Endangered Species Act was designed to protect. Finally, because it is unlikely that all endangered species will be afforded equal protection and recourse, proposed bases for priority ranking of endangered species have been advanced. For example, one such criterion for conservation priority involved taxonomic distinctiveness, or depth of phylogenetic divergence (May, 1988). According to this philosophy, an aardvark, which has no close relatives, would rank higher for conservation concern than would a lion, which has several close (less than two million years away) phylogenetic relatives.

Despite the wide popularity of cats as research objects, there remains considerable confusion as to the evolutionary relationships among the living species (Hemmer, 1978; Leyhausen, 1979; Neff, 1982; Collier and O'Brien, 1985; Kitchener, 1991; Nowak, 1991; Salles, 1992). Cat taxonomy based on morphological and behavioral criteria produced earlier classification schemes that grouped cats into as few as two or as many as 19 genera (Nowak, 1991). A major reason for this confusion seems to be a rather recent adaptive radiation that has produced 37 distinct felid species all within the last 6–12 million years (Savage and Russell, 1983; Wayne et al., 1989; Nowak, 1991). Each species displays specific adaptations that play an important role in its ecological balance. For example, 10 African cat species are sympatric but occupy distinctive niches. The same is true for seven South American felids, whose common ancestor invaded the continent only after the formation of the Panama land bridge about 2–3 million years ago (Pecon-Slattery et al., 1994), yet which now exhibit a diverse array of ecological adaptations.

Molecular Phylogeny of the Felidae

Our research group has applied four molecular techniques (protein electrophoresis, microcomplement fixation, DNA–DNA hybridization and G-banded karyology) to estimate phylogenetic relationships within the Felidae (Figure 3.1; Collier and O'Brien, 1985; O'Brien, 1986; O'Brien et al., 1987a; Wayne et al., 1989). These results did not resolve all relationships, but provided evidence for the occurrence of three primary radiations within the felids. Under the assumption of a molecular clock calibrated with paleontological fossil dates, the data suggest that the earliest separation occurred approximately 10 million years ago, when the ancestor to the South American ocelot lineage diverged. Seven to nine million years ago, the domestic cat lineage was formed, followed by a gradual divergence of the remaining large cats forming the pantherine lineage. The most recently derived species are a group of six large cats forming the *Panthera* genus (lion, tiger, jaguar, leopard, snow leopard, and clouded leopard). In agreement with molecular data (Collier and O'Brien, 1985; O'Brien, 1986), a study of 44 cranial characters in extant felid species (Salles, 1992) resolved three primary clades corresponding to *Leopardus* (ocelot), *Felis* (domestic cat), and the pantherine lineages. However, the morphological data differed by placing several of the pantherine cats (notably Asian golden and marbled cats) outside of the pantherine lineage.

Until recently, further resolution of the phylogenetic topology of the Felidae has been difficult or equivocal with both molecular and morphological approaches. Sequence analysis of mitochondrial (mt) DNA (12S RNA and cytochrome *b* genes) has given additional insight into the pantherine lineage (Janczewski et al., 1995). As illustrated in the majority-rule consensus topology presented in Figure 3.2, the mitochondrial genes analyzed with phenetic, maximum parsimony, and likelihood methods provide additional support for: (1) inclusion of clouded leopard (*Neofelis nebulosa*) in the *Panthera* genus; (2) monophyletic association of puma (*Puma concolor*) and cheetah (*Acinonyx jubatus*); and (3) polyphyletic origins of two golden cat species, *Profelis temmincki* and *P. aurata*. In the ocelot lineage, phylogenetic reconstruction based on high resolution 2DE gel proteins (Figure 3.3) and isozyme markers ($N = 40$ loci) indicated that a major split occurred approximately 5–6 million years ago, leading eventually to three phylogenetic groups (Pecon-Slattery et al., 1994). The earliest divergence led to *Leopardus tigrina*, followed by a split between an ancestor of an unresolved trichotomy of three species (*Oncifelis guigna*, *O. geoffroyi*, and *Lynchailurus colocolo*) and a recent common ancestor of *Leopardus pardalis* and *L. wiedii*.

The South American Radiation

The ocelot lineage provides an opportunity to study more closely the pattern of a recent monophyletic radiation, because it is known when the radiation likely began. Before the formation of the Panama land bridge

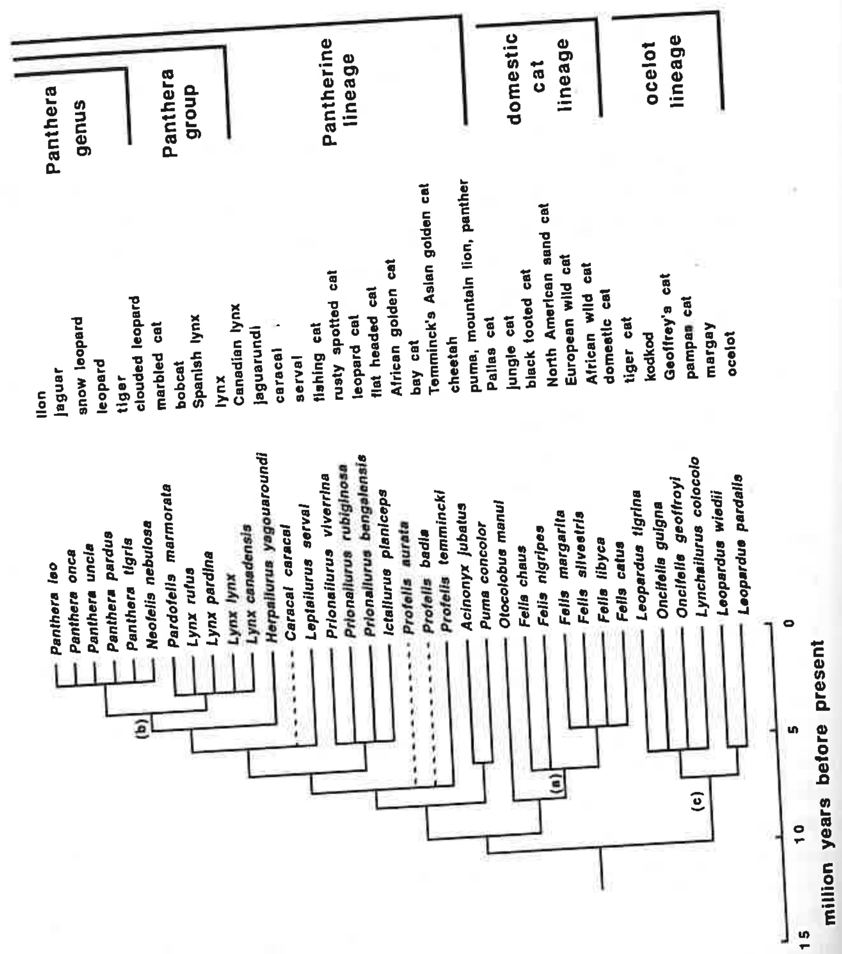

Figure 3.1. Phylogenetic relationships of Felidae based on immunological distances (Collier and O'Brien, 1985), isozyme electrophoresis (O'Brien et al., 1987c), karyology (Wurster-Hill and Gray, 1975; Wurster-Hill and Centerwall, 1982; Modi and O'Brien, 1988), and endogenous retroviruses (Benveniste, 1985): (a) indicates entry of endogenous retroviral families feline leukemia virus and RD-114; (b) indicates members of *Panthera* group with identical karyotypes; (c) indicates South American ocelot lineage, all species of which have 36 chromosomes and share a unique metacentric chromosome C3. Dashed lines indicate tentative placements of species. Classification used as per Kitchener (1991) modified from O'Brien (1986). (From Janczewski et al., 1995).

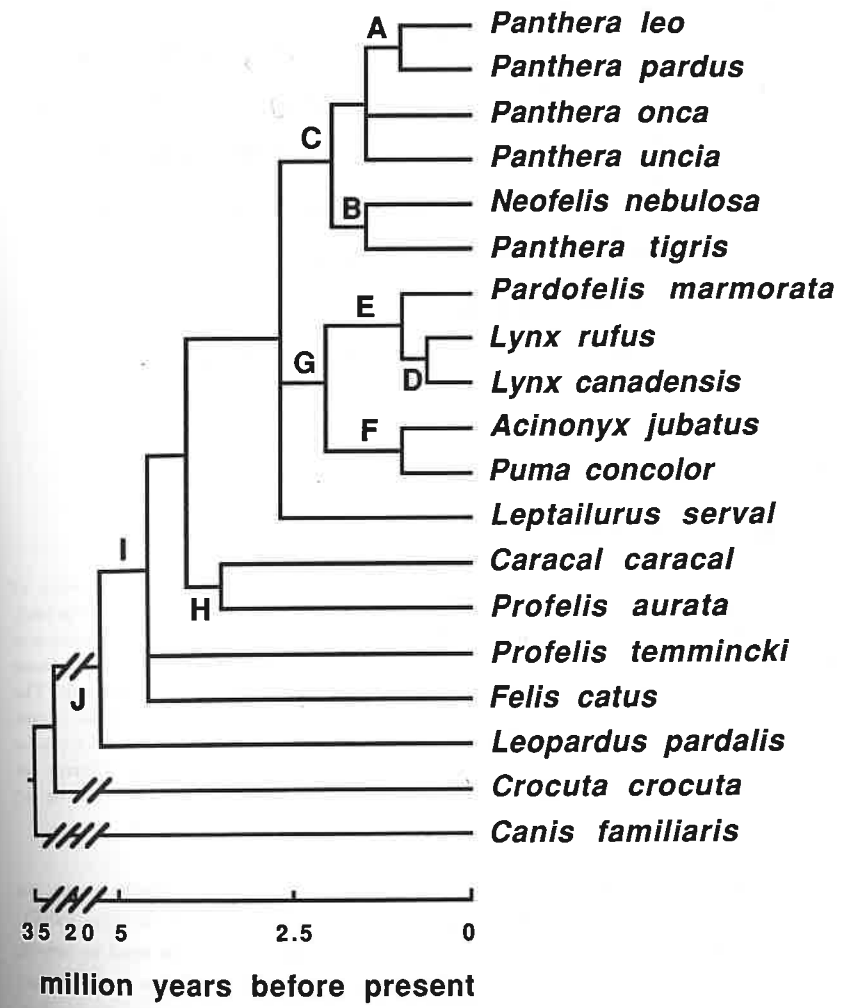

Figure 3.2. Phylogeny of the Felidae based on maximum parsimony analysis of mtDNA sequences at the 12S RNA and cytochrome *b* genes, calibrated using the divergence from the hyena (*Crocuta crocuta*) at 20 million years ago (Hunt, 1989). Also included is another outgroup pecies, the dog *Canis familiaris*. Species associations shown here (A–J) represent those observed in a majority of the trees constructed from these genetic data, and are supported by isozymes, albumin immunological distance, karyology, DNA–DNA hybridization, endogenous retrovirus identification, and morphological data (Benveniste, 1985; Collier and O'Brien, 1985; O'Brien et al., 1987c; Modi and O'Brien, 1988). (From Janczewski et al., 1995).

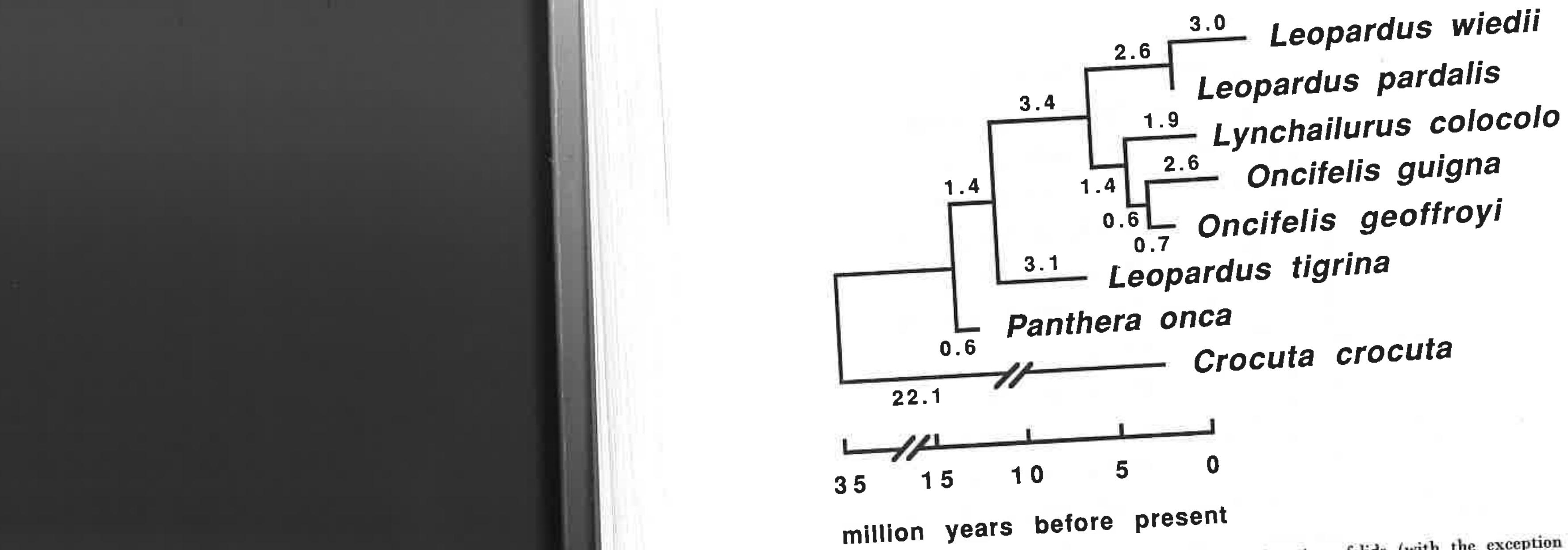

Figure 3.3. Phylogenetic reconstruction of South American felids (with the exception of *Oreailurus jacobita*) based on two-dimensional electrophoretic (2DE) data ($N = 548$ protein loci). Shown is a phenetic summary from the neighbor-joining method (in the Phylip 3.5 computer package) as applied to a distance matrix of Nei's (1978) unbiased minimum genetic distance (Pecon-Slattery et al., 1994). The hyena (*Crocuta crocuta*) is included as an outgroup. The observed inconsistency by which the estimated divergence times (5–10 MYA) of the extant South American species predates the formation of the Panama land bridge (2–3 MYA), can be attributed to either: (a) unequal rates of evolution in the 2DE metric among the different cat species, leading to an overestimation of the divergence times within South America; or (b) divergence of some of the species lineages prior to migration into South America.

between North and South America 2–3 million years ago, there were no carnivores (except marsupials) in South America (Stehli and Webb, 1985). The phylogenetic separation of the ocelot lineage (which was to lead to seven extant species) may have coincided with this event, and if so was very recent (but see Figure 3.3). We have initiated a collection of living "voucher specimens" (blood and skin fibroblast cell culture) from throughout the range of each species (Figure 3.4), with the initial intent of further examining the extent of intrinsic genetic diversity within and between species as assessed from rapidly evolving mitochondrial and nuclear microsatellite loci. Such information should soon permit a coupling of molecular variation with geographic isolation and evolutionary divergence. The major goal is to define precisely the "units" of conservation for each species based on present and historic genetic structure.

Figure 3.4. Geographic ranges of seven felid species of the ocelot lineage that occur in South and Central America (Oliveira, 1994).

RECOGNIZING CONSERVATION UNITS WITHIN SPECIES: THE SUBSPECIES QUESTION

The subspecies designation for differentiated, geographically isolated populations has been one of the most controversial topics in the biological sciences. Darwin (1859) was well aware of recognizable biotic divisions below the species level, and called these *races* or *incipient species* because they appeared to be preludes to species development. Mayr (1963) defined a *subspecies* as "an aggregate of local populations of a species, inhabiting a geographic subdivision of the range of the species, and differing taxonomically from other populations of the species." Dobzhansky (1937) termed *subspecies* as "any populations sufficiently distinct to merit a Latin name." More recently, Avise and Ball (1990) attempted to provide objective criteria for subspecies recognition by recommending that subspecies designation should be reserved for populations displaying concordant distinctions in multiple, independent, genetically based traits. O'Brien and Mayr (1991) synthesized the subspecies classification to include "individual populations that share a unique geographic range or habitat, a group of phylogenetically concordant phenotypic characters and a unique natural history relative to other subdivisions of the species."

Many felid species have been extensively subdivided taxonomically, largely by 19th century mammalogists who named populations with little more criteria than a hide or skeleton from a particular geographic locale. As an extreme, there are 27 named subspecies of leopard (Figure 3.5), 30 subspecies of puma, and five subspecies of tiger. The bases of these designations are soft. However, contrary to some authors (Ehrlich and Raven, 1969; Cracraft, 1989), we believe that a formally demonstrated subspecies category is an important unit of conservation because of two factors (O'Brien and Mayr, 1991). The first is the potential to become a new species given sufficient time (Darwin's incipient species). The second is the acquisition of ecologically relevant adaptations during allopatric separation. Of course, it is difficult to say which particular subspecies will realize either or both criteria, but every subspecies has at least the potential.

To provide greater historical genetic rigor to subspecies recognition, the disposition of molecular markers (isozymes, mtDNA restriction fragments, nuclear DNA fingerprints) has been examined in a group of leopard subspecies (Miththapala, 1992). By examining population genetic structure of 90 leopards from 14 named subspecies (see Figure 3.5), the molecular data were sufficient to resolve eight subspecies partitions, and to permit the recognition of several identified groups as distinct populations. For example, all African subspecies were virtually indistinguishable, whereas island populations from Sri Lanka and Java shared several distinctive molecular genetic

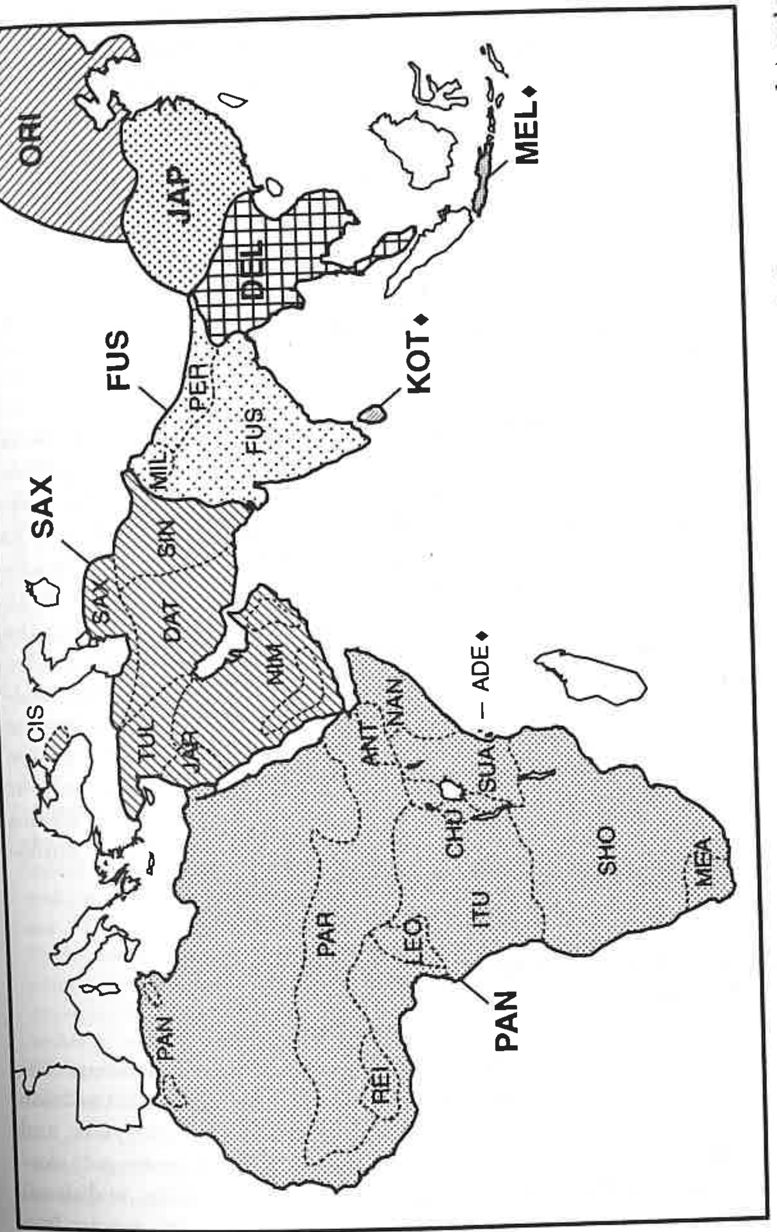

Figure 3.5. Described geographic ranges of 27 previously recognized subspecies of leopards (denoted mostly by smaller letter codes), and recent revision to eight verifiable subspecies partitions (larger, bold letter codes) based on a combined molecular and morphological analysis (Miththapala, 1992). Different hatchings and patterns indicate geographic ranges of the revised subspecies.

characters. A parallel morphological analysis of metric cranial characters in leopards affirmed the conclusions of the molecular study, adding credence to the recommendation that the 27 original subspecies be subsumed into eight verifiable subspecies. A similar analysis with puma and tiger subspecies, but utilizing more powerful genetic assays (of mtDNA control-region sequences, microsatellites, and major histocompatibility complex (MHC) Class II sequences) is underway. These results should lead to formal definitions of feline subspecies, which in turn should provide a more solid basis for conservation efforts.

WHEN ENDANGERED SPECIES HYBRIDIZE IN NATURE

An area that has led to confusion and to legal assaults on protection involves the question of *in situ* hybridization of endangered species or subspecies. Historically, the U.S. Fish and Wildlife Service had interpreted that "hybrids" between taxa listed by the Endangered Species Act would not be eligible for protection, a directive largely intended to concentrate management responses on "pure" endangered species (O'Brien and Mayr, 1991). Thus, when molecular genetics revealed natural hybridization involving the Florida panther (Box 3.2), or geographically restricted hybridization between wolves and coyotes (Lehman et al., 1991; Chapter 4), litigious challenges to the protection of these endangered species were based on the precedent of the so-called "hybrid policy." Fortunately, the hybrid policy was suspended after O'Brien and Mayr (1991) argued that these sorts of hybrid events were natural outcomes of evolution, and that the species should not be penalized due to a bureaucratic precedent that did not anticipate the resolving power of molecular genetics.

THE BIG CATS ILLUSTRATE THE COST OF INBREEDING

More than a decade ago, the first results were obtained indicating that African cheetahs (*Acinonyx jubatus*) had significantly less genomic variation than did other felid or mammal species (based on a survey of allozymes, and cellular proteins resolved by two-dimensional polyacrylamide gel electrophoresis [PAGE; O'Brien et al., 1983]). In subsequent studies, additional molecular genetic data confirmed the genetic uniformity of this species (see Table 3.1), and led to the conclusion that the cheetah's ancestors experienced a severe demographic reduction and extreme inbreeding several thousand years ago (likely at the end of the Pleistocene, the time of the most recent Northern Hemisphere glaciation; O'Brien et al., 1983, 1985, 1987d; Wayne et al., 1986; Yuhki and O'Brien, 1990; Menotti-Raymond and O'Brien, 1993). Overall, genetic variability of modern cheetahs was reduced by one to two orders of magnitude compared to other large cat species,

Box 3.2. The Florida Panther: A Lesson about Subspecies Hybridization in Nature

The Florida panther is a small relict population of mountain lion (also called cougar or puma) descended from the subspecies *Puma concolor coryi* that ranged throughout the southern United States in the 19th century (O'Brien et al., 1990; Roelke et al., 1993). Less than 50 animals survive today in the Big Cypress Swamp and Everglades ecosystem in southern Florida. The remaining panthers show physiological impairments as a consequence of inbreeding depression, including a 90° kink in the tail vertebrae, a cowlick in the middorsal back, and reproductive defects (see text). The Florida panther was listed as endangered by the U.S. Fish and Wildlife Service in 1967.

In the late 1980s, the existence of two highly distinct genetic stocks was discovered when two family groups appeared in the Everglades. The animals seemed different from the larger population in the adjacent Big Cypress Swamp because they lacked the cowlick and tail kink diagnostic for the subspecies. An allozyme and mtDNA–RFLP analysis showed that the Everglades pumas were indeed distinct from the Big Cypress animals, as well as from pumas in the western U.S. (O'Brien et al., 1990). Phylogenetically, they were closer to puma subspecies from South and Central America. Retrospective inspection of the archives of the Everglades National Park revealed an explanation. Between the years 1957 and 1967, in cooperation with National Park Service officials, seven animals from a captive stock were released into the Everglades (and promptly forgotten). This stock was a mixture of authentic North American *P. concolor coryi* and South American founders. Today, the Everglades population contains a mixture of these two distinct puma lineages.

The genetic advantages of introducing some additional genetic material into a population suffering from inbreeding would have been comforting except for one detail. Three independent opinions from the Solicitor's Office (the legal counsel of the U.S. Fish and Wildlife Service) have ruled with the force of precedent that hybrids between endangered taxa (species, subspecies, or populations) cannot be protected. Their opinions, known as the "Hybrid Policy," concluded that protection of hybrids would not serve to recover listed species, and would likely jeopardize that species' continued existence. My collaborators and I were in an untenable position, wherein publication of the new data would threaten the Florida panther's endangered species status. The solution came when U.S. Fish and Wildlife suspended the hybrid policy indefinitely, largely in response to this "catch-22" of the Florida panther (O'Brien and Mayr, 1991).

Table 3.1. Evidence for Genetic Uniformity in Cheetahs, and Observed Physiological Correlates

	References
A. Methods indicating reduced genetic variation	
1. Allozymes—52 loci	O' Brien et al., 1983, 1987d
2. Two-dimensional PAGE—155 loci	O'Brien et al., 1983
3. Allogeneic skin graft accepted	O'Brien et al., 1985
4. MHC-RFLPs—(six restriction enzymes)	Yuhki & O'Brien, 1990
5. mtDNA—RFLPs	Menotti-Raymond & O'Brien, 1993
6. Microsatellite loci	Menotti-Raymond & O'Brien, 1995
7. Increased fluctuating asymmetry of skeletal measurement	Wayne et al., 1986
B. Physiological correlates	
1. Diminished sperm count	O'Brien et al., 1983; Wildt et al., 1983, 1987b
2. Elevated frequency of morphological abnormalities in sperm development (~70%)	O'Brien et al., 1983; Wildt et al., 1983, 1987b
3. Low fecundity in captive breeding attemps	Marker & O'Brien, 1989; Marker-Kraus & Grisham, 1993
4. Captive population is not self-sustaining	Marker & O'Brien, 1989; Marker-Kraus & Grisham, 1993
5. Relatively high incidence (~30%) juvenile mortality even among unrelated parents	O'Brien et al., 1985; Marker-Kraus & O'Brien, 1989
6. Increased population vulnerability to infectious disease outbreaks, notably feline infectious peritonitis	O'Brien et al., 1985; Heeney et al., 1990

Table 3.2. Correlation of Genetic Variation and Reproductive Parameters in Three Lion Populations[1]

Parameter	Serengeti, Tanzania	Ngorongoro Crater, Tanzania	Gir Forest, India
Genetic properties			
Allozyme heterozygosity (%)	3.1	1.5	0.0
Mean % difference			
MHC-RFLPs	21.8	8.0	0.0
DNA fingerprints	48.1	43.5	2.8
Reproductive measures			
Sperm count (X 10^{-6})	34.4 ± 12.8	25.8 ± 11.0	3.3 ± 2.8
% sperm abnormality	24.8 ± 4.0	50.5 ± 6.8	66.2 ± 3.6
No. motile sperm per ejaculate (X 10^{-6})	228.5 ± 65.5	236.0 ± 93.0	45.3 ± 9.9
Testosterone, ng/ml	1.3 − 1.7	0.5 − 0.6	0.1 − 0.3

[1] O'Brien et al. (1987b, 1987c), Wildt et al. (1987a), Yuhki and O'Brien (1990), and Gilbert et al. (1991). When indicated, data are the mean ± standard error of mean.

Table 3.3. Evidence for Genetic Uniformity in the Florida Panther [*Felis (Puma) concolor coryi*] and Observed Physiological Correlates[1]

A. Methods indicating reduced genomic variation

1. Allozymes—41 loci
2. mtDNA—RFLPs
3. DNA fingerprints—feline minisatellites
4. Aberrant morphological characters
   - a. Kink tail
   - b. Cowlick

B. Physiological correlates relative to other puma populations

1. Spermatazoal abnormalities
   - a. Diminished sperm count
   - b. Low motile sperm per ejaculate
   - c. Elevated frequency of morphological abnormalities in sperm development (~ 95%)
   - d. 48% abnormal acrosomes in sperm development
2. Rapid rise to 80% cryptorchidism
3. Heart murmurs and fatal atrial septal defects
4. Multiple and widespread exposure to feline pathogenic infectious agents

[1] O'Brien et al. (1990), O'Brien and Mayr (1991), Roelke et al. (1993), and Barone et al. (1994).

Box 3.3. Conservation Concerns for the Asiatic Lion

As recently as 200 years ago, the Asiatic lion (*Panthera leo persica*) occupied a wide range extending from Syria to northern India. The advance of agriculture, the increased use of firearms, and other familiar companions of human population pressure brought the subspecies to extinction in Syria, Iraq, Iran, Afghanistan, and Pakistan in the latter part of the 19th century. The last remaining population consists of about 250 individuals in a 1,400 km^2 area in the Gir Forest in Gujarat State of western India. Published estimates of fewer than 20 lions in the early 1900s led to a complete prohibition of hunting in 1900. The tiny population survives today, but is severely limited by available habitat and by proximity to human agricultural settlements. In the last decade, over 100 lion attacks on humans have occurred, resulting in twelve fatalities. Man-eaters are captured, held in the Sakkarburg Zoo in Junagadh, and used for captive breeding and for research.

A captive breeding program under the Species Survival Plan (SSP) in U.S. zoos was initiated from five founders in 1981. The program was highly successful in producing lions, but the disappearance of phenotypic traits found in free-ranging Asian lions (reduced mane and belly fold) led to a molecular genetic study. The results of an allozyme analysis showed that two of the original founder animals were actually African lions, and that the SSP lions probably were doing so well because of hybrid vigor (O'Brien et al., 1987b, 1987c). The Asiatic lions thus provided an unexpected natural example of the direct improvement that can be achieved by hybridization between subspecies, particularly when one subspecies had a history of inbreeding and associated inbreeding depression (Wildt et al., 1987a).

suggesting that the proposed bottleneck likely persisted for several generations or perhaps occurred several times (Nei et al., 1975; O'Brien et al., 1987d). In addition, cheetahs underwent a significant range retraction whereby they disappeared from North America, Europe, and parts of Asia at the end of the Pleistocene.

Correlated with the genetic uniformity of cheetahs are a number of physiological impairments that influence reproduction and contribute to a difficulty in establishing self-sustaining captive populations (Table 3.1). Sperm abnormalities are observed in both free-ranging and captive cheetahs and likely play a key role in the difficulty in achieving a self-sustaining captive population (Marker and O'Brien, 1989; Marker-Kraus and Grisham, 1993). Furthermore, an extreme morbidity and mortality of cheetahs from outbreaks of a nearly benign domestic cat virus (feline infectious peritonitis virus) was interpreted to be a consequence of the homogeneous state of genes that mediate immune defenses (O'Brien et al., 1985; Heeney et al., 1990). Several of these immunological loci, particularly the MHC, are highly vari-

able in other feline and mammalian species. The evolutionary explanation for high variation among immune response loci would be that they offer a "moving target" for microbial pathogens that themselves rapidly evolve genetic adaptations that override the immune defenses of individuals (O'Brien and Evermann, 1988).

The cheetah example has served as a paradigm of the potential for hidden perils that threaten small populations from within. The interpretations have been reinforced by the variety of genetic observations that support the bottleneck hypothesis. Evidence of the cheetah's genetic uniformity was obtained with seven distinct measures of genomic variation (Table 3.1). The three genomic assays that did reveal modest variation in cheetahs (mtDNA–RFLPs, DNA fingerprints, and microsatellites) involve rapidly evolving DNA sequences that likely accumulated variation by mutation after the hypothesized bottleneck (Menotti-Raymond and O'Brien, 1993, 1995). The concordant genetic diminution of multiple estimators of genomic variation lent strong support to the hypothesis of close inbreeding resulting from demographic collapse(s) in the cheetah's history.

The developing legacy of the cheetah led to investigations of the genetic structure of several other endangered felid species. Three other big cat populations are now documented to have suffered severe historical population contractions, leading to inbreeding and probable physiological consequences: lions in the Ngorongoro Crater in Tanzania, Asiatic lions from the Gir Forest in India (Table 3.2; Box 3.3), and pumas in Florida (Table 3.3). Because estimated levels of genomic variation within species are relative measures, the populations of Florida puma and the Ngorongoro and Gir Forest lions provided the equivalent of case-controlled studies for the consequences of genetic depletion (O'Brien et al., 1987b, 1987c, 1990; Wildt et al., 1987a; Roelke et al., 1993). The two lion populations had dramatically reduced variation in allozymes, MHC loci, and DNA minisatellite fingerprints relative to a larger outbred lion population living in the Serengeti (Figure 3.6; O'Brien et al., 1987c; Yuhki and O'Brien, 1990; Gilbert et al., 1991; Packer et al., 1991). Both lion populations also displayed elevated sperm abnormalities and a large reduction in circulating testosterone concentration relative to their outbred Serengeti lion counterparts (O'Brien et al., 1987b; Wildt et al., 1987a). Reproduction by the most genetically deficient lion population (the Asiatic lion) is known to be severely compromised in captive settings (O'Brien et al., 1987b). Furthermore, when Asiatic lions were inadvertently bred to African lion subspecies in North America, the fecundity, reproductive success, and spermatozoal development improved dramatically (Box 3.3; O'Brien et al., 1987b). Combined with the results for the cheetah, it seems clear that inbreeding, at least in the Felidae, can have a direct effect on reproductive performance.

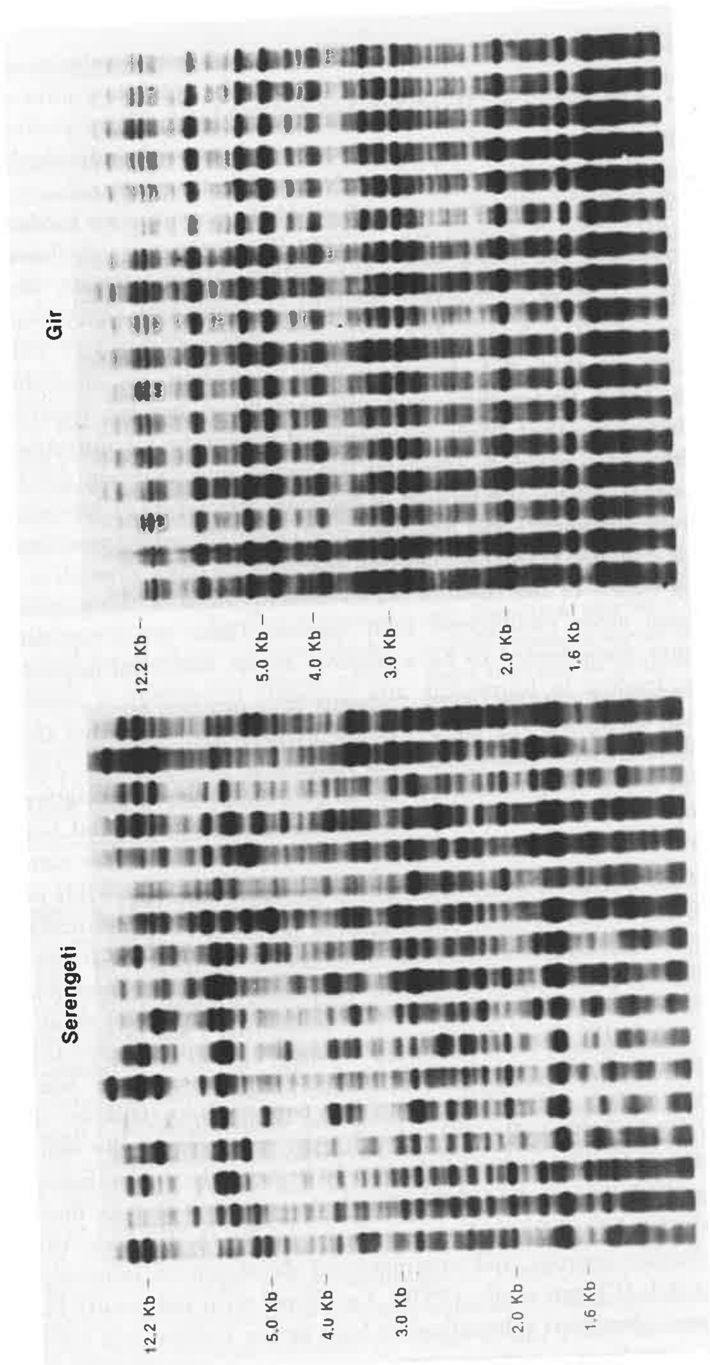

Figure 3.6. DNA fingerprint patterns of unrelated lions from the Serengeti National Park, Tanzania, and from the Gir Forest Sanctuary, India. Both Southern blots contain DNA digested with *Msp*I and hybridized with FCZ8 feline-specific minisatellite probe (Gilbert et al., 1991). The genetic uniformity of the Gir Forest population relative to the Serengeti population is evident (especially so in the original gels).

A compelling addition to this inference came from the dramatic story of the Florida panther (*Puma concolor coryi*), a native American subspecies of puma (O'Brien et al., 1990; O'Brien and Mayr, 1991; Roelke et al., 1993). Human depredation spurred principally by fear and legends of ferociousness toward livestock and mankind, plus the imposition of bounties, reduced the panther's range from the entire American Southeast to hardwood swamps and adjoining ecosystems in the Everglades National Park and Big Cypress Reserve of south Florida, the only habitat east of the Mississippi occupied by wild pumas today. The major threats to the Florida panther were thought to have been mortality factors, with road kills and illegal hunting accounting for 63% of documented mortalities since 1973.

Genetic studies (Table 3.3) revealed that the Florida panther retained less genomic variation than any puma subspecies from North or South America; also, several cases of incestuous (father/daughter) matings were documented *in situ* (Roelke et al., 1993). The cost of inbreeding in this population was dramatic. Florida panthers have the poorest sperm observed in any felid species; about 95% of the sperm in each ejaculate are malformed (Roelke et al., 1993; Barone et al., 1994). The incidence of cryptorchidism, a rare heritable defect that causes either one or both testicles to remain undescended, has risen from 0% to 80% in males born in the last 15 years. In addition, a new fatal, congenital cardiac abnormality has recently appeared in four panther kittens. Finally, Florida panthers are riddled with pathological viruses, bacteria, and parasites, and these represent a time bomb waiting to explode as the animals develop debilitating disease. One of the viruses endemic in Florida panthers is a close relative of the feline version of the human AIDS virus—feline immunodeficiency virus (FIV; Olmsted et al., 1992). FIV causes severe immunodeficiency in domestic cats, but whether it causes disease in panthers is not yet certain.

The lessons learned from these studies of population genetic variability in the felids (Tables 3.1–3.3) are several. First, there can be hidden genetic perils, not so apparent from traditional ecological observations, that threaten natural populations. Second, when populations drop to very low numbers (as most endangered species by definition do), the associated genetic depletion from genetic drift and close inbreeding carries the risk of inbreeding depression and the expression of congenital abnormalities resulting from homozygosity of rare deleterious genes. These genes can affect any aspect of development, survivorship, or reproduction in an unpredictable manner. Third, in addition to these heritable defects, inbreeding homogenizes variation at abundantly polymorphic genes that mediate the immune response, thereby increasing the population's risk of extinction from pathogens that abrogate the immune defenses of an individual.

CONCLUSIONS

The last decade has seen the emergence of a field that applies the principles and methods of population genetics to species conservation. As for other areas of molecular biotechnology, conservation genetics is an applied science with one important goal being to explicitly describe the composite genomes of small endangered populations. By comparison to well-studied examples, such as those reviewed here, one can make realistic approximations of the recent natural history, present status, and future prognosis of endangered populations. When combined with data from other disciplines (e.g., reproductive biology, epidemiology and the study of infectious disease, and field ecology), the synthesis offers some valuable insights that can be applied directly to species management plans.

The cats comprise but a small fraction of the nearly 5,000 described species of mammals. Close examinations of their molecular genetic structure, and integration of the genetic information with ecological, reproductive, medical, and natural history data have added to an understanding of factors that should be considered in efficacious management plans for these as well as other endangered species groups. Not all species will be saved in the coming decades; indeed, extinction has been a natural process since long before the accelerating influence of humans. However, equipped with the technologies and accumulated knowledge already collected on many of these endangered felids, it is now possible to identify and to address some of the many threats to their continued survival.

SUMMARY

1. All of the world's 37 extant wild species of Felidae are threatened or endangered, often as a direct result of persecution by humans. Ironically, as impressive top-level carnivores, these cat species also hold a special fascination for humans, making them especially important subjects for conservation efforts. Here, an overview is provided of how molecular genetic methods have been employed to ascertain the evolutionary histories, present conservation genetic status, and prospects for the future survival of felid species.

2. A variety of molecular genetic assays, including one- and two-dimensional protein electrophoresis, microcomplement fixation, DNA–DNA hybridization, and direct DNA sequencing, have been employed to examine phylogenetic relationships among felid species. Although these molecular phylogenetic analyses have identified certain evolutionary lineages (e.g., the ocelot lineage, domestic cat lineage, and pantherine lineage), several unresolved clusters of species remain. The lack of resolution is presumably related to the relatively recent and rapid radiation of extant felid species, which has taken place within the last 6–12 million years.

3. Below the taxonomic level of species, most felids were probably "oversplit" into numerous subspecies by 19th century mammalogists. For example, more than 25 subspecies of leopards were traditionally recognized but often poorly defined. Molecular assays provide opportunities for reexamining geographic variation in multiple attributes with known genetic basis, and thereby can yield more robust information for the development of intraspecific taxonomies of relevance to conservation and management. In leopards, for example, such molecular studies indicate that only about eight geographic subspecies probably warrant formal recognition.

4. The genetic and conservation consequences of hybridization between subspecies are discussed, with particular reference to the Florida panther. In this isolated and endangered population in southern Florida, an infusion of genes from South American panthers (following the release of some individuals from a captive stock) has been documented using molecular markers. In this case, the hybridization may actually be of fitness benefit to the recipient population, which was highly inbred. In any event, the genetic findings led to a reinterpretation of an earlier legal directive (the "hybrid policy") under the Endangered Species Act.

5. The severe cost of inbreeding in small populations is well-evidenced by several endangered felid species, including the cheetah, Asiatic lion, and Florida panther. In these populations, a severe depletion of genetic variability (as estimated by several molecular genetic assays) is associated with diminished performance in a number of physiological and reproductive measures related to fitness.

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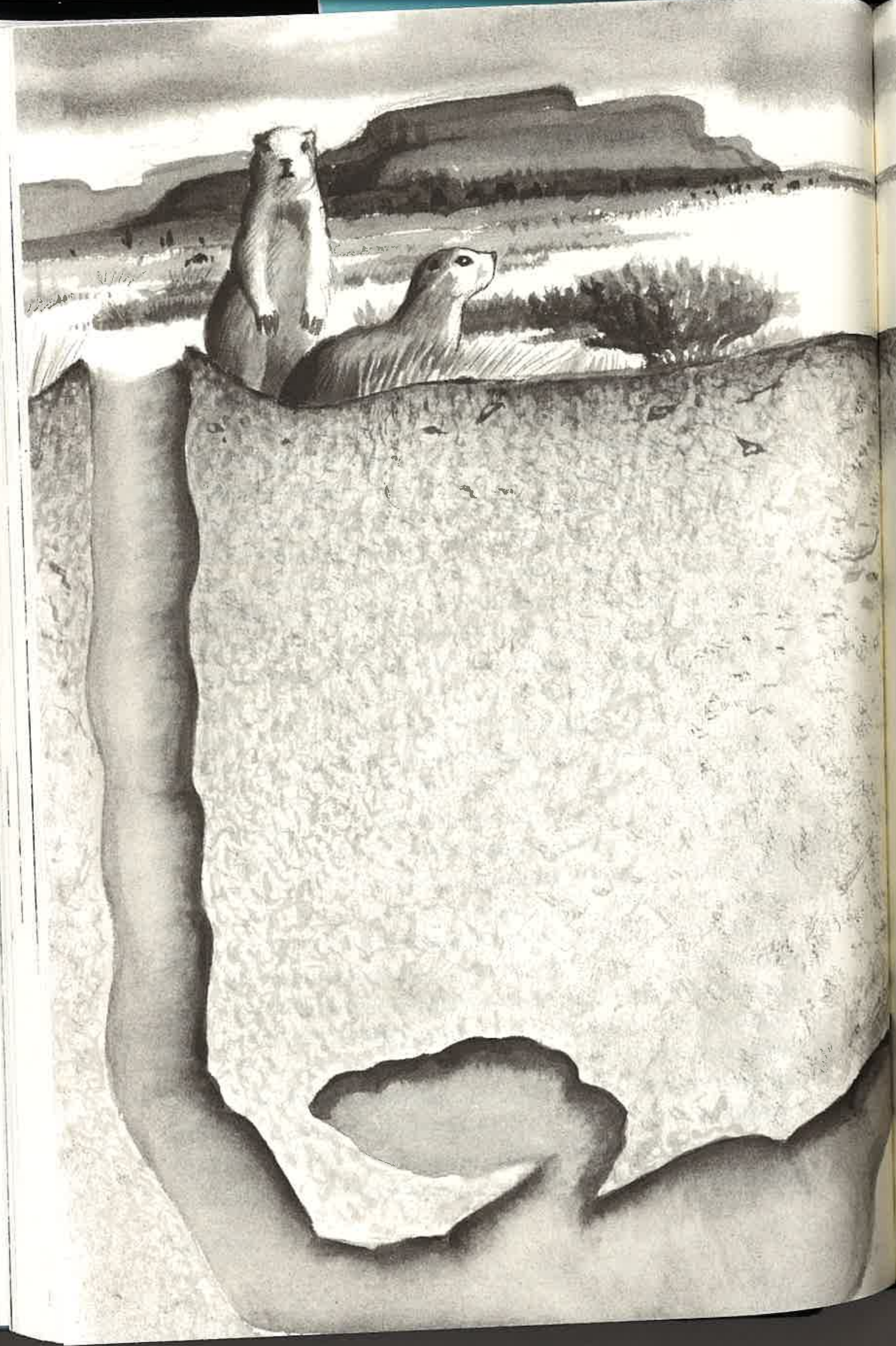


FIVE

A SEA OF GRASS

Grasslands, the geographer Carl O. Sauer first observed in 1950, are the consequence not of climate alone but also of a complex set of periodic disturbances, such as fires and grazing. Grasslands develop in areas where occasional droughts dry out the vegetation, but they are not exclusively determined by rainfall. They grow where level to gently rolling land facilitates the spread of regular fires over large areas and accommodates large herds of grazing animals, which trim the vegetation. In the grasslands of North America, periodic droughts, high temperatures, and strong winds provided an ideal environment for the ignition and spread of fire, while great herds of buffalo and elk did the grazing.

The grasslands of the interior ran north/south in three vast irregular belts. The tallgrass prairie—the easternmost belt—was characterized by giant grasses that often reached a height of 12 feet. The tallgrass prairie got 35 inches or more of rain a year; it included most of Indiana and Illinois, and extended about 100 miles west of the western borders of Minnesota, Iowa, and Missouri. With less rain came the mixed-grass prairie of the Dakotas, Nebraska, Kansas, Oklahoma, and central Texas, where tallgrasses grew on the lower, moister land and shorter grasses grew on the uplands. The short-grass prairie, where short blue grama and buffalo grasses predominated, began where the annual rainfall drops to 20 inches or less and reached to the Rocky Mountains. It included northeastern Montana; the eastern stretches of Wyoming, Colorado, and New Mexico; and the Texas-Oklahoma Panhandle.

Humans and lightning subjected the Plains to repeated and extensive burnings for thousands of years, and the plant and animal species adapted to regular burning. Fire released the nutrients bound in the litter, which would otherwise be unavailable for plant uptake until the litter decayed. Early spring burning increased the number of shoots and consequent flowering stems of the grasses, by fertilizing the plants at the start of the growing season. Grasses produce biomass more quickly than the existing biomass can decompose, and if grasslands aren't burned, growth and flowering are suppressed and plant vigor visibly declines. Fire also encouraged the growth of grasses at the expense of woody plants; shrubs and tree seedlings were often killed outright, and woody plants that were top-killed and resprouted would likely be eaten by browsing elk or deer.

Tallgrass prairie reverts to scrub woodland in a matter of decades without regular fires, so these grasslands in particular are thought to have been the product of deliberate, routine firings by the North American Indians. The Indians used broadcast fire for pasturage, for reduction of brush and ease of travel,

for slash-and-burn agriculture, for hunting, for warfare, and more subtly too: most evidence suggests that Indians frequently started grassland fires in order to modify habitat and attract wild game to the tender new growth. Grasslands were typically burned annually, with occasional unplanned holocausts from lightning and escaped campfires and periodic conflagration in times of drought. Fire was predominantly local, but the local burnings had enormous cumulative effects.

The anthropogenic grasslands of pre-Columbian North America extended virtually unbroken from east of the Mississippi to the Rockies. As they radiated east and west from these borders, their continuity broke down and individual grassy "barrens" appeared, including the Central Valley of California, Oregon's Willamette Valley, the Shenandoah Valley, and the celebrated Barrens of Kentucky.

The colonists had a language problem, for the English word "meadow" didn't describe the Indians' firebuilt grasslands. The terms "barrens," "openings," and "deserts" were often used, with the scholarly types resorting to "champion fields," from the French *campaigne*. The Great American Desert is from the French *déserter*, "to abandon," since the land was seen as cleared and deserted rather than as naturally desiccated, while "barrens" reflected the English perception of land without forests as infertile.

The Barrens of Kentucky, the eastern outpost of the tallgrass prairies, was a crescent-shaped meadow of 6,000 square miles surrounded by virgin forest. It was burned annually by the Indians and supported thousands of buffalo. John Filson, the first chronicler of Kentucky, wrote in 1784, "The amazing herds of buffalo which resort thither, by their size and numbers, fill the traveler with amazement and terror." As soon as the settlers moved in and the Indians were moved out, regular burnings stopped, the great herds were annihilated, and the land was quickly treed over.

After the explorers breached the Appalachians and the individual barrens began to give way to a vast sea of grass, the French explorers dubbed the ecosystem a prairie, from Latin *pratum*, for "meadow." The Spanish, meanwhile, called it savannah, but the settlers of the Great Plains came largely from the north, and the name that stuck was "prairie." "Grasslands" is a twentieth-century term.

In forested land, animal species have adapted to life in a variety of habitats, from below ground to the top of the canopy. In grasslands, there is limited vertical variation, and the habitats differ horizontally, from patch to patch, where different disturbances have left their mark. The Plains vegetation is not a standard mix of grasses and forbs (that is, leafy plants) but varies widely from place to place. There are about two hundred and fifty species of plants on the prairie: some, like the little bluestem, are generalists that live across the entire grasslands; others require specific conditions in order to thrive. The plant species can be roughly divided into tall grasses, short grasses, tall forbs, and short forbs. These plants live together in an ecological community, and have different responses to the stresses of prairie life. A nearsighted view of a patch of prairie shows an area dominated by a few common grasses, with roots that create a dense underground web, and a broad range of interstitial species.

Drought, grazing, and fire are the large-scale disturbances affecting the plant mix, creating a patchwork of slightly varying vegetation. Drought affects tall grasses more seriously than it does short grasses, so the dominant grass species will shift in response to prolonged local droughts. Buffalo and cattle much prefer grasses to forbs, so grazing increases the available space for interstitial plant species. Fire, which burns some areas and not others, appears to increase the dominance of some grasses, killing many interstitial species and the year's seed crop for the few species that are flowering when the land is burned—though many grasses can multiply even when their seeds are burned, via shoots that grow laterally below ground. Grasses

protect themselves from drought by dying down to their underground organs. Their growing points lie below the surface of the soil, which also protects them from fire and overgrazing. Unlike a leaf, a blade of grass continues to grow from the base after the tip is removed, so grazed grasses produce leaf tissue throughout the growing season. Small-scale disturbances, like buffalo wallows, gopher mounds, prairie dog towns, and badger holes, provide a series of radically different habitats in this superficially uniform landscape.

On the Great Plains, most of the rain falls in brief violent storms in late spring and early summer, while the area from Utah north receives its precipitation in the winter and early spring. Most of the rainfall on the prairie clings to the vegetation, where it either evaporates or drips down to the soil, which is shielded from the direct impact of the rain. Some of the water will course over the surface as runoff, but generally the vegetation impedes its progress. A raindrop on the ground can sink into the soil because of gravity, capillary action, and air pressure (spaces in the soil are filled with air too, but barometric pressure above ground changes faster than the pressure below ground), but these are small forces; the difference in vapor pressure between water and air usually causes the water molecules to evaporate instead of entering the soil. If any raindrops do make it underground, the dense root systems take them up; in a semiarid climate, rainfall rarely percolates below the root zone to replenish the groundwater.

The prairie evolved with fire, and also with large herds of herbivores, which grazed on the grasses (and on the forbs when they had to). There once were perhaps sixty million buffalo on the grasslands, but the buffalo's gregarious nature didn't exclude other grazers. When Meriwether Lewis crossed the Plains in the spring of 1805, he described them as covered with "immence herds of Buffaloe, Elk, deer, & Antelopes feeding in one common and boundless pasture." Lewis and Clark reported killing over a hundred large game animals, including twenty-nine elk, twenty-eight deer, seventeen buffalo, fifteen black and grizzly bears, a few goats and bighorn sheep, and a "lion." The goats and the lion were what we today call mountain goats and mountain lions; species so closely associated with mountainous terrain that it has become part of their common name, and which have actually been sequestered there by hunters. Although mountain goats are now pursued in the highest crags, two centuries ago they roamed the Western plains. Similarly, elk now summer in high mountain meadows and come down to the foothills for winter, but in 1805 they were grazing on the prairie.

The herds were predominantly buffalo, though—"buffalo" is the common name for *Bison bison*, a branch of the Bovidae family that is not directly related to the African Cape buffalo or the Asian water buffalo—and they grazed the prairie cyclically, in groups as large as a few million individuals, feeding in one area for a week or two and then moving on when the pasture began to thin. They are huge animals, especially compared to the scrawny cattle of the time. A mature bull weighs over a ton and stands about 6½ feet at its hump. Most of its weight is up front, in the massive low head and powerful shoulder and neck muscles, which are built to sweep away snow from the forage. An unusually long spine dwindles bowlike to the haunches. The coat is blizzard-proof: a shock of black hair grows over the head like a hood, while curly brown fur covers the rest of the body. The hair on the animal's forepart is permanent, but the hindquarters shed annually, beginning in March. By early summer, the buffalo's hind end is nearly naked, and very attractive to bloodsucking bugs.

To protect themselves from insect bites, the buffalo would dig shallow ponds with their sharp, cloven hoofs. The wallows averaged about 20 feet across and 2 feet deep—large enough to allow the buffalo to cover their hindquarters with mud, which dried in the sun and formed a protective coating that lasted for several days. In drier areas, the buffalo would take dust baths in dry wallows, which were about 10 feet in diameter and less

than a foot deep. The wallows dotted the plains wherever the buffalo roamed, providing drinking holes for animals and patches of moister ground that could support distinctive plant communities.

Buffalo wallows were dug in low areas, and they collected runoff as well as rainfall. The fate of the water that pooled in those little ponds was very different from that of the water that fell on the grasses. Only the uppermost layer of water in a wallow could evaporate; the rest seeped down to the water table, creating a zone of saturated soil that extended from the bottom of the wallow to the groundwater. Every wallow was a pathway for runoff and rainfall to percolate down to the water table. Civil engineers dig recharge ponds that look just like buffalo wallows, in order to increase the rate of groundwater recharge; the only problem is that a layer of silt will collect on the bottom of the pond and, over time, clog it. The buffalo's hooves prevented such a layer from forming, so an active buffalo wallow could be described as a perfectly designed groundwater recharge pond.

Given the lack of trees and the regular fires, many of the smaller animals on the prairies lived below ground. Prairie dogs, like beavers, are a keystone species—that is, one that significantly alters the ecosystem and provides habitat for auxiliary species. No one knows for sure how many there used to be, but it is thought that billions of prairie dogs once burrowed in the Great Plains. The black-tailed prairie dog (*Cynomys ludovicianus*) ranged throughout the mixed- and short-grass prairies; the white-tailed prairie dog (*Cynomys leucurus*) lived generally to the west, at higher elevations in the short-grass prairies. Two related species with white tails are the Utah prairie dog (*C. parvidens*) of southwest Utah and the Gunnison prairie dog (*C. gunnisoni*) of high short-grass prairies in Utah, Colorado, New Mexico, and Arizona. Prairie dog towns extended for thousands of square miles, with about fifty holes per acre. Indeed, their social structure and burrowing skills are so refined that prairie dogs might have taken over the grasslands but for *Pasteurella pestis*, the plague bacillus (also harbored in cottontails, marmots, mice, and a few other rodents); large-scale outbreaks have long been noted among them.

Prairie dog towns are underground mazes of 5-inch-diameter tunnels, which range in length from less than 20 to over 80 feet. The tunnels usually lie within the root zone, which may reach as deep as 10 or 12 feet in some parts of the Plains. The burrows have pockets, turn-around rooms, and nest chambers lined with grass. Some burrows have one opening, some burrows have several; some burrows have underground connections, others don't. In the process of constructing their towns of tunnels, the prairie dogs once moved tons of subsoil above ground, where they mixed it with topsoil and organic matter, including clipped grass and roots, feces and urine, insect parts, and other by-products of life; they made loam in a sandy world. The greens between the holes were kept clipped to expose predators, creating a short-grass plant community. New growth was tender and higher in protein than the surrounding grasses, so buffalo and cattle grazed preferentially on prairie dog towns. Since the grass around their towns was kept short, fire often passed by colonies entirely, providing an oasis of unburned vegetation where the rabbits, mice, and other small creatures could eat until the prairie greened again.

Life underground is more temperate than life on the Plains, and the burrows stay cool in summer and warm in winter. (In a 1954 study, Maxwell Wilcomb, of the University of Oklahoma, found that in the grasslands of that state the average temperature 4 feet underground ranged from 50°F in winter to 80°F in summer, while the surface soil temperature varied from −10°F to 120°F.) Snakes, cottontail rabbits, skunks, mice, box turtles, and burrowing owls live in abandoned prairie dog holes. Toads, lizards, and tiger salamanders use the burrows to

escape from drying winds. Birds, too, are attracted to the towns, because the thin groundcover and sparse grasses make it easy to see insects. Even ground beetles sometimes congregate in large numbers outside prairie dog burrows, and presumably go underground to winter below the frost line. According to the Bureau of Land Management, 10 species of amphibians, 15 species of reptiles, 101 species of birds, and 37 species of mammals use prairie dog towns as feeding grounds or shelter, and the population and diversity of insects is also greater there.

Like beavers, prairie dogs are rodents; they are short-tailed ground squirrels that measure from 13 to 17 inches and weigh from 1½ to over 3 pounds. They have short legs, long toenails, a keen sense of sight and hearing, and a complex social structure that includes a lot of nuzzling, grooming, and open-mouthed kisses lasting ten seconds or more. The kissing is often followed by snuggling and lying together. Individuals live from eight to ten years, usually in polygamous bliss in groups called clans or coteries, which are typically composed of one male, several females, and a half dozen young. During most of the year, the prairie dog's reproductive equipment is dormant, but starting in the fall the male's penis and the female's uterus begin to enlarge. They breed for two or three weeks in January or February, after which the reproductive organs of both sexes subside and they go back to nuzzling.

Prairie dogs are winsome creatures, but their survival strategy has a darker side as well. After the babies are born, many mothers go on an orgy of infanticide, killing and often eating the pups of others. Whether this behavior developed as a means of reducing competition for food or providing an extra shot of protein at nursing time, there are four to six weeks in the spring when hungry mothers turn prairie dog towns into dangerous places for newborns. When the pups that survive are able to care for themselves, the older prairie dogs move to the periphery of the town and expand its limits, leaving the youngsters in the safer, central burrows.

Prairie dogs are prey and act like it. Much of their day is spent watching for eagles and hawks, coyotes, bobcats, badgers, black-footed ferrets, and snakes, all of which rely on prairie dogs as food. When a prairie dog sees a predator, it utters a warning bark that sends all prairie dogs within earshot scurrying for their mounds, where they sit up and start barking too. In all, ten different calls have been identified: besides the warning bark, there is a specific warning for hawks, an all-purpose defense bark, a muffled bark, territorial call, disputing *chrrr*, chuckle, fear scream, fighting snarl, and tooth chatter. (The latter is occasionally used during disputes).

Prairie dogs are primarily vegetarians, and they are especially partial to wheat grasses and plants of the goosefoot family—though when food is low they will eat almost anything, from prickly pear cactus to burrs. They also enjoy grasshoppers and other succulent insects. Their caecum (which we've retained as our appendix) is as large or larger than their stomach, enabling two hundred and fifty tubby little prairie dogs to consume about as much food as a cow weighing half a ton.

When water falls on a prairie dog town, it falls on soil filled with what hydrologists call macropores—tunnels larger than a millimeter in diameter. Elsewhere, the entire soil profile, from the surface of the earth down to the water table, needs to be saturated before water can percolate down to the table freely, as it does from a buffalo wallow. But soil containing macropores doesn't need to be saturated, for macropores promote rapid transport of water through the soil. This process, called short-circuit bypass flow, violates a basic tenet of soil-water theory: prairie dog burrows allow water that would ordinarily not make it past the root zone to bypass the whole struggle and move directly to the water table. The soils in prairie dog towns are moister than soils in the surrounding area, and according to the hydrologists a higher soil moisture increases the total volume of water that percolates downward. Moreover, the high-intensity, short-duration rainfall that the Plains are likely to

receive is the type of precipitation most apt to enter macropores and be rapidly funneled below the root zone. Clearly, the prairie dog population increased the amount of rainfall percolating down to the groundwater—and thence feeding the region's streams and rivers—as surely as the endless wallowing herds of buffalo did.

Here you have the great American grasslands, an incredibly complex system where Indians managed the fire, tens of millions of buffalo took care of the grazing, and billions of prairie dogs dug holes that, along with the wallows, increased the flow of water to the water table. The buffalo and the prairie dog, along with the beaver, made patches of habitat that ultimately raised the flow in the rivers, while the Indians' regular fires maintained the productivity of the grasslands.

Enter, from the right, Americans of European descent. The woodsmen who ventured West had never seen herds as large as those found on the grasslands, and the sight of so much meat on the hoof seems to have triggered a sort of blood lust. The buffalo were shot by the settlers for their tongues; the carcass and skin were thought to be worthless and were left to rot where the animal fell. The frontier diarist Nathaniel Henderson wrote of the Kentucky Barrens on May 9, 1775, "We found it very difficult to stop the great waste in killing. . . . For want of obligatory law, our game as soon as we got here, if not before, was driven off very much." Which is to say, no one owned the animals, so they were killed.

The bison herds of the Plains, though, were obliterated by market hunters for money. The economics were simple: salted buffalo tongues were bought for 25¢ each and sold in Eastern markets for 50¢. An undressed calf hide generally brought 50¢ (overcoats made of young bison fur were common and inexpensive), while those of adult animals in good condition cost $1.25. The bones, which were ground and sold to farmers as fertilizer, sold for $7 to $10 a ton. To maximize profits, many hunters dealt only in tongues, for it took far less effort to cut out a tongue than to strip off a hide. Men would often bring in two barrels of salted buffalo tongues without a pound of meat or a single robe. In a time when money was scarce and buffalo were plentiful, there were a great many hunters hauling barrels of salted tongues and packs of hides to steamboats on the Missouri.

John Charles Frémont, who surveyed the northern Plains for the U.S. Topographical Corps in 1839, noted that before 1836 a traveler crossing the Plains "would always be among large bands of buffalo." By 1840, the herds were shrinking noticeably. Frank Gilbert Roe, in his definitive study *The North American Buffalo*, quotes one Dr. Josiah Gregg, who observed in that year: "The vast extent of the prairies upon which the buffalo now pasture is no argument against their total extinction, when we take into consideration the extent of the country from which they have already disappeared; for, it is well known, that, within the recollection of our oldest pioneers, they were nearly as abundant east of the Mississippi as they are now upon the western prairie; and from history we learn that they once ranged to the Atlantic coast. Even within thirty years, they were abundant over much of the present States of Missouri and Arkansas; yet they are now rarely seen within two hundred miles of the frontier." In 1842, Frémont found the Sioux of the upper Plains *démontés*—undone—by the devastation of the buffalo. The following year, large villages of Sioux from the upper Missouri moved 500 miles southwest to the Platte in search of the dwindling herds. John James Audubon took a trip that year on the northern Plains and noted that the prairies were "literally *covered* with the skulls of the victims." And in 1844 Frémont noted that the buffalo occupied "but a very limited space . . . along the eastern base of the Rocky Mountains."

By the end of that decade, steamboats were bringing people up the Missouri as far west as Montana; the Santa Fe Trail led to New Mexico; and the Oregon Trail led from Independence,

Missouri, to the Pacific. In 1849, four thousand wagons and fifty thousand animals trekked west on the Oregon Trail in pursuit of California gold. This concentrated traffic was beyond the grasslands' carrying capacity, and the emigrants created a temporary desert, devoid of grass or game, in a long strip between Missouri and the mountains. Pioneers crossing the plains had killed buffalo whenever they could, and the constant harassment drove the animals away from the trails; after 1849, travelers crossing the Plains on the major trails rarely saw buffalo at all.

At the end of the Civil War, Texans drifted home to find millions of feral longhorns on the Texas plains, with ownership determined by whose land they grazed on. The first big cattle drive was in 1866, when over a quarter of a million steers were herded up to Kansas. The Kansas Pacific Railroad reached Abilene in 1867, and in four years more than a million Texas steers had been shipped to packinghouses in Kansas and Chicago, or to Iowa, Nebraska, Illinois, and Missouri farms for fattening on corn grown in fields carved out of the prairie. New cattle trails developed and their termini moved west to Newton, Wichita, and Dodge City, Kansas, to meet the Santa Fe Railroad. When stockmen learned that cattle could survive the cold winters, they moved them into Colorado, Wyoming, Utah, and Oregon.

As the railroads extended west and the longhorns pushed north, market hunters cleared the range of buffalo. Where buffalo were at all plentiful, every hunter killed between one thousand and two thousand during the hunting season, when the pelts were prime. The slaughter was greatest along the lines of the three great railways—the Kansas Pacific, the Atchison, Topeka & Santa Fe, and the Union Pacific. From 1872 to 1874, the railroads carried 1,378,359 hides, 6,751,200 pounds of meat, and 32,380,050 pounds of bones to market. On the Santa Fe route, it was said that one could walk 100 miles on the bloated bodies of slaughtered buffalo, and the southern buffalo range became a vast abattoir. Putrefying carcasses, many of them with the hide still on, lay thickly scattered over thousands of square miles of the level prairie. The remaining herds had become scattered bands, harried by hunters who now swarmed almost as thickly as the buffalo.

White hunters were not allowed to hunt in Indian Territory (the boundaries of which had been set as those of the present-day Oklahoma State in 1824), but they picketed the southern boundary of Kansas, and every herd that crossed north into Kansas was annihilated. Every watering hole was guarded by a camp of hunters, and whenever a thirsty herd approached, it was met by bullets. By 1874, the great southern herd was gone.

Before the construction of the Northern Pacific Railway, in 1880–1882, the only way to market the tongues and hides of the northern herd was to ship them down the Yellowstone and the Missouri Rivers to steamboats that brought them to railheads. Beginning in 1830, as many as a hundred thousand robes a year were sold from the northern herd, but the herd's denouement dates from the 1880s and the completion of the Northern Pacific.

As with the southern herd, it was the fact that a single hunter could destroy many hundreds of buffalo in a single day that erased the herd before the people of the United States were fully aware of what was happening. The Plains were so immense that few were able to imagine the great herds as finite. The Indians had believed that buffalo streamed perpetually from a cave deep in the prairies, and the buffalo hunters themselves had no idea that the great beasts were gone: they geared up in 1885 and went out right on schedule to find . . . no buffalo. In 1887, the zoologist William T. Hornaday wrote, "Twenty years hence, when not even a bone or a buffalo chip remains above ground . . . , it may be difficult for people to believe that these animals ever existed in such large numbers." And so the wallows slowly began to disappear.

While the herds were being slaughtered, the Plains Indians were being destroyed by gunfire, disease, and alcohol, as well as by the loss of their herds and their land. The U.S. military had

turned its attention to emptying the Plains of Indians after the Civil War. The tribes' traditional religious, social, and governmental patterns were shattered, while the telegraphs and railroad allowed the federal government to move men and matériel wherever it was needed to quash the latest rebellion. Tribe by tribe and band by band, the Indians were defeated and moved onto reservations, where they were given hoes and seeds and told to become agriculturists. And so the annual burnings of the grassland ended.

The most obvious use of grasslands cleared of buffalo and Indians was to raise cattle, which could be taken by rail to be sold in the East. The only need was capital, which was supplied by Eastern dudes and British investors. The West had the grass and the cowboys; the East had the capital; the railways linked the two together. So grazing, at least, continued on the grasslands—but cattle and buffalo have important behavioral differences. Cattle have to be fed in winter, when they look around stupidly for hay on the surface of the snow. The buffalo found their own forage, scraping away the snow with their heavy heads and hooves. The grazing patterns of the two species are similar—if anything, buffalo are even more single-minded in their selection of grasses over forbs—but cattle and buffalo behave differently when they drink. Buffalo, being wild, don't linger streamside: they come down to the water, drink, and then leave. Cattle, long domesticated, just lounge around by the water, churning the slender green riparian edge into a muddy wasteland.

Like all edges, the riparian edge is the most productive fraction of its ecosystem, and streams that flowed clear when the buffalo drank from them grew muddy and rank under the clumsy hooves of cattle. Fish that once hid in the cool shadows along the banks lost their shelter, stream temperatures rose, and fish populations dropped along with the oxygen content of the water. Silt covered the gravel beds where fish had spawned; there were fewer places for frogs to hide from predators; the stream biota was simplified; and more soil washed into the water.

Prairie dogs, which are hard to shoot but exceedingly easy to poison, were the last to come under attack. Horses were said to break their legs galloping across prairie dog towns, and so were cattle, but the prairie dog was classified as a pest on account of its appetite, not its tunnels. Because they keep the vegetation in their towns closely clipped, it was assumed that they competed directly with sheep and cattle for forage. In 1901, the Yearbook of the U.S. Department of Agriculture described them as an evil that reduced the number of cattle an area could support by 50 to 75 percent, and the USDA provided detailed instructions on how to remove them with strychnine, at a total cost of 17¢ an acre or less. In 1920, the USDA Yearbook stated that prairie dogs cost ranchers $300 million annually by "selecting the most productive valleys and bench lands for their devastating activities"—never wondering why these lands were the "most productive." A concerted chemical assault was launched: that year, 132,000 men festooned 32 million acres with poisoned grain to improve the grazing for cattle.

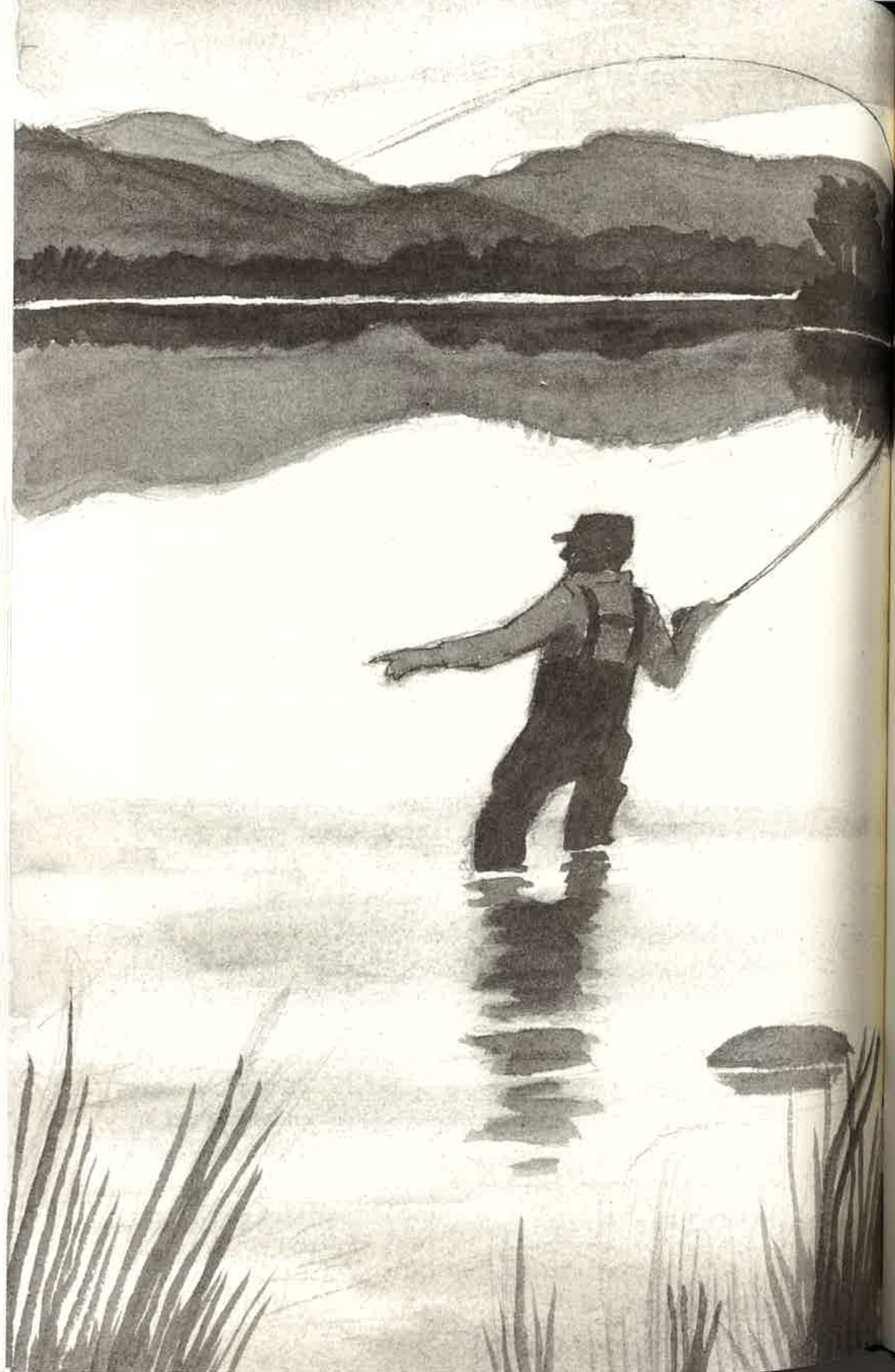
Routine poisoning of prairie dog towns has continued unabated. Today zinc phosphide has supplanted strychnine as the poison of choice, and prairie dogs are still classified as pests. On public land, poisoning is attended to by the U.S. Forest Service, the Bureau of Land Management, and the National Park Service, while in many states prairie dogs on private land are "managed" by county weed and pest boards, which poison the prairie dog towns and attach the costs to the landowners' tax bills.

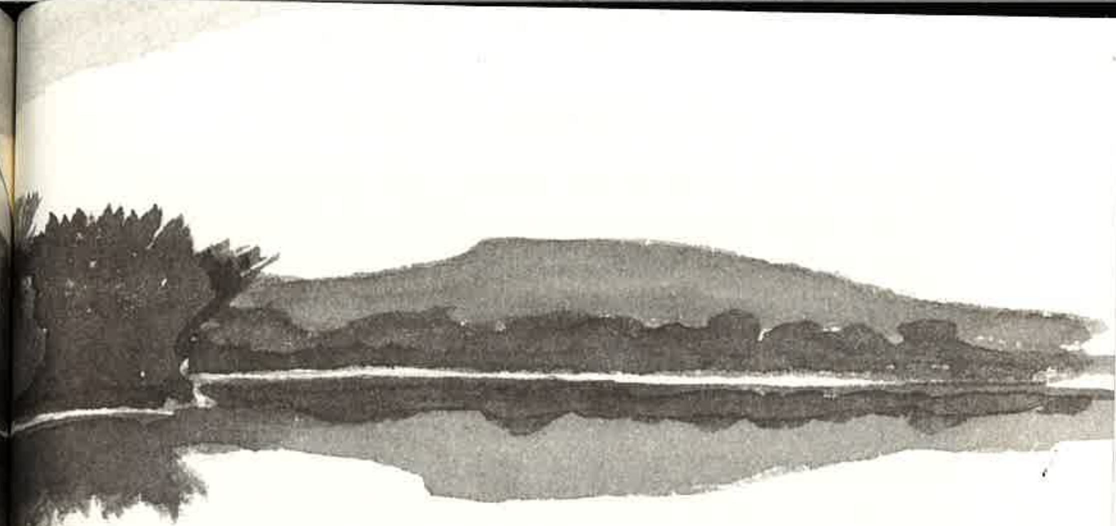
Ironically, recent research has shown that prairie dogs and cattle have a mutually beneficial relationship. Prairie dogs on the mixed-grass prairie need the help of large grazers to keep the plant cover low, for safety. When cattle are fenced out of a prairie dog town, the colony is unable to maintain a short-grass plant community, and the taller grasses hide predators that soon

overwhelm the colony. For their part, cattle grazing in prairie dog habitat gain more weight than cattle grazing elsewhere on the Plains, thanks to the higher protein content of the tender clipped grasses. Forage quantity may be reduced, but its quality is improved, leaving at worst a neutral outcome. And it is also thought that the higher water content and organic content of the soils in prairie dog towns make the grass grow better there.

Nonetheless, the distaste of ranchers for these humble soil-making, groundwater-replenishing rodents lingers. They are tolerated only on a small fraction of their range on public land, and rarely go unpoisoned on private land. Prairie dog towns may have once covered a few hundred million acres; they now burrow in a total of about two million acres.

Without regular fires, the productivity of the grasslands declined. Without prairie dog towns to hide in and feed in, the snakes, box turtles, toads, and tiger salamanders, the cottontail rabbits, skunks, prairie chickens, and dozens of other populations began to decline; and the eagles and hawks, coyotes, foxes, badgers, and black-footed ferrets had less prey to feed on. As the biological diversity declined, the old buffalo wallows and prairie dog tunnels started filling in. The rate of groundwater recharge dropped, there was less underground water to feed the streams and sloughs, and slowly, slowly, across the Plains, the waters began to recede.





ELEVEN

WHAT SLUDGE TELLS YOU

The Clean Water Act set curbs on discharges of all types, but since most of the problem was perceived to have been caused by cities and industries, most of the money was focused on reducing pollutants from these sources. In the decade after passage of the Clean Water Act, the federal government disbursed billions of dollars in wastewater-treatment-plant construction grants, and industries spent countless more billions on in-house solutions to clean up their effluent. Industry by industry and city by city, discharge reduction and source reduction were implemented, treatment plants were built, and toxic flows were reduced.

There were noticeable improvements. Fish kills declined, algal blooms began to disappear, and rivers and lakes around the country began to revive. The banning of DDT allowed the populations of ospreys, bald eagles, and brown pelicans to rebound, and recycling matured from a fringe activity to standard behavior. One of the most obvious effects of the new environmental laws was that the coal-fired plants that once belched great gobs of black smoke were required to clean up their smokestack emissions. When the particulates were removed, the results were completely unexpected.

The larger particulates in smoke—mostly ash—are chemically basic. When the smokestacks were low and black smoke blanketed a city, the basic particulates neutralized the acids that form in the air from the nitrogen oxides and sulfur oxides released during combustion. The rain was dirty, but the pH was probably neutral; even London, known for its black shroud, had healthy trees and gardens. In the 1940s, taller smokestacks were built to raise the soot above the cities, and this is thought to have been the start of acid rain. The particulates still fell on the surrounding communities, but the acids circulated high and were swept northeast by the prevailing winds. When the Clean Air Act passed and the smokestacks of the Rust Belt were no longer allowed to blast wastes into the air, the largest particulates were removed by filters, while the sulfur oxides and nitrogen oxides went straight out the chimney. In the Northeast, the rain was soon as acidic as orange juice.

As long as the pH of soil is neutral or basic, the minerals and trace metals that lace the soil are bound in place. The soils of the Northeast were barely neutral to start with, and after three decades of increasingly acid rain, the soil was unable to buffer

the onslaught. The metals that had been bound in the soil moved into solution, and fish began to die from metal poisoning. Amphibians, with their permeable skin, were directly affected by the acids, as were high-altitude trees, which were bathed in acid fog. By the early 1980s, trees on the summit of mountains in upper New York and Vermont had begun to die, and the mountain ponds in the region were often fringed with blanched corpses of salamanders and frogs. More equipment on every smokestack followed, but abatement technology was not the whole story. Energy conservation, improved combustion efficiency, changes in products and in the means of production soon contributed to cleaner skies and sweeter rain.

In 1987, fresh out of MIT with a master's degree in Technology and Policy in hand, I was persuaded that we could engineer our way to clean water as well. And so I went to work on the last of the big-city wastewater projects: the Boston Harbor Clean-Up.

Boston has one of the oldest sewer systems in the country, and one of the most sprawling. In the 1860s, the city built holding tanks on Moon Island in Boston Harbor, and released the sewage on the outgoing tides. At the time, this was a thoughtful step forward in sewage management, and Boston's innovative system was written up in civil engineering journals here and abroad. Over a century later, however, little had changed but the number of towns connected to the wastewater collection system. Two primary treatment plants, sited on small former islands south and north of the city, received the wastewater from forty-three communities, including over six thousand industrial dischargers and 2.3 million people. And the sludge was still being released on the outgoing tide every day. The brown slick was supposed to drift out to sea, but more often it ended up circling back to shore instead. And along with the sludge, the prevailing tides washed ashore thousands of pink plastic tampon applicators.

In 1982, the Quincy city solicitor was jogging along a beach near Boston and realized that he was running in turds. Within a year, the city of Quincy sued the Boston municipal commission that managed the wastewater treatment plants. Soon the EPA joined in the fray with another lawsuit, and it was ruled that a secondary wastewater treatment plant would be built and that sludge would no longer be dumped into Boston Harbor.

I worked for the Massachusetts Water Resources Authority, which assigned five of us to divert the treated wastes to some sort of application on land. The disposition of the sludge awaited the siting and construction of a sludge-pelletizing plant, but the court had ordered that the scum be taken care of immediately. Before we get down to the details, though, we need to go deep into the innards of a wastewater treatment plant.

The tour starts in the lobby. Municipal funds for dressing up such unglamorous budget items are scarce, so wastewater treatment plants across the country are remarkably similar: the cheap linoleum and steel desks are as ubiquitous as the aquarium in the entryway and the whiff of digesting sludge from the works outside. The main that brings the raw sewage into a wastewater treatment plant is often enormous. In the United States, per-capita wastewater production is about 100 gallons a day, so city flows become epic. In Boston, it's greater than the combined flow of the three rivers—the Charles, the Mystic, and the Neponset—that feed into the harbor.

Wastewater is nearly all water, containing just 1 or 2 percent solids, including excrement and food, toilet paper and detergents, soaps, shampoos, cleansers, household hazardous waste, and oil and grease. The water is gray, and festooned with shards of toilet paper. A series of preliminary screens separate the socks, rags, sticks, and lumber from the sewage and protect the plant's pumps from debris. Next, the wastewater passes through chambers designed to slow the flow enough for grit to settle to the bottom. The grit is mostly sand and gravel, but also includes melon seeds, coffee grounds, cigarette butts (and, within a very

short time, wiggly white worms); both the grit and the screened debris are usually turned into landfill.

The next stage of cleaning is done in giant rectangular open-air primary sedimentation tanks, or clarifiers. A blade on rails moves slowly across the surface of each tank, skimming off scum and shunting it to thickening tanks. Seagulls whirl above, and dive down to fish out vegetables and tampon applicators, which litter the walkways between the tanks. Clarifiers hold the wastewater for an hour or two, which is long enough for the flow to separate into layers. The scum floating on top of the tanks includes grease, soap, skin, vegetable and mineral oils, some paper, wood, and cotton, along with most of the Band-Aids, condoms, and plastic tampon applicators people flush down the toilet. (These applicators are a wastewater engineer's nightmare. Aerodynamically designed, they slip through screens like a torpedo. In the 1980s, roughly fifty thousand applicators a day were arriving at the wastewater treatment plants in Boston. This translates to a flush rate for these items of about 40 percent, though Playtex, their principal manufacturer, claimed at the time that informal surveys indicated only 1 percent of their customers flushed the applicators.)

Meanwhile, the sludge—mostly feces, toilet paper, and the heavier suspended solids—sinks to the bottom of the clarifier tank, where it is scraped into a sump or a hopper and sucked out the bottom of the tank for further processing.

After primary treatment, the water has dropped about two-thirds of the solids it carried, but it still contains some suspended, colloidal, and dissolved solids—urine, for example. Before Boston built its secondary treatment plant, this water was chlorinated and released to the harbor. During secondary treatment, the dissolved solids in the water are eaten by a complex community of microorganisms that are already part of the flow. The temperature, oxygen level, and contact time are controlled to maximize the growth of a slimy, bulbous bacterial sludge, which looks like it would be ready to walk out of the refrigerator in different circumstances. The effluent itself is chlorinated and discharged to the waterways. Secondary treatment routinely removes about nine-tenths of the solids in wastewater, and 95-percent removal is not unheard of. Tertiary treatment, including filtration or chemical precipitation (in which chemicals are used to flocculate the dissolved solids), can remove over 99 percent of the solids in water. This effluent is drinkable (if you are so inclined), but tertiary treatment costs are generally considered much too high for such a marginal improvement, and only a handful of cities today have such systems in place. Ninety percent cleaner is pretty good, but secondary treatment is no cure-all. One-tenth of anything you put down the drain or the toilet or into the washing machine sneaks through the treatment plant and out to the waterways within hours.

Meanwhile, we've left the residuals still in progress back at the treatment plant. The scum is concentrated in the thickening tanks, where the water is drained off and piped to the head of the plant, leaving mostly grease behind. The sludge is thickened as well, and then these residuals are both piped to an enormous covered vat called a digester, in which the raw sludge brew—a pungent, dark brown liquid the consistency of pancake batter—ages and ripens. It is kept warm, to encourage the growth of microorganisms, which consume—digest—the solids and give off methane. In most wastewater treatment plants (Boston's included), this methane is collected and used to provide part of the plant's power. A digester usually holds the sludge for at least three weeks, so large treatment plants need several large digesters.

In a typical two-stage anaerobic digester, a half million gallons of sludge is kept well mixed during the first stage, maximizing the contact of the organic matter with the microorganisms to encourage their growth. In the second stage, the mixer is turned off, and the sludge stratifies into four layers. Scum and odd chemicals rise to the top, and the comparatively clear

supernatant below is piped back to the head of the plant for reprocessing. The actively digesting sludge burbles below all this, and the digested sludge—with most of the organic matter consumed by bacteria—sinks to the bottom, where it is pumped out of the digester to a holding tank.

The grease in the scum is digested more slowly than the organic matter in the sludge, so a scum blanket breaks down steadily as it accumulates. The plastics in scum, though, are less tractable. Bacterial digestion usually reduces condoms to an innocuous-looking ring easily mistaken for a rubber band, but the plastic tampon applicators have great structural integrity, and in a few years a layer of them 6 to 8 feet thick builds up, and the digester has to be emptied and cleaned.

When bacteria and other microorganisms have consumed most of the organic matter in the water and the sludge is well digested, the result resembles composted cow manure mixed with water. The phosphorus in digested sludge once polluted the waterways, but it is a valuable fertilizer on land, while the organic material and the microorganisms build up the soil biota. Digested sewage sludge was routinely reused as fertilizer until the 1940s, when cheap chemical fertilizers became available. For the next forty years, sewage sludge was used as landfill, or else it was incinerated or dumped back into the waterways. But after the Clean Water Act curbed industrial contributions to sewers, sludge began to be used on land again. Seattle sprayed its sludge on forests to promote tree growth, while composted sludge from Maryland was used to fertilize the White House lawn. New York City continued to fill up barges and dump its sludge at sea, however, and Boston continued to release its sludge on the outgoing tides. Not until 1988 did Congress prohibit the release of sludge to the ocean, and the ocean dumping of sewage sludge in the United States finally ended in June 1992.

For two years—from 1988 to 1990—Boston's scum was mine, but there was nothing to do with it. Landfill equipment slipped on the grease, so landfills would not accept it; incineration works poorly with a feedstock of grease and water; the fats were laced with sewage and useless for animal feed or soaps. Disposing of scum as a liquid was hopeless, so we made it into a solid. Every day, thousands of gallons of thickened scum were mixed with cement kiln dust, another waste product. The chemically fixed scum was a gray material encrusted with personal hygiene items. It behaved like a soil, mechanically, and eventually a few hundred thousand cubic yards of fixed scum was stored in three bulldozed hills. The rats and gulls would congregate there to eat; perhaps they liked the fats. My scum piles were ultimately incorporated into one of the berms designed to hide the new secondary treatment plant from view—a fitting use, I thought, for the concrete evidence that people won't change their behavior until they understand that their toilets are connected to the waterways.

Along with managing the scum, my job was to assess sludge quality to make sure that we met the EPA regulations for any sludge products that would be used on land. Nearly all the toxins and heavy metals in wastewater are transferred to sludge and scum in the wastewater treatment process. The chemical contaminants are not destroyed; some volatilize into the air, but most chemicals and heavy metals bind to either organic matter or grease, and end up in the digested sludge. Secondary treatment transfers 92 percent of PCBs in wastewater to the sludge, for example, along with 90 percent of the dimethyl phthalate and 70 percent of the cadmium. This means that digested sludge carries the fingerprint of all of the industrial discharges to the wastewater collection system.

Every city of fifty thousand people or more is therefore required by law to establish discharge limits for its industrial dischargers, a requirement that was initially ignored. When sludge started to be reused, though, municipalities got more involved in what arrived at the treatment plant. As soon as a city starts recycling its sludge, the industrial-discharge permit system tightens up. The inspectors pay closer attention, and an industry's furtive slips down the drain tend to decrease. A forty-city sludge survey in 1982 and the National Sewage Sludge Survey of 1988 both showed that cities that recycled their sludge had cleaner sludge, regardless of the number of industrial dischargers. According to the 1988 sludge survey, 13,458 wastewater treatment plants were generating nearly 6 million dry tons of sludge a year—or roughly 50 dry pounds of sludge per person annually. Of that, over a third was land-applied, an amount that was steadily increasing.

This tale of the dwindling industrial contaminants in the wastewater grew even stranger, though, because not all the industrial contaminants in sludge get there because of industrial discharges. When rain falls on pavement, it sweeps oil, gasoline, and the detritus of tire treads down into the sewers. Households add detergents, soaps, cleansers, household hazardous waste, lawn-care products that would never be bought if people read the small print, and oil that weekend mechanics dump into the gutter. The water itself from the reservoir has its own baggage of metal and other contaminants.

With municipal-sludge quality reports from around the country piled on my desk, I began to realize that industries themselves are no longer directly dumping much down the sewers. Whether or not industrial discharge reports are reliable, sludge implacably reflects whatever contaminants are present in the waste stream; sludge doesn't lie. And most city sludge is remarkably clean. The waterways, however, are still polluted.

What was dawning on me in the late 1980s because of local experience was beginning to show up nationwide. Water quality had markedly and rapidly improved in the 1970s, but by the mid-1980s a third of the nation's waterways were still assessed as unfit for fishing or swimming—and so they have remained. About 40 percent of the lake acreage and 30 percent of the stream miles in this country are still polluted. Water quality has changed little in the last decade.

Over half the rain that falls on the continental United States—roughly 35 billion gallons of water a day—is made into wastewater by our cities and our industries, and our cities clean it reasonably well. The overwhelming majority of water pollutants are now contributed by big agriculture. In 1992, the Executive Office's Council on Environmental Quality attributed 6 percent of the impairment in streams and lakes to industrial pollution and a whopping 60 percent to silt and excess nutrients from fertilizer runoff. In 1992, the U.S. Public Interest Research Group, a nonprofit environmental organization, estimated that toxic industrial contributions to the waterways and oceans totaled about 155,000 tons—or less than 5 percent of what Detroit alone used to contribute every year in the 1960s. In the meantime, however, tens of millions of tons of topsoil wash into the streams, and farmers dump about 20 million tons of fertilizer on fields across the country, along with between 250,000 and 375,000 tons of pesticides. Agricultural subsidies—which were designed in the 1930s, before the advent of chemical fertilizers and pesticides—are at the heart of the problem. These subsidies, which are now being phased out, allow farmers to grow more crops than would be grown in a consumer-driven market, and in order to maximize their yields many farmers turned to the use of fertilizers and pesticides. Fortunately, organic farming techniques and biological (rather than chemical) pest management are gaining ground. Over a third of the nation's corn crop is now grown using low-till or no-till farming, in which the crop waste is recycled into the soil and earthworms create macropores, which reduce runoff and increase water uptake by the soil. The high costs of chemical fertilizers and pesticides—and the premium that consumers are willing to pay for organically grown crops—is changing the way many farmers manage their land.

But some types of pollution are far more difficult to manage. Groundwater pollution has proved to be surprisingly intractable; once a plume of contaminants is loosed into an

aquifer, it is nearly impossible to remove. Likewise, airborne pollutants continue to rain down steadily from the skies even though the air has grown clearer. Remote ponds that appear to be pristine are polluted by assorted wind-deposited chemicals and metals, including mercury from incinerator smokestacks, DDT from Central American fields, and traces of other assorted hazardous wastes. Finally, we cannot undo what we have done. New hazardous waste sites are not being created, but the old ones are very costly to clean up; PCBs, once they have been released to the environment, cannot be taken back.

Cleaning up industrial and municipal discharges has cost hundreds of billions of dollars, and a third of the nations's waterways are still polluted. Water pollution is clearly more complicated than we had realized, and discharge control has not solved the problem.

Consider this: after water leaves a reservoir, it takes hours or days to move through the pipes to a house or factory, where it's polluted; through a wastewater treatment plant, where it drops most of its pollutants; and out to the waterways or to the sea. After days running through the engineered system, it enters the natural water cycle for a decade or more, where it may run to the sea and eventually move to the clouds, be blown inland to rain onto forests and fields, run into wetlands and streams, or percolate down to the groundwater. And then, perhaps, it moves into a well or reservoir again. For each day that water flows in pipes, it might spend a decade or more in the natural world. And nature is the best cleanser—at least, it once was.

This country's waterways have been transformed *by omission*. Without beavers, water makes its way too quickly to the sea; without prairie dogs, water runs over the surface instead of sinking into the aquifer; without bison, there are no groundwater-recharge ponds in the grasslands and the riparian zone is trampled; without alligators, the edge between the water and land is simplified. Without forests, the water runs unfiltered to the waterways, and there is less deadwood in the channel, reducing stream productivity. Without floodplains and meanders, the water moves more swiftly, and silt carried in the water is more likely to be swept to sea.

The beaver, the prairie dog, the bison, and the alligator have been scarce for so long that we have forgotten how plentiful they once were. Beaver populations are controlled, because they flood fields and forests, while wetlands acreage decreases annually. Prairie dogs are poisoned, because they compete with cattle for grass, while the grasslands grow more barren year by year. Buffalo are generally seen as photogenic anachronisms, and alligators are too reptilian to be very welcome. But all of these animals once shaped the land in ways that improve water quality.

It is not only water quality that has been affected, though. Without these builders, the contour of the land has been smoothed, and many niches have disappeared; the base of the food chain has withered, and in the process the abundance and the productivity of the land has declined. In 1993, the National Biological Service was created by Secretary of the Interior Bruce Babbitt to gather biological data on public and private lands nationwide. Babbitt, a geologist by training and a former two-term governor of Arizona, was eager to bring ecosystem management to federally owned lands. In 1995, the National Biological Service completed the first ecological review of the United States. The study found that the extent and vitality of dozens of ecosystems throughout the country have suffered a sweeping, but largely unnoticed decline. In spite of gaps and uncertainties in the data, the researchers concluded that the information "portrays a striking picture of endangerment."

The tallgrass prairies, the oak savannas bordering the grasslands, and the old-growth, fire-managed deciduous forests of the Eastern United States are among the largest imperiled

ecosystems, along with more than 100,000 square miles of longleaf pine forests that once covered the Southeastern coastal plain. The Eastern forests were cut, the Midwestern grasslands have nearly disappeared under crops, and the oak savannas have been degraded by fire suppression. The longleaf pine ecosystem has faced both types of decline: great swaths were cut down in the early part of the twentieth century, and without periodic fires the pines have been taken over by hardwoods.

Cattle and sheep have destroyed much of the riparian edge in the grasslands, degrading the aquatic ecosystems. When a stream has a well-developed edge, it supports life that cleans the water. In the mixed-grass and short-grass prairies, cattle trample the edge of the stream. Without beavers to cut down or drown the older streamside trees, the cottonwoods become enormous, siphoning water from the flow. What used to be a live stream, with fish and a lush edge, becomes a barren gulch. The water table drops, erosion progresses, and in fifty or a hundred years the land becomes desert. In 1988, an Arizona Fish and Game Department report concluded that less than 3 percent of the state's original riparian zone remained intact, while New Mexico has lost at least 90 percent of its riparian zone to grazing.

According to the National Biological Service's 1995 report, ecosystems that once covered at least half the area of the contiguous United States are now critically endangered. The face of the land has changed, and as ecosystems are fragmented and simplified, the species that rely on them for habitat are under increasing assault. The Nature Conservancy's 1996 Annual Report Card for United States Plant and Animal Species, a comprehensive assessment of the country's indigenous fauna and flora, has found that the mammals and birds are doing relatively well; however, flowering plants and freshwater species (like most mussels and many riverine fish) are not. Of 20,481 native species of plants and animals surveyed, about one-third are faring poorly. Over two hundred and fifty species are extinct or possibly extinct, over thirteen hundred are critically imperiled, eighteen hundred are imperiled, and over three thousand are considered vulnerable.

In the last century, twenty-one species of freshwater mussels and forty species of freshwater fish became extinct. Today, about two-thirds of the remaining freshwater mussel species in this country are at risk of extinction, along with about one-third of the species of amphibians and freshwater fish. All depend on rivers, streams, or lakes, which are becoming biologically poorer even as water quality improves. In their Annual Report Card, the Nature Conservancy attributes part of this to the long-term effects of dams and other water diversions.

When the Federal Energy Regulatory Commission (FERC) first issued fifty-year operating licenses for dams in the 1940s and 1950s, rivers were managed to provide energy production, irrigated acreage, and city water supplies. Life in the river itself and along its banks and on its floodplains was not included in the equation. Dams cause periodic and drastic fluctuations in the channel flow, as water is released to generate electricity for peak power demands. Fish are cut off from their spawning grounds or killed in the electric turbines. Dams block the flow of nutrients, slow and heat the water, and use the kinetic energy that would reaerate the water to generate electricity. In the last twenty years, however, our view of a river has expanded to include recreation and aquatic habitat, and dams are beginning to be managed differently. In 1986, the FERC was required to give recreational and biological issues equal consideration with power generation whenever it renewed a dam's license or issued a new one. In many cases, so little of a dammed river's water had been dedicated to the aquatic habitat that a small decrease in power production resulted in huge gains for wildlife. On the Deerfield River in Massachusetts, for example, a 1996 agreement to decrease power generation by 10 percent is expected to result in a fifteenfold increase in the trout habitat.

The movement to give rivers back their form was spearheaded by whitewater enthusiasts, but soon reached many environmental and governmental organizations. In 1991, the Department of the Interior ordered that dams in Wyoming, Utah, and Colorado release water flows on the Colorado River in the spring and early summer to enhance river rafting, rather than using the water to generate power at peak usage times. On March 26, 1996, a week-long artificial flood was released from the Glen Canyon Dam, and the Grand Canyon was scoured by high spring flows after thirty-three years of low water. As a result, for the first time since it was dammed, the Colorado River is beginning to regain its natural flow. About eight hundred dams nationwide are up for relicensing between 1996 and 2010, and the waterways should eventually show the difference.

When more water is allocated to maintaining a river's ecosystem, there is, obviously, less water available for cities, industry, and agriculture. Demand, though, has proved to be more flexible than people had imagined. Agriculture consumes the largest fraction of Western water by far—some 90 percent of it—and installing more efficient irrigation systems and growing crops that require less water can reduce water consumption considerably. Industrial and municipal water consumption are both rate-sensitive, and when the price of water climbs the purchase of low-flow appliances increases, another way of reducing demand.

The Army Corps of Engineers—past masters of dredging and channelization—have also become more environmentally aware. In 1969, the Corps was branded Public Enemy No. 1 by Supreme Court Justice William O. Douglas for its environmentally devastating activities. In southern Florida in particular, the Corps projects were so destructive that they are finally now being undone.

The Kissimmee River originally meandered south for 140 miles before it drained into Lake Okeechobee. South of the lake lies the Everglades, a great sheet of water supporting a river of grass that once extended unbroken 150 miles to the southern tip of Florida. In 1928, a flood in south Florida drowned 2,750 people, and the Corps avenged their death by trammeling the Everglades. The sinuous curves of the Kissimmee were straightened into a 56-mile canal 175 feet wide and 30 feet deep. An immense earthen levee was built around Lake Okeechobee, and 1,400 miles of canals, levees, spillways, and pumping stations were built to free up over half of the total Everglades marshlands for agriculture. Land speculators, cattle ranchers, sugarcane growers, and other agriculturalists grew rich and powerful, but by the 1960s the river and lake were polluted. The southern end of the Everglades (1.4 million acres) was left wild, but too little water was allocated to maintain its ecosystem. By the 1970s, the former hordes of waterfowl had dwindled to flocks, agricultural runoff had overfertilized the plants and poisoned the animals, and the Everglades began to dry up.

Today the Corps is working to free the Kissimmee from its dikes and locks, and to restore the wetlands that once cleaned the river. The original $372 million Corps of Engineers' project to restore 22 miles of canal into 43 miles of curvaceous Kissimmee has expanded into a $1.2 billion federal and state effort to restore the entire river. New water allocations to the Everglades are reviving the marsh, and people throughout the state are working together to ensure that Florida's paradise of grass is not lost. The Everglades is not an isolated case: in states across the country, the Corps now works in concert with the Audubon Society and other environmental organizations to manage water to maximize its benefit to wildlife.

After a hundred years of taking away the form of our waterways, we are starting to put some of the pieces back. This about-face will doubtless do much to help many aquatic species, but it may be too late to save most of the native freshwater mussels.

The zebra mussel (*Dreissena polymorpha*) is an ancient resident of the Caspian Sea that spread throughout the European waterways in the last two centuries. In 1985 or 1986, biologists believe that a ship from Europe jettisoned a number of larval zebra mussels along with its ballast water into the waters of Lake St. Clair, which is tucked between Lake Erie and Lake Huron. The larvae of the zebra mussels, unlike that of the fish-dependent American freshwater mussels, are free-floating. And while the American mussels burrow in the bottom sediments, the zebra mussels, like their saltwater counterparts, cling with tough byssal threads to such surfaces as water intake pipes and ship hulls. The native freshwater mussels have been in decline for a century, and the zebra mussels are spreading to fill the ecological void. This alien has reproduced so successfully that in some areas the sparse populations of native mussels are encrusted with pistachio-size, elegantly striped zebra mussels. Each small mussel filters about a quart of water a day as it gorges on microorganisms, and the water in the Great Lakes and the Mississippi River is finally beginning to be cleaned by filtering mollusks again. The native mussels, though, are unlikely to survive the competition.

The success of the zebra mussel could bring the Endangered Species Act to its knees. This continent is rich in species of freshwater fish and mollusks endemic only to a relatively few small and scattered places. The Mississippi River drainage system is a major center of endemism, as are the springs of the Southwest. As the populations of freshwater mussels, Texas blind salamanders, tiger salamanders, Lahontan cutthroat trout, humpback chubs, Colorado River squawfish, and Devil's Hole pupfish dwindle, one can't help but wonder; Do we have to save *all* of them?

It's the wrong question. By focusing on the preservation of endangered species one after another, as if they were items in a catalog, we are missing the larger, ecological picture. Without the ancestral complement of keystone species—nature's engineers—the path that water takes through the land, and the shape of the land itself, have been simplified. The central actors, which once numbered in the hundreds of millions and billions, are missing or scarce in most of their former range. Where do the salmon fingerlings hide and feed without the beaver ponds they coevolved with? How can the eagles prosper with no prairie dogs to eat? The tiger salamanders have no tunnels to hide in; the prairie chickens have no stage for their courtship dances. Without restoring the ancestral populations of engineers to at least some of the landscape, it seems unlikely that the supporting players will manage to survive.

Back when I was managing scum, I learned that before people are willing to change the ways in which they impact the waterways, they have to understand how the system works. People will continue to flush plastics down the toilet, for example, until they understand that their toilets are connected to the waterways. People will continue to keep prairie dog towns and beaver colonies off their land until they understand that the pathways water takes through the land are changed by tunnels and wetlands and that their land will hold more water, and grow more grass, with these animals. Ranchers in the Southwest are still poisoning phreatophytes that steal water from the river, and the beavers that once made wetlands in that arid region—and cut down the cottonwoods before they grew to be river-draining goliaths—are forgotten. It seems unlikely that enough private landowners will allow either rodent species back on their land to make a difference in the nation's water quality.

We have an enormous national commons, however. Over a fifth of the contiguous United States—626,000 square miles—is publicly owned and federally managed by the Bureau of Land Management, the Forest Service, the Fish and Wildlife Service, and the National Park Service. In theory, both the prairie dog

and the beaver could be restored on all that vast acreage with a stroke of the pen. But while it is well understood that degraded land pollutes the waterways, public land is managed with little thought to water quality. For the last century, timber production, grazing, and oil and mineral extraction have been the primary uses of our national commons. Beaver populations are controlled to maximize timber revenue, while net wetlands loss continues; riparian habitat is stripped by livestock, lowering water tables and degrading water quality; careless lumbering clogs the streams with silt.

The U.S. Forest Service manages about 265,000 square miles of forestland in the contiguous United States (and a lot more in Alaska), or about 8 percent of the forty-eight states. Although forests are water purifiers, that capability has been largely ignored. In the West, vast clear-cuts allow silt to clog mountain streams, affecting salmon fisheries and municipal water supplies. Forests, instead of cleaning our water, are fouling it. By logging in ways that preserve stream integrity—for example, by avoiding the logging of steep mountainsides and by limiting clear-cutting—public forestlands could begin improving stream quality rather than impairing it.

The Bureau of Land Management, which manages our public grasslands, controls about 275,000 square miles of land (or about 9 percent) of the lower forty-eight. Some 23,000 livestock raisers lease this land and parts of Forest Service land as well, to graze a total of over 4 million cows and 2 million sheep. Some of the National Parks (which total about 75,000 square miles, or 2 percent, of the contiguous United States) support herds of buffalo, but the public grasslands of the Bureau of Land Management do not. There are 3,000 buffalo in Yellowstone National Park alone; in 1991, only an estimated 448 wild buffalo grazed on the bureau's 275,000 square miles. Aside from ripping up the water's edge, cattle and sheep are beset by predators in the forests and on the open range. Coyotes, bears, mountain lions, and wolves all prey on domesticated animals, and ravens pluck out the eyes of lambs. To keep the public lands safe for domesticated animals, the U.S. Department of Agriculture's Animal Damage Control Program destroys about 80,000 coyotes, 200 mountain lions, nearly 10,000 black bears, and 125,000 prairie dogs annually.

Without prairie dogs, beavers, or an intact riparian edge, the grasslands have barely survived. In 1991, the Executive Office's Council on Environmental Quality estimated that half the country's public rangelands were in poor or fair condition, while only 5 percent were judged to be in "excellent" condition—and because of recent efforts to reduce overgrazing and restore riparian habitat, this is the best condition the public rangelands have been for the past century. (Range in "fair" condition has between one-quarter and one-half the vegetation it should, while range in "excellent" condition has 75 percent or more.)

Grasslands need to be grazed, and cattle can be raised without degrading the land and water. Some Western ranchers are restoring riparian habitat by herding their cattle across the land to keep them from congregating streamside and by limiting foraging to specified parcels at particular times of the year. When sheepdogs protect a flock, predation drops sharply, and some ranchers are learning to live with more wildlife. Better still, buffalo are finally being raised for meat, and their populations are the highest they've been for a century. In 1993, a hundred and thirty thousand buffalo grazed, wallowed, and took good care of the water's edge; most of them lived on private ranchland, along with a hundred million cattle. In 1993, three private buffalo ranchers had larger herds than Yellowstone's. The country's largest buffalo herd is owned by media mogul Ted Turner, who recently also returned the prairie dog to his land.

Buffalo are excluded from public grasslands because they are carriers of brucellosis, a disease that has little effect on buffalo but causes cows to abort their fetuses. As the buffalo population has increased, though, it appears that brucellosis is far less contagious than had been assumed, and that buffalo pose little threat to the cattle with which they share the range. Buffalo meat tastes a lot like lean beef. And since buffalo evolved on the prairies, they are far hardier than cattle and can be raised without antibiotics, hormones, or artificial growth stimulants. In the winter, they sweep the snow away from the grass with their massive heads and shoulders and eat snow for water; they survive temperatures that freeze cattle solid. Ranchers who raise buffalo sell their meat to specialty restaurants and some of the better meat markets countrywide; the price ranges from about $6 a pound for ground meat to $20 a pound for steaks, and so far the demand has outstripped the supply.

The popularity of the prairie dog, however, has not improved. Now probably no more than 1 percent of the area once covered by prairie dog towns is tunneled. Although millions survive, their populations are vulnerable. The sylvatic plague is still endemic in prairie dogs, but the establishment of new colonies is restricted; without migration, *Pasteurella pestis* may get the best of the prairie dog. According to metapopulation theory, species are composed of networks of small, interacting populations that help to maintain one another: when populations decline, they can be rescued by healthy migrating neighbors. Healthy populations produce many migrants, thereby creating a positive-feedback loop resulting in a healthy population network. But if enough colonies falter, the network collapses. The sylvatic plague still depopulates prairie dog towns, and the migrants needed to repopulate them could become scarce.

Since the early 1980s, tensions have escalated between environmentalists and the spokesmen (mostly conservative politicians from Western states) for "endangered" loggers, mining companies, and ranchers. Large-scale logging, careless grazing, and corporate mining are still the main uses for our public land, but the environmentalists have succeeded in cordoning off nearly 52,000 square miles in eleven Western states—almost 5 percent of the West—as wilderness. The Northern Rockies Ecosystem Protection bill (not passed at this writing) seeks to set aside another 25,000 square miles in five areas, with wildlife corridors between them, which would put 1 percent of the country's old-growth forests under protection. Another 50,000 square miles of land—about the size of Iowa—has been taken out of agricultural production along the Mississippi flyway as part of the Conservation Reserve Program, which was set up in 1985. Ten years later, an estimated 83 million birds migrated south along the flyway, the biggest such migration in half a century.

There is the will to restore our land. We have just forgotten much of what is missing from it. The balance of nature that existed before we turned things upside down, and the richness and abundance of the land, were based on a few keystone species. What really matters are the numbers. In an area of 2.9 million square miles, billions of prairie dog tunnels and countless millions of beaver dams and buffalo wallows are significant. With their removal went an ecological system that cleaned the water and enriched the land. In spite of our earnest engineering efforts, about a third of the waterways are still polluted, and the natural water cycle is still hugely simplified. But some of the filtering mollusks and the buffalo are coming back, and the prairie dogs and the beavers have both survived with their culture intact.

This land once had clouds of birds, dense herds of grazers, myriad shoals of anadromous fish—and so it could again. It is time to restore the balance to our land and allow nature's engineers to do their work. If the prairie dogs and the beavers are allowed to reestablish their ancestral populations on public land, the dirt will fly, and the waterways will begin to regain their former pristine glory. On public land, at least, it is time for the beavers and the prairie dogs to come home.

NOTES

CHAPTER 1: THE FUR TRADE

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3–4 The wearing of furs in the Middle Ages: Douglas Gorsline, *What People Wore: A Visual History of Dress from Ancient Times to Twentieth-Century America* (New York: Viking, 1952); R. Turner Wilcox, *The Mode in Furs: The History of Furred Costume of the World from Earliest Times to the Present* (New York: Scribner's, 1951); Robert Fossier, *Peasant Life in the Medieval West* (Oxford: Blackwell, 1988).

4 Skins bought by King Edward I: See Clive Ponting, *A Green History of the World*, 1991 (New York: St. Martin's Press: *The Environment and the Collapse of Great Civilizations*) p. 178.

4 For the price of new and used furs, see Elspeth Veale, *The English Fur Trade in the Later Middle Ages* (Oxford: Oxford University Press, 1966) p. 12.

4 Viking trade in furs: Ibid., p. 62.

4–5 Records of furs imported from Russia are in Robert Delort's *Le commerce des fourrures en Occident à la fin du Moyen Age* (Rome: École Français de Rome, 1978) p. 196; and in Veale, *English Fur Trade*, p. 69.

5 The reasons for the high demand for beavers: See Delort, *Le commerce des fourrures*, p. 181, and Joseph Reichholf, "Beavers," in Grizmek's Encyclopedia of Mammals, vol. 3 (New York: McGraw-Hill, 1990).