- *Silent Spring* (1962), the Leopold Report (1964), and *Must They Die?* (1971) stirred opposition to the poisoning of prairie dogs. President Richard Nixon's Executive Order 11643 in 1972 slowed poisoning of prairie dogs on federal lands, as did protection of black-footed ferrets in 1973 via the Endangered Species Act.
- The effects of one-time or infrequent poisoning of prairie dogs are usually short-lived. Colonies commonly recover almost completely within only two to three years after a single poisoning—because it is difficult to obtain 100% mortality in a single treatment, and because prairie dogs survive and reproduce so well under the conditions of low population density and reduced competition that follow poisoning of some, but not all, colony residents.
- Since 1973, the two most commonly used USEPA-approved toxicants have been zinc phosphide (administered via oats or some other grain) and fumigants (administered via insertion into burrows).
- The magnitude of today's poisoning is low relative to poisoning over the last century due to simple numerics: because today's cumulative population size is less than 2% of the former population size, comparatively few prairie dogs are left for poisoning.
- Despite the trends regarding the magnitude of today's level of poisoning relative to levels over the last century, poisoning has increased over the last year following the removal of the prairie dog from the candidate list for FLETWP. The future of chemical control for the management of prairie dogs is thus hard to predict.
- Besides prairie dogs, toxicants kill other animals that consume poisoned bait at colony-sites. Further, fumigation kills not only prairie dogs, but also all other organisms within targeted burrows. Finally, by removing prairie dogs, toxicants and fumigants adversely affect the many plants and animals that depend on prairie dogs for survival. For these reasons, poisoning should be the last resort for controlling today's prairie dogs.

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CHAPTER 9

Methods and Economics of Managing Prairie Dogs

William F. Andelt

People have been managing prairie dogs for more than 100 years (Chapter 8). In this chapter I focus on the methods and economics of managing prairie dogs, but do not consider ethical and humane issues regarding various methods of elimination. First I summarize methods that do and do not work well. I then discuss how prairie dog colonies quickly repopulate after control. Finally, I investigate whether poisoning prairie dogs is worth the cost for farmers and ranchers, and then offer some recommendations.

Methods That Do Not Work Well for Managing Prairie Dogs or Are Too Expensive

Alteration of Habitat

Treatment with 2,4-D (a herbicide) reduces the number of forbs and shrubs at colony-sites, but evidently does not reduce body mass or numbers of prairie dogs (Fagerstone et al. 1977). Similarly, the following items do not significantly reduce numbers of prairie dogs (Knowles 1987): piles of logs or rocks; freshly cut ponderosa pines; telephone poles (to facilitate perching by predatory birds such as ferruginous hawks); and hay bales.

Predator Odors

Cage litter from black-footed ferrets placed in burrow-entrances evidently does not affect either the survivorship or reproduction of prairie dogs (Andelt and Beck 1998).

Translocation

Wildlife managers sometimes reduce the population size of prairie dogs in one area by moving individuals to another area (i.e., translocation; Chapter 13). A paucity of nearby suitable recipient-sites for translocated prairie dogs often limits the utility of this form of management, however, as does the high cost. Though translocations are usually impractical for reducing numbers of prairie dogs in one area, they are crucial for initiating colonies in other areas (Chapter 13).

Contraceptive Agents

With growing opposition to the use of lethal methods for controlling prairie dogs (Miller et al. 1990, 1994; Roemer and Forrest 1996; Chapter 8), contraceptive agents might provide an alternative. Immunocontraceptives (i.e., chemicals that involve the immune system to deter conception) might limit prairie dog reproduction, for example. Immunocontraceptives administered via treated bait, however, are quickly denatured and inactived by digestion before they can be absorbed into the circulatory system (Miller et al. 1998). For immunocontraceptives to be useful for conservation, researchers must find an easy, inexpensive, effective method for administering them to wild prairie dogs.

Administered via oats, diethylstilbestrol (DES) is a synthetic estrogen that dramatically reduces reproduction among prairie dogs by deterring the implantation of, and increasing the resorption of, embryos (Pfeiffer and Linder 1973; Garrett and Franklin 1981, 1983). Because DES accumulates in tissues, however, one detrimental consequence is that it might inhibit the reproduction of predators and scavengers that consume DES-treated prairie dogs (Fagerstone and Ramey 1996). Contraceptive agents such as DES are currently unavailable for public use.

In theory, sterilization of 100% of male prairie dogs within a colony should preclude all reproduction. In practice, however, sterilization of all males is difficult and expensive. Surgical sterilization of as many as 50% of males within a colony does not significantly reduce reproduction (Schwartz 2002) because females in coteries with sterilized males mate with fertile males

Gas Exploding Devices

The Rodentorch (Mertens' Repair Shop, Orovada, Nevada) and the Rodex-4000 (Rodex Industries, Midvale, Idaho) are explosive devices for controlling prairie dogs. Both mechanisms inject a gaseous mixture of propane and oxygen through tubes inserted into the burrow-entrance, and then ignite the mixture to create an explosion within the tunnel. Gas exploding devices can reduce numbers of prairie dogs by more than 50% (Sullins and Sullivan 1992; Randy Buehler, Logan County Pest Control District, Sterling, Colorado, personal communication, 2002). The Rodentorch and Rodex-4000 are expensive and hazardous, however, and are illegal in some states.

Visual Barriers

Prairie dogs depend on low vegetation that allows visual contact with coterie members, identification of trespassers from other coteries, and detection of predators (Hoogland 1995). Barriers that diminish visibility sometimes reduce use of an area by prairie dogs (Franklin and Garrett 1989), but other times they do not (Hygnstrom 1995). Most barriers are expensive and require regular maintenance (e.g., because of wind or rubbing by ungulates), and thus are usually impractical for use in pastures with domestic livestock.

Methods That Do Work Well for Managing Prairie Dogs

Limitation or Postponement of Grazing by Livestock

Prairie dogs commonly prefer areas with intensive grazing by livestock and avoid areas with taller vegetation (Allan 1954; Koford 1958; Smith 1967; Licht and Sanchez 1993). One implication of this finding is that prairie dog colonies can be an effect, as well as a cause, of reduced availability of forage (Chapter 5). Another implication is that limitation or postponement of grazing by livestock will deter colonization of new areas by prairie dogs—especially in mixed-prairies with tall and mid-height grasses, versus the shortgrass steppe with lower vegetation (Chapter 5)—and also will inhibit expansion of extant colonies (Uresk et al. 1981; Knowles 1986b; Cincotta et al. 1987a,b; Truett and Savage 1998). Numerous lines of circumstantial evidence support both these implications (e.g., Koford 1958; Snell and Hlavachick 1980; Snell 1985; Cable and Timm 1988; Knowles and Knowles 1994; Chapter 5).

If limitation of grazing deters the initiation of new prairie dog colonies and the expansion of current colonies, then why don't more ranchers practice such limitation? At least three reasons are important. First, as noted above, the benefits of limiting grazing are most pronounced in tall- and mid-grass prairies—but the benefits are probably meager for many ranches on the short-grass prairie. Second, many ranchers do not believe the notion that heavy grazing by livestock can improve the habitat for prairie dogs (Chapters 5 and 7). The third reason concerns short-term versus long-term perspectives. In a particular year, a rancher might realize a higher profit if he or she allows livestock to heavily forage throughout the ranch—so that the number and size of prairie dog colonies probably will increase while vegetation for livestock decreases. Over many years, however, the same rancher might earn more money by limiting or postponing grazing in many areas—so that the number and size of colonies will remain the same or decrease while vegetation for livestock increases.

We need more research to investigate the feasibility of reducing prairie dog numbers by limiting grazing by livestock. With so many economic implications, and because limiting grazing has few negative side effects for other organisms, the dearth of rigorous information about this method for controlling prairie dogs is perplexing.

Recreational Shooting

Recreational shooting reduces size and density of prairie dog colonies. Recreational shooting is the subject of a separate chapter (Chapter 10), so I will not discuss this issue further.

Zinc Phosphide

The only toxicant registered for use on bait for prairie dogs is 2% zinc phosphide. Baits with zinc phosphide are classified as Restricted Use Pesticides, and landowners must obtain certification from the United States Environmental Protection Agency (USEPA) before using them. Precipitation deactivates zinc phosphide, which is most effective during clear weather with moderate temperatures (Tietjen 1976a), probably because prairie dogs are most active under the same conditions (Hoogland 1995). Zinc phosphide also is more effective when vegetation at colony-sites has become dry and dormant—that is, when natural food is scarce, so that prairie dogs are more likely to consume poisoned bait (Tietjen 1976a). Extermination with zinc phosphide usually is legal only from 1 July through 31 December or 31 January, and therefore does not occur during the periods of mating, gestation, and lactation (Chapter 2).

Prebaiting with untreated oats two to three days prior to baiting with zinc phosphide is a legal prerequisite and is important for maximal elimination of

prairie dogs (Tietjen and Matschke 1982). Efficiency of zinc phosphide, measured as percentage of prairie dogs killed, ranges from 66% to 97% after prebaiting (Hygnstrom et al. 1998), but the range is only 30% to 73% without prebaiting (Holbrook and Timm 1985). Highest efficiency involves spreading approximately 4 grams (about 1 heaping teaspoon) of toxic bait at the base of every burrow-mound and near every burrow-entrance (Tietjen 1976b) (Figure 9.1). A typical prairie dog colony-site requires about 400 grams of toxic oats per hectare (6 ounces per acre).

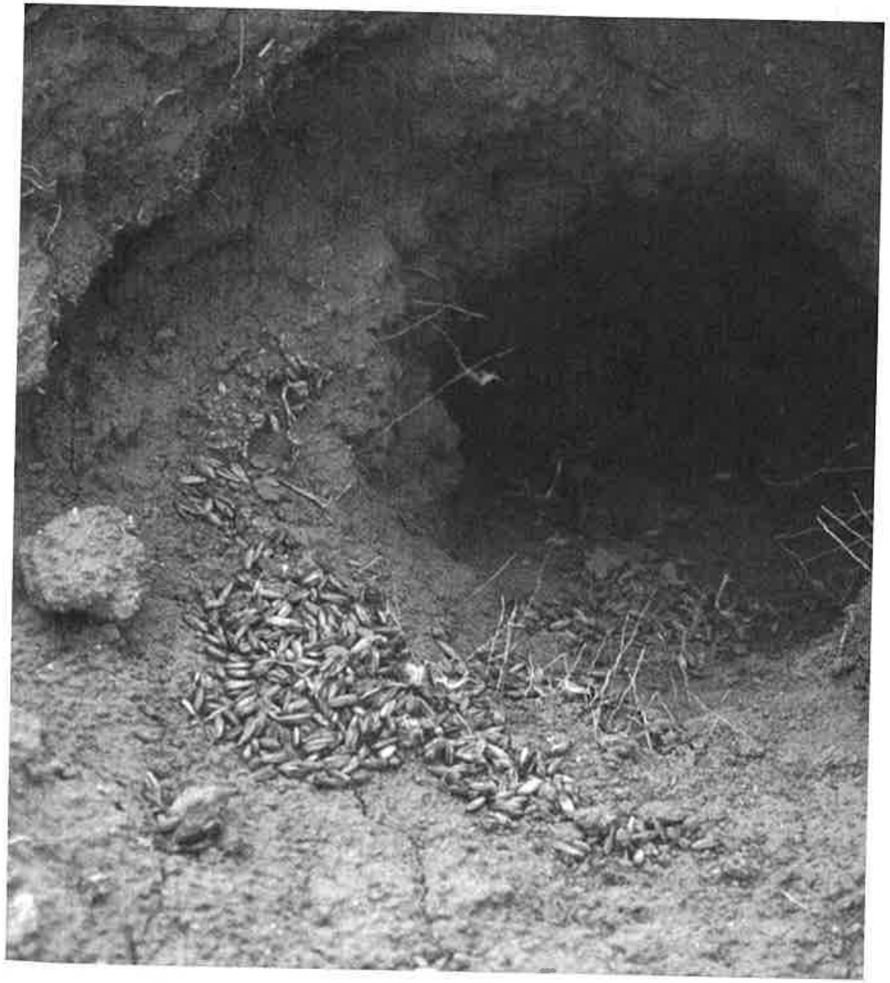

Figure 9.1. Oats treated with zinc phosphide at burrow-entrance. Toxic oats kill not only prairie dogs but also grain-eating insects, birds, and mammals. Photo by David Stern.

Zinc phosphide reacts with acids in the stomach and produces hydrogen phosphide (also called phosphine), a colorless gas that smells like garlic and kills prairie dogs, usually underground. For humans, hydrogen phosphide can cause fatigue, ringing in the ears, vomiting, diarrhea, disorientation, convulsions, paralysis, coma, and sometimes death (Hood 1972; Degesch America 1999).

Zinc phosphide evidently does not accumulate in fat or muscle tissue, and therefore, in theory, should not harm scavengers that consume carcasses of poisoned prairie dogs (Bell and Dimmick 1975; Schitoskey 1975; Hill and Carpenter 1982; Matschke et al. 1992). Zinc phosphide also does not seem to harm certain species of birds and mammals that frequent prairie dog colony-sites (Tietjen 1976b; Uresk et al. 1987; Deisch et al. 1990; Apa et al. 1991). Zinc phosphide does, however, kill animals other than prairie dogs that consume poisoned bait at colony-sites. Nontarget victims include granivorous (i.e., seed- and grain-eating) birds and insects, and also granivorous mammals such as various species of ground squirrels, chipmunks, and rabbits (Deisch et al. 1989; Sharps and Uresk 1990; Johnson and Fagerstone 1994; Chapter 8). Further, by eliminating prairie dogs, zinc phosphide adversely affects the nontarget plants and animals that depend on prairie dogs for survival (Chapter 4).

Fumigants

Landowners sometimes eliminate prairie dogs by using fumigants, which are of two types: aluminum phosphide tablets and gas cartridges. Fumigants are most lethal to prairie dogs when used in moist soils (to reduce dissipation of gases) in early spring (Ramey and Schafer 1996). Because they are so expensive, fumigants are most cost-effective as a follow-up to toxic baits.

Fumigation with aluminum phosphide—which, like zinc phosphide, is a Restricted Use Pesticide—involves insertion of two tablets into a burrow-entrance, followed by plugging the entrance with newspaper and moist soil. Prairie dogs die in response to hydrogen phosphide, which is produced when the tablets react with moisture from the air or soil. Aluminum phosphide tablets typically kill at least 90% of targeted individuals, and are most lethal when soil temperatures are above 16°C (60°F) (Moline and Demarais 1987; Hygnstrom and VerCauteren 2000).

With a diameter of 4 centimeters (1.5 inches) and a length of 9 centimeters (3.5 inches), gas cartridges are incendiary devices, which are General Use Pesticides (i.e., USEPA certification is not required). Use involves punching a small hole in the end of the cartridge, inserting and lighting a fuse, gently rolling the cartridge into a burrow, and plugging the burrow-entrance with moist soil. Gas cartridges usually do not work well if the soil is dry. Combustion of cartridges produces carbon monoxide, a colorless, odorless gas that kills prairie dogs. For humans, carbon monoxide can cause headache, throbbing at the temples, disorientation, nausea, vomiting, unconsciousness, and sometimes death (Timm 1994).

Fumigation via aluminum phosphide or gas cartridges kills not only prairie dogs, but also all other organisms within targeted burrows. Applicators therefore must use caution to avoid fumigating burrows occupied by American badgers, black-footed ferrets, burrowing owls, prairie rattlesnakes, tiger salamanders, and other nontarget species. By eliminating prairie dogs, fumigants negatively impact the many nontarget organisms that associate with prairie dogs (Chapter 4).

Wildlife Services (WS, called Animal Damage Control [ADC] before 1997), a division of Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA), is the primary federal agency that helps landowners who want to eliminate prairie dogs. Some state agencies assist with poisoning, but others do not. In Wyoming, assistance is available from county agencies. Some landowners distribute the poisons themselves, and others hire commercial firms. Poisons are available from WS, some state departments of agriculture, and commercial vendors.

How Quickly Do Prairie Dog Colonies Repopulate After Treatment with Zinc Phosphide?

Colony size routinely increases by about 30% per year for several consecutive years following control with toxicants such as zinc phosphide (Collins et al. 1984; Apa et al. 1990). Following intense, but not total, elimination, colony size can increase by as much as 71% per year for one to two years before the rate of increase begins to diminish (Knowles and Knowles 1994; see also Uresk and Schenbeck 1987). Colonies usually require three to five years to attain pretreatment numbers following treatment of burrow-entrances with zinc phosphide throughout entire colony-sites, but need only one to two years to attain pretreatment numbers following treatment of peripheral entrances only (Schenbeck 1981; Knowles 1986a). Because prairie dog colonies repopulate so quickly, long-term management usually will require more than one treatment with zinc phosphide. Complete eradication might solve this problem of repopulation, especially for isolated colonies for which immigration from other colonies is unlikely, but 100% mortality via any method is formidably elusive.

Is Controlling Prairie Dogs Worth the Cost?

Wildlife managers all agree that controlling prairie dogs is expensive (Table 9.1), but they disagree about whether the benefits of control justify the costs (Stapp 1998). Bell (1921) concluded that the benefits to ranchers from controlling prairie dogs outweigh the costs. More recently, however, Schenbeck (1981) and Collins et al. (1984; see also above and Chapters 2 and 5) have argued that controlling prairie dogs with zinc phosphide usually is not worth the cost, for five reasons:

- Zinc phosphide and the bait necessary for poisoning are expensive.
- The effort necessary for dispensing poisoned bait is time-consuming, and therefore expensive.
- Colonies usually repopulate quickly after poisoning unless eradication is complete.
- Competition between livestock and prairie dogs is sometimes insignificant.
- Livestock only rarely step into prairie dog burrows.

Hygnstrom and VerCauteren (2000) have countered that controlling prairie dogs is profitable for ranchers when the protocol includes oats laced with zinc phosphide followed by fumigation of burrows with aluminum phosphide. One reason for the discrepancy among wildlife biologists regarding poisoning is that financial gains or losses are not constant, but instead vary with factors such as rainfall, type and abundance of vegetation, age and size of colonies, densities of prairie dogs and burrow-entrances, proximity of other colonies, method of control, and human effort (Schenbeck 1985; Knowles 1986a). Another reason is that biologists make different assumptions about costs and benefits when calculating the economics of controlling prairie dogs.

Table 9.1. Costs of various methods for controlling prairie dogs. Each cost is an estimate at the time of research. One hectare = 2.471 acres.

Method	*Cost per hectare ($)*	*References*
Zinc phosphide (applied with grain)	11.05–19.16	Schenbeck 1981; Collins et al. 1984; Roemer and Forrest 1996; Hygnstrom et al. 1998
Aluminum phosphide (fumigant)	75.00	Hygnstrom and VerCauteren 2000
Gas cartridge (fumigant)	96.88	Hygnstrom and VerCauteren 2000

Even when elimination of prairie dogs is 100%—and thus most likely to be worth the cost of control—such extermination does not necessarily guarantee the immediate recovery of terrain for grazing by livestock. Additional steps such as leveling of burrow-mounds, reseeding, and temporary exclusion of livestock, for example, might be necessary to rehabilitate deserted colony-sites.

Recommendations

For many reasons (Chapters 4, 8, 17, and 18), the elimination of prairie dogs can be imprudent. Further, the financial costs of many types of control sometimes exceed the benefits (see Table 9.1; Chapter 8). Before using any method to eliminate prairie dogs, farmers, ranchers, politicians, and wildlife managers should appraise both the costs and benefits. They also should carefully evaluate the negative effects for black-footed ferrets, burrowing owls, mountain plovers, and other species that depend on prairie dogs for survival.

Summary

- Methods that do not work well, or are impractical or too expensive, for the elimination or reduction of prairie dog colonies include alteration of habitat by killing certain plants or by adding perches for predatory birds; addition of cage litter from black-footed ferrets; translocation; contraceptive agents such as DES; sterilization of males; gas exploding devices; and visual barriers.
- Methods that do work well for eliminating prairie dogs include limitation or postponement of grazing by domestic livestock; recreational shooting; zinc phosphide; and fumigants.
- We need more research to investigate the feasibility of reducing prairie dog numbers by limiting grazing by livestock. With so many economic implications, and because limiting grazing has few negative side effects for other organisms, the dearth of rigorous information about this method for controlling prairie dogs is perplexing.
- Colony size routinely increases by about 30% per year for several consecutive years following control with toxicants such as zinc phosphide. Complete eradication might solve this problem of repopulation, especially for isolated colonies for which immigration from other colonies is unlikely, but 100% mortality via any method is formidably elusive.
- Efforts to eliminate prairie dogs are expensive. Regarding livestock, wildlife managers disagree about whether the benefits of controlling prairie dogs outweigh the costs. One reason for the discrepancy is that financial gains (or

losses) vary with factors such as rainfall, type and abundance of vegetation, age and size of colonies, densities of prairie dogs and burrow-entrances, proximity of other colonies, method of control, and human effort.

- Even when elimination of prairie dogs is 100%—and thus most likely to be worth the cost of control—such extermination does not necessarily guarantee the immediate recovery of terrain for grazing by livestock.
- Before using any method to eliminate prairie dogs, farmers, ranchers, politicians, and wildlife managers should appraise both the costs and benefits. They also should carefully evaluate the negative effects for black-footed ferrets, burrowing owls, mountain plovers, and other species that depend on prairie dogs for survival.

CHAPTER 10

Recreational Shooting of Prairie Dogs

Archie F. Reeve and Timothy C. Vosburgh

Recreational shooting of prairie dogs is controversial—entertaining to some, abhorrent to others. Because recreational shooting recently has killed more than two million prairie dogs per year, the implications for conservation are significant.

In this chapter we examine recreational shooting, but we do not consider ethical and humane issues regarding harvesting (shooting) of wildlife in general or recreational shooting of prairie dogs in particular. We begin with a brief history of recreational shooting, examine the impacts, and then investigate levels at which shooting might be sustainable. We document that juveniles and adult (at least one year old) females are most vulnerable, and discuss the management of colonies for recreational shooting. Finally, we examine the risks to humans from recreational shooting, and then explore the ironic possibility that recreational shooting sometimes might enhance the conservation of prairie dogs on private land.

History of Recreational Shooting

Many residents of western states remember their teenage "plinking" of prairie dogs with a slingshot, BB-gun, or 22-caliber rifle. For more than 100 years in Kansas, for example, shooting of prairie dogs has been common after school and on Sunday afternoons (Smith 1967). Reasons to shoot prairie dogs are numerous. Most people shoot them for fun (36%) or target practice (29%), while others view the opportunity as time with family and friends (13%) or time outdoors (11%); only 3% shoot for damage control (Keffer et al. 2001).

Black-Tailed Prairie Dog (*Cynomys ludovicianus*) Response to Seasonality and Frequency of Fire

A THESIS

Presented to the Graduate Division

College of Arts & Sciences

New Mexico Highlands University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Natural Science

By

Felicia D. Archuleta

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BLACK-TAILED PRAIRIE DOG RESPONSE
TO SEASONALITY AND FREQUENCY OF FIRE

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By

Approved by Examining Committee:

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Discipline of______________________

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ABSTRACT

Fragmentation of the landscape, habitat loss, and fire suppression, all a result of European settlement and activities, have precipitated both the decline of Black-tailed prairie dog (*Cynomys ludovicianus*) populations and the occurrence of fire throughout the Great Plains, including the Shortgrass steppe of northeastern New Mexico. The presence of Black-tailed prairie dogs, a keystone species, and the occurrence of fire both play a vital role in maintaining the integrity and diversity of grassland ecosystems. In addition to serving as prey for the endangered Black-footed ferret (*Mustela nigripes*), Black-tailed prairie dogs conspicuously alter grassland landscapes and provide foraging, shelter, and nesting habitat for a diverse array of grassland species.

While agricultural politics have interfered with efforts to list the species as threatened under the Endangered Species Act, a lack of knowledge regarding the mechanisms for colony expansion have hindered the development of recovery plans that effectively manage for the persistence of prairie dog colonies. Previous studies have shown that manipulations of vegetation, through prescribed fire and brush removal, encourage and facilitate colony expansion. Here, with the use of Geographic Information Systems (GIS) and Remote Sensing technology, we determine how Black-tailed prairie dogs have responded to growing season and dormant season burns at 3, 6, and 9 year intervals. Knowledge of prairie dog response to seasonality and frequency of fire may aid in the development and implementation of prescribed fire regimes that can be used to effectively manage Shortgrass ecosystems.

INTRODUCTION

Since its introduction in 1969 by Robert T. Paine, the term keystone species has evolved to describe a species whose presence is crucial in maintaining the organization and diversity of their ecological community and is exceptional to the rest of the community in its importance (Mills *et al*., 1993; Paine, 1969). Another keystone trait is that the activities of the species are not wholly duplicated by other members of the community (Kotliar *et al*., 1999). The Black-tailed prairie dog (*Cynomys ludovicianus*) significantly alters grassland ecosystems, and it is estimated that more than 150 different species associate and depend on prairie dogs as a food source and upon their colony sites for shelter from weather and predation (Hoogland, 2006). For these reasons, the Black-tailed prairie dog is considered by ecologists to be a keystone species in grassland ecosystems (Miller and Cully, 2001). In an effort to maximize biodiversity it has been suggested that strongly interactive species, such as the Black-tailed prairie dog, be a top priority for protection and management programs; a necessity in re-establishing and sustaining ecosystem structure and stability (Miller *et al.*, 1994, Soule et al., 2005).

Of the estimated 150 different species that benefit at some level from prairie dog activities, one of the most notable is the Black footed ferret (*Mustela nigripes*)—an endangered species whose primary food source is the Black-tailed prairie dog (Anderson *et al*., 1986). The Kiowa and Rita Blanca National Grassland Ranger District, located in Shortgrass steppe in the southern Great Plains, is receiving consideration as a proposed release site for the Black-footed ferret. However, the prairie dog population in this area is not extensive enough to support a release, and management for the persistence of prairie dog colonies has been hindered by lack of knowledge regarding the mechanisms for colony expansion.

Previous studies (Milne-Laux and Sweitzer, 2006; Northcott *et al.*, 2008) have shown that manipulations of vegetation, through fire and brush removal, facilitate Black-tailed prairie dog colony expansion. Numerous other studies (King, 1955; Koford, 1958; Butler, 1995; Garrett and Franklin, 1998) have shown that the reestablishment of periodic fire is fundamental to the ecological restoration of grassland ecosystems. However, prior to reintroducing large-scale fire as a management tool, the appropriate fire season, frequency, and fire effects on ecosystem components need to be determined. The purpose of this study is to examine how the seasonality and frequency of prescribed fire affects Black-tailed prairie dog colony expansion in the Shortgrass steppe of northeastern New Mexico.

LITERATURE REVIEW

European Settlement of the Grasslands

The North American grasslands once formed one of the largest prairies in the world, stretching 1,000 miles from east to west and 2,000 miles from north to south (USDA Forest Service). Prior to European settlement, approximately 162 million ha of extensive and unbroken grasslands existed throughout the Great Plains (Samson and Knopf, 1994). At the time of early exploration by Meriwether Lewis and William Clark, the Great Plains were lightly settled by native people and the grasslands supported a diverse array of plant and animal species. In May of 1804, Lewis and Clark traversed the Great Plains and, over the course of 14 months, documented and described the new landscapes, native people, plants, and wildlife that they had encountered (Johnsgard, 2003). In the years after the Lewis and Clark expedition, settlers streamed across the Mississippi River and settled the Great Plains (Johnsgard, 2003). The pristine and extensive grasslands were divided, domestic cattle populations rose, and the prairie ecosystem was converted into farmland and rangeland (Cunfer, 2005).

The Homestead Act of 1862, a landmark law that was responsible for helping settle much of the American West, is perhaps the single most influential event associated with shaping the character and biological diversity of the Great Plains today. Under this act, which was signed into law on May 20, 1862, up to 160 acre parcels of land were granted to citizens and newly arrived immigrants who wished to settle in the western United States. Between 1862 and 1976, 600,000 families took advantage of the Homestead Act, and 270 million acres of the western United States were turned over to private citizens who converted the prairies to farmland and rangeland (Kennedy and

Cohen, 2013). This increase in settlement in the western US resulted in a significant loss of native grasslands and soils as the homesteaders set out to make a living through agriculture (Bradsher, 2012).

The homesteading rush began to slow around 1917 when America entered World War I; however, by this time most of the productive agricultural land was already claimed (Bradsher, 2012). Sod-busting incentives and a demand for wheat after the war accelerated the cultivation of the Great Plains, and new machinery, such as disc plows, and a series of wet years in the late 1920s led to the plowing of more than 33 million acres (Hazlett *et al*., 2009). Very little value and effort was placed into keeping the native grassland intact, and by the 1930s almost all of the prairie and forest had been broken to the plow and converted into an agricultural cash crop. The environmental consequences of these activities would not be realized until the rains stopped and the drought and the winds came. Between 1931 and 1938, the worst drought in US history spread across 75 percent of the country and affected 27 states—crops died and the dust from over-plowed and over-grazed land began to blow (Cunfer, 2005).

An estimated 23.5 million acres of plowed farmland lost between 2.5 -5 inches of top soil. Furthermore, the organic matter and nitrogen content was carried away with the wind-blown soils, leaving behind very poor soil. When all was said and done many farms were bankrupt and deserted, leaving approximately 2.5 million farmers as refugees (Bradsher, 2012). As part of the Roosevelt Administration's New Deal program, the U.S. government put an end to the practice of giving away public lands and bought back 11.3 million acres of overgrazed and mismanaged farmland and rangeland. On June 20, 1960, 3.8 million acres of the purchased land was turned over to the USDA Forest Service and later designated National Grasslands (Perry, 1999).

Grassland system loss across the Great Plains is currently estimated at 70%. The direct loss of prairie to urbanization, and exploitation by overgrazing and farming practices has stressed and destroyed much of what once was a pristine and continuous grassland ecosystem (Samson and Knopf, 1994). Furthermore, grassland species are in constant competition with humans for available habitat and resources. Habitat loss and fragmentation of the grasslands restricts and alters the spatial distribution of grassland species more than any other factor (Johnson, 1995). The potential for grassland species extinction, as a result of human activities, habitat loss, and fragmentation of the landscape is best exemplified by the 100 previously unknown species of vertebrate animals that were first described by Lewis and Clark. Of these 100 species, approximately 40 percent have a state or federal level designation indicating that active protection or conservation concern is warranted. Of these, 13 species are now classified as nationally endangered (Johnsgard, 2003).

Prehistoric Black-Tailed Prairie Dog Range

Prehistoric fossil evidence collected throughout North America indicates that black-tailed prairie dogs, *Cynomys ludovicanus*,resided on the Great Plains. Although two records from the Senecan period (2.5 -1.8x10^6 years ago) show the genus *Cynomys* to be present in the Central Great Plains, the subgenera was indeterminate (Goodwin, 1995). Further fossil evidence suggests that black-tailed prairie dogs were present in the southern and central Great Plains in the Sappan (early Irvingtonian, 1.8 -0.75x10^6 years ago), and in Nebraska and Colorado during the Sangamon (125,000-75,000 years ago).

The geographically most complete and accurate fossil records for prairie dogs is from the Wisconsin (75,000-10,000 years ago), which indicate that the range of black-tailed prairie dogs extended as far north as central Nebraska and east into western Iowa and Kansas, well east of its current range, and as far south as southeastern Chihuahua, Mexico and as far west as southwestern New Mexico (Goodwin, 1995).

Throughout the Pleistocene, the black-tailed prairie dog retained its core range in the central and southern Great Plains, despite major climatic shifts that were associated with five glacial-interglacial cycles (Goodwin, 1995; Lomolino and Smith, 2003). The climatic and environmental oscillations during the late Pleistocene altered the vegetation of the Great Plains from conifer woodland to expanded grassland—neither of which caused a change or reduction in prairie dog ranges (Goodwin, 1995).

Historical Black-Tailed Prairie Dog Range

Despite the broad and relatively stable distribution of the prairie dog colonies throughout the Pleistocene (Goodwin, 1995), historical evidence suggests that black-tailed prairie dog population numbers and occupied acreage have declined dramatically over the last 100 years (Northcott *et al., 2*008). It is estimated that prairie dog colonies once covered between 40 and 160 million ha of mixed and short grass prairies of North America (Marsh, 1984; Hoogland, 2006). This historic range spanned thousands of square kilometers from southern Canada to northern Mexico, with portions in 12 states – Arizona, New Mexico, Colorado, Oklahoma, Kansas, Montana, Nebraska, North Dakota, South Dakota, Oklahoma, Texas, and Wyoming (Hall and Kelson, 1959; Mulhern and Knowles, 1997).

Anglo-European settlement of the grasslands, with widespread cultivation and grazing during the late 19th century, has had a long lasting effect on the ecological structure of the Great Plains (Brockway *et al*., 2002). Prairie dog population numbers and area of occupied habitat began to decline almost immediately after European settlement because of human persecution and habitat destruction (McCain *etal*., 2002). Prior to changes in land use by the settlers, a systematic inventory of the distribution of prairie dogs was never performed; therefore, it is impossible to accurately estimate the average size or density of prairie dog colonies in pre-settlement times. Rough estimates from the Bureau of Biological Survey indicate that all five species of prairie dog occupied approximately 40 million ha in the early 1900s (Merriam, 1902, Knowles *et al.*, 2002) Other data from the same time period, such as regional maps that were created from land surveys or from poisoning and eradication efforts, illustrate that prairie dogs once occupied between 2%- 15% of the Great Plains; with numerous colonies measuring as large as 20,000 ha in size. Some exceptionally large colonies occupied more than 2 million ha (Hoogland, 2006).

Recent Black-Tailed Prairie Dog Range and Status

Today, the lands currently occupied by prairie dog colonies are thought to represent less than 2% of their historical range (Anderson *et al*., 1986; Stapp 1998). By the 1960s, the large and numerous black tailed prairie dog colonies of yesteryear had been reduced to 600,000 ha (Lomolino *et al*., 2003), and this trend continues today. In 1995, it was estimated that black tailed prairie dogs occupied approximately 540,000 ha in the United States, by 1998 this number had been reduced to 280,000-320,000 ha (McCain *et al.*, 2002). More recent estimates from the United States Fish and Wildlife

Service suggest that the cumulative area occupied by prairie dogs is between 500,000 – 800,000 ha of 160 million ha of potential habitat in their former geographic range (Miller and Cully Jr, 2001). Although their former range and numbers have decreased dramatically, black-tailed prairie dogs can still be found in Canada, Mexico, and all of the states that were part of its historic range—with the exception of Arizona, from which the species has been extirpated (Mulhern and Knowles, 1997).

Habitat availability for prairie dogs and other grassland species continues to be threatened and reduced by municipal, agricultural, and industrial development (Mulhern and Knowles, 1997). Furthermore, approximately two thirds of prairie dog colonies are restricted to small, isolated colonies—making them more susceptible to local extinction(Hoogland, 2006). In 1998, the National Wildlife Federation petitioned the U.S. Fish and Wildlife Service to list the black-tailed prairie dogs as a threatened species under the Endangered Species Act. This petition led to the species being listed as a federal candidate for listing as threatened until 2004. Although it was warranted for listing but precluded, conservation efforts increased drastically and yearly reviews were conducted to determine to the status of the listing. Under these conservation efforts, recreational shooting and poisoning efforts declined or were eliminated on public lands (Johnson and Cully, 2004).

The "warranted, but precluded" designation by the USFWS also flamed an already heated and complex political debate over the relationship among black-tailed prairie dogs, agricultural interests, and wildlife. Advocates of the agricultural industry promote the management of publicly owned lands in ways that benefit the livestock industry by citing arguments that historic estimates of prairie dog numbers are greatly inflated and that prairie dogs reduce the carrying capacity for livestock and other wildlife. (Miller *et al.*,2007). In 2007, another petition to list the species was filed, but the USFWS determined in 2009 that listing the species was not warranted. Although a species must meet only one of the five criteria used by the USFWS to list a species under the Endangered Species Act, agricultural politics have hindered efforts to list the black-tailed prairie dog, despite the fact that the species meets all five of the criteria (see Miller *et al* 2007 for a discussion of all five criteria).

Prairie Dog Range in New Mexico

It is estimated that prairie dogs occupied approximately 4,838,460 ha in New Mexico in 1919 (Mulhern and Knowles, 1997).   By 1980, this area had been reduced by 96%, to an estimated 200,000 ha (Henderson, 1979; Mulhern and Knowles, 1997).   In New Mexico, the black-tailed prairie dog has been assigned an S2 ranking by the New Mexico Natural Heritage program –meaning they are rare. Colonies were once extensive and abundant east of the Rio Grande and in the grasslands, open woodlands, and semi-desert habitats of the southwestern section of the state, but they have since been extirpated (Johnson and DeLay, 2000).

Today, current black-tailed prairie dog colonies in New Mexico can be found in small numbers in the eastern plains (Johnson and Delay, 2000). The BLM and White Sands Missile Range have also reported that prairie dogs have been extirpated from several sites, with only 140 ha of occupied habitat remaining on BLM land, and 300 ha on the Missile Range (Mulhern and Knowles, 1997).

Prairie Dogs within Kiowa and Rita Blanca National Grasslands

As part of their research involving spatial patterns of plague, Tammi Johnson and Jack Cully Jr. (2004) mapped prairie dog colonies on five national grasslands that had experienced epizootic die-offs, including the Kiowa and Rita Blanca National Grasslands. Cully and Johnson visited all locations in which prairie dogs had previously occupied, and mapped only the active areas of each colony to show year-to-year changes. The results of Cully and Johnsons mapping efforts indicated that active colony areas on the Kiowa and Rita Blanca National Grasslands in 1999, 2001, 2002, and 2003 were 696; 1,663; 2,186; and 2,750 ha, respectively (Johnson and Cully, 2004).

Human-Prairie Dog Conflicts

In part, the considerable reduction of prairie dog populations can be attributed to eradication efforts carried out on a very large scale (Anderson *et al.*, 1986). In some years, prairie dogs were intentionally poisoned on more than 19,760,000 acres in the United States (Clark, 1989). Throughout history, prairie dogs and grazing mammals of the Great Plains coexisted and flourished within their native habitats (Miller *et al*., 1994). However, since the early 1900s, much attention has been focused on the economic impact that prairie dogs have on rangeland productivity. Soon after the Great Plains were settled, ranchers began to view prairie dogs as competitors with cattle for rangeland resources, and they became concerned that prairie dogs were both consuming and destroying grasses and other forage plants (Hollister, 1916; Antolin *et al*., 2002).

In 1902, the US Department of Agriculture published a paper titled “The prairie dog of the Great Plains,” in which it was estimated that range productivity decreased as much as 50-75% when prairie dogs were present on the landscape (Merriam, 1902).

Other studies, such as the one Koford (1958) published, suggested that prairie dogs negatively impact forage crop and pasturage directly by removing it, and indirectly through the long-term influence their burrowing activities have on certain plant species (Koford, 1958). The result of these studies was government funded eradication programs and poisoning campaigns that are responsible for reducing prairie dog populations to less than two percent of their historical populations as of several decades ago(Whicker and Detling, 1988; Anderson *et al*., 1986; Marsh, 1984).

Merriam's (1902) estimates were not based on scientific evidence, and research later showed they were a ten-fold exaggeration with levels of competition between 4% and 7% (Uresk and Paulson, 1989). Both Hansen and Gold (1977) and O'Meilia et al. (1982) reported that there was not a significant difference in the market weight of livestock that were living on the same landscape as prairie dogs and livestock that did not coexist with prairie dogs. Derner et al. (2006) found a 5.5% reduction in cattle weight when 20% of the pasture was prairie dog colony and 14% reduction in weight when 60% of the pasture was occupied by prairie dogs. For a review of competition between prairie dogs and wildlife see Miller et al. (2007). Numerous other studies showed that grazing mammals, including domestic cattle, preferentially graze in areas in which prairie dogs towns are present—where the forage is often more succulent and nutritious (Krueger, 1986; Knowles, 1986; Whicker and Detling, 1988).

Although these studies sparked a change in the scientific and conservation communities' attitudes toward prairie dogs, political complexity regarding the relationship among black-tailed prairie dogs, agricultural interests, and wildlife species has increased in recent years (Miller *et al.,* 2007). Despite all the modern research that indicates prairie dogs have little effect on range productivity, the agricultural industry actively promotes management of public lands in ways that benefit the livestock industry. These management programs include eradication and poisoning campaigns that have been carried out on a very large scale, affecting millions of ha of land (Mulhern and Knowles, 1997). In the1980s, the US government spent over six million dollars to eradicate 185,600 ha of prairie dogs in South Dakota, including a 110,000 ha complex — which was the largest remaining at the time. In the early 1990s, it was estimated that 80,000 ha of prairie dogs were eliminated annually (Miller *et al.*, 1994), with almost every federal land management agency having being involved in these efforts (Mulhern and Knowles, 1997). Much of this effort still continues today, with statewide legislation in Wyoming, Colorado, Kansas and South Dakota either mandating, or allowing for, control of prairie dogs. New Mexico, Nebraska, Montana, North Dakota, Oklahoma, and Texas do not mandate control; however, assistance may be available to landowners who believe they have a prairie dog population problem (Mulhern and Knowles, 1997).

Sylvatic Plague

The most persistent threat facing black-tailed prairie dogs today is Sylvatic plague—which is caused by *Yersinia pestis,* a bacterium that spreads through contact between flea vectors and mammalian hosts (Barnes, 1982; Perry and Featherson, 1997; Coolinge *et al*., 2005). Y. *pestis*, was first introduced to North America from Asia and was first recorded in the United States in 1899 on ships in port in numerous US cities (Antolin *et al.,* 2002). The bacterium was first reported to affect prairie dogs around 1945 when plague-positive fleas were discovered in prairie dog burrows in Kansas; two epizootic die-offs occurred around the same time in Texas and Colorado (Cully *et al.*, 2010). Prairie dogs have neither a natural immunity nor adaptive protection against the plague, which often results in 100% mortality rates when plague enters a colony (Coolinge *et al*., 2005).

The mortality rate is not the only impact that plague has on a colony, even after the death of many individuals; plague persists in the colony and results in a longer population recovery time (Mulhern and Knowles, 1997). Between 1999 and 2005, Jack Cully and his colleagues mapped the perimeter of four prairie dog complexes that had a history of plague, and compared this data to two prairie dog complexes that had never been affected by the disease. The researchers found that in areas in which plague had been present, colony sizes were smaller and the distance between colony sites was greater when compared to the sites in which the disease had never been reported. The researchers also found that the proportion of potential habitat that was occupied was less in plague-positive areas when compared to plague-negative areas (Cully *et al*., 2010). Furthermore, Knowles and Knowles (1994) suggested that prairie dogs have continued to exist, despite plague, simply because of their large, highly dispersed populations. Further reductions in population numbers could make prairie dogs much more susceptible to local and regional extinctions (Knowles and Knowles, 1994).

<u>Keystone Role of Prairie Dogs</u>

Since its introduction in 1969 by Robert T. Paine, the term *keystone species* has evolved to describe a species that is exceptional, relative to the rest of the community, in its importance and whose presence is crucial to maintaining the organization and diversity of their respective ecological community (Paine, 1969). Power et al. (1996) further defined this broadly applied term to describe any species whose impact on its community or ecosystem is disproportionately large relative to its abundance. Kotliar et al. (1999) added that the functional role is not wholly duplicated by other members of the community. Increasingly, many scientists agree that prairie dogs meet the criterion of a keystone species because they are a strongly interactive species that have large effects on their community structure and function, and these effects are disproportionately large relative to their abundance (Kotliar, 1999). Prairie dogs are crucial to the structure and function of native prairie ecosystems, and it is estimated that more than 150 different species of vertebrates, arachnids, protozoans, and invertebrates associate and benefit from prairie dogs and their colony sites (Hoogland, 2006).

Through their burrowing activities, prairie dogs influence grassland ecosystem structure, composition, and function by conspicuously altering landscapes and providing foraging, shelter, and nesting habitat for a diverse array of species (Whicker and Detling, 1988; Hoogland, 2006). Within colonies, black-tailed prairie dogs excavate an elaborate system of deep burrows that cover several acres to hundreds of acres of land. The burrow entrances are characterized by large rim craters—some measuring up to 12 centimeters high and two meters in diameter—that serve to prevent flooding, improve underground ventilation, and provide a vantage point when scanning for predators (Hoogland, 1995). Burrows provide nesting and shelter sites for many grassland species, such as burrowing owls (*Athene cunicularia*) and tiger salamanders (*Ambystoma tigrinum*). Prairie dogs also serve as prey for a number of predators, including American badgers (*Taxidea taxus*), coyotes (*Canis latrans*), ferruginous hawks (*Buteo regalis*) and the Black-footed ferret (*Mustela nigripes*), which is an endangered species (Whicker and Detling, 1988; Hoogland, 2006).

In addition to their burrowing activities, prairie dogs facilitate predator detection by voiding the area surrounding their burrow entrances of any vegetation that is higher than 30 centimeters. These activities create an open habitat that is preferred by species such as Mountain plovers (*Charadrius montanus*), and alters species composition and structure of plant communities (Kotliar, 1999). Through grazing and clipping activities, prairie dogs create a distinct and recognizable disturbance patches that are characterized by minimal woody vegetation and short, clipped grasses. It has been suggested that the decline and removal of prairie dogs may have played a role in grassland conversion to shrublands and woodland vegetation states (Johnson and Delay, 2000). Everett (2002) found shrub cover was 7.5 times higher outside of prairie dog colonies than inside of colonies on Thunder Basin National Grassland in Wyoming. Similarly, mesquite (*Prosopis* spp.) increased from 27% to 61% of the cover in the first 23 years after prairie dogs were removed from an area in Texas (Weltzin *et al*., 1997). In Chihuahua, List (1997) documented that there was a 14% increase in mesquite in the first eight years after a prairie dog colony was poisoned.

Historic Range and Variability

Little question exists that the loss of native prairie has had a profound effect on grassland communities; however, conservation efforts have been hampered by limited knowledge regarding the historical conditions in which the grasslands evolved. The structure, composition, and function of today's prairies bear little resemblance to those of the past. A comparison of the historical context of the prairies provides a baseline for information regarding the frequency and extent of major ecological drivers, as well as an indication of the presence and impact of disturbances. This information can serve as a foundation for the development of conservation strategies that maintain and restore grassland ecosystem communities and the ecological processes that maintain them (Samson *et al*., 2004).

Historic range and variability (HRV) is the full variation and range of conditions, of historical ecosystem characteristics and processes occurring across multiple scales of time and space (Kean *et al.*, 2009). HRV is a relatively new concept that is based on the idea that historical variation and range of conditions provides a representative time series of reference conditions to guide land management (Aplet and Keeton, 1999; Kean *et al*., 2009). The ultimate goal of ecosystem management is said to be a healthy, sustainable ecosystem that can maintain its structure and organization through time (Whitford and DeSoyza, 1999; Kean *et al*., 2009). To achieve this goal, land must be managed as a whole—all organisms, patterns of abundance, and connectivity of their habitats, and the ecological processes that influence these organisms on the landscape must be taken into consideration (Kean *et al*., 2009). Furthermore, the historical conditions and variations that represent the broad envelope of conditions that support landscape resilience and self-organization, must also be considered (Swetnam *et al*., 1999; Kean *et al.*, 2009). Analysis of HRV can help identify and describe dynamic changes in ecosystems, such as vegetation types that were important historically, but are less abundant today.

Ecological drivers, such as drought, fire, and grazing, significantly influence the composition and distribution of grassland communities (Knopf *et al.,* 2004). Two assumptions of HRV are: (1) ecosystems are dynamic, and their responses to changing processes are represented by past variability, and (2) ecosystems are complex and have a range of conditions within which they are self-sustaining and beyond this range they transition to disequilibrium (Kean *et al*, 2009). Based on these assumptions, we should expect that when ecological drivers act with characteristic behavior, ecosystems will exhibit characteristic composition and behavior (Samson *et al.,* 2004). Often times, a degraded system can be restored along successional pathways once the historical physical environment is reestablished. In other cases; however, changes in landscape connectivity and organization, loss of native species pools, shifts in species dominance, trophic interactions and/or invasion by exotics, and concomitant effects on biogeochemical processes can push a degraded system to a persistent, alternative state that is resilient to traditional restoration techniques (Suding *et al.*, 2004).

The ecological phenomena that drive ecosystem structure, composition, and function normally vary within bounded ranges; however, if threshold values are exceeded, rapid, nonlinear changes to an alternative state may occur. Once an ecological threshold is crossed, an ecosystem loses its ability to return to the original steady-state after disturbance or change by external forces, and is deflected toward a new state (Burkett *et al.*, 2005). Analysis of HRV may be useful in guiding land managers to restore and maintain the ecosystem conditions that sustained biological diversity prior to the dramatic changes that occurred after European settlement of the Great Plains, especially if ecological thresholds have not been crossed.

Historic Grazing and Fire Regimes within the Grasslands

Drought, grazing, fire, and the grasslands of the Great Plains have a long relationship that evolved over the course of several million years. Increased aridity during the Miocene-Pliocene transition (7-5 million years ago) gave rise to the North American Grasslands (Anderson, 1990). During this dry period, grasses, which are better adapted to drought, spread at the expense of forest vegetation and the number of grazing ungulates rose (Axelrod, 1985; Anderson, 1990). Disturbance from grazing and fire impact both the spatial and temporal patterns of animal and plant communities in grassland ecosystems. Historically, native herbivores moved nomadically in response to changes in vegetation associated with fire and precipitation patterns (Samson *et al*., 2004). According to historic archaeological records, the time lag for return to previously grazed areas was estimated to be 1-8 years, which allowed for natural rest and re-growth of the vegetation (Irby *et al.*, 2002; Samson *et al*., 2004). The interaction of fire and grazing led to a natural habitat mosaic of short, mid and tall seral stages (Samson *et al.*, 2004).

After European settlement of the Great Plains, destruction of bison, an increase in domestic livestock, fragmentation of the landscape, and fire suppression resulted in dramatic changes in the number and distribution of native herbivores (Hartnett *et al*., 1997; Samson *et al*., 2004). Furthermore, current fire regimes bear little resemblance to those of the past, with fire size and frequency decreasing significantly since the 1800s (Bahre, 1991; Ford and McPherson, 1996). Although it is known that Native Americans used grassland fires as a management tool to modify habitat and to aid in driving and attracting wild game during their hunts, (Bahre, 1985; Pyne, 1982; Ford and McPherson, 1996) historic fire frequency and extents cannot be accurately estimated due to the absence of direct evidence from fire-scarred trees. Our best estimates of historic fire frequencies in the Great Plains come from studies in which charcoal fragments were taken from lake sediment cores to construct historical records of fire frequency in the northern Great Plains. This research indicated that post-settlement charcoal deposition was much lower than pre-settlement, suggesting that fire frequency decreased after European settlement of the Great Plains (Umbanhower, 1996; Ford and McPherson, 1996).

Post-settlement decline in fire frequency and size can most likely be attributed to active fire suppression by the European settlers and the removal of fine fuel by overgrazing. Fragmentation and habitat loss from agriculture and urban development have also affected the natural fire process in which grasslands evolved (Gottfried *et al*., 1995; Hartnett *et al*., 1997; Frank *et al*., 1998; Brockway *et al.*, 2002). Fragmentation, cultivation, and cattle grazing substantially reduced the amounts of aboveground biomass that normally serves as fine fuel for fire (McGinnies *et al*., 1991; Frank *et al*., 1998; Hart and Hart, 1997; Brockway *et al.*, 2002). Along with fire suppression programs that were implemented in the 1950s, the decrease in standing biomass and fragmented prairie landscape decreased the probability of ignition and spread of grassland fires, virtually eliminating fire in modern prairie ecosystems (Brockway *et al.*, 2002). The interaction of fire with the grasslands is vital to sustaining ecosystem integrity; however, uncertainty exists concerning the season, frequency, and methods that would be most beneficial in restoring fire in Shortgrass steppe (Mutch, 1994; Brockway *et al.*, 2002).

Importance of Fire in Grassland Ecosystems

Fire, a commonly recognized component of the disturbance regime in grassland ecosystems, disrupts community structure and changes the physical environment, resources, or availability of space. Fire in the grasslands is heavily influenced by climatic variability; precipitation, temperature, wind, and lighting all play a role in determining fuel dynamics and ignition rates (Swetnam and Betancourt, 1997). Grassland fire provides numerous benefits by increasing the rate of nutrient turnover, regulating plant communities, reducing woody species, suppressing the growth of fire-intolerant plants, and discouraging invasion of non-native species (Pyne, 1982; McPherson, 1997; DeBano *et al*., 1998; Brockway *et al*., 2002). Numerous studies (Anderson, 1982; Dyer *et al*., 1982; Knapp and Seastedt, 1986) suggest that productivity increases in grassland ecosystems when plant litter is removed by fire, light grazing, or mechanical removal. Grassland plants in the Great Plains have evolved alongside periodic drought, fire, and grazing and have adapted the ability to die down to underground organs, leaving only dead tops exposed aboveground. The advantage to having their growing points beneath the surface of the soil allows grasses to avoid desiccation during drought, insulation from heat during a fire, and from below ground tissue removal during grazing (Gleason 1922, Anderson 2006). Furthermore, research by Golley and Golley (1972) suggests that an adaptation to grazing resulted in grasses producing more biomass than can be decomposed of; therefore, periodic fire and light grazing are necessary to maintaining a healthy grassland system.

Relationship between Prairie Dogs and Fire

Prairie dog burrowing and grazing activities significantly influence grassland ecosystem function and composition; therefore, factors that influence their distribution and abundance are of great importance to rangeland managers (Augustine *et al*., 2007). Disturbance from fire is known to influence the spatial distribution of many plant and animal species in shortgrass steppe ecosytems; however, the degree to which fire influences prairie dog colonies in not well known (Brockway *et al*., 2002; Ford and Johnson, 2006, Augustine *et al*., 2007).

Prairie dog colonization occurs mainly during the spring in open, flat grasslands with minimal woody vegetation (King, 1955; Koford, 1958; Butler, 1995). Previous studies, by Milne-Laux and Sweitzer (2006) and Northcott and his colleagues (2008) have shown that manipulations of vegetation, by fire and brush removal, are conducive to prairie dog colony expansion, which occurred and was directed towards experimental plots that had been treated by fire. In 2007, Augustine et al., examined the expansion rates of prairie dog colonies into two areas that had been affected by a prescribed burn, and one that had been affected by a wildfire, in the shortgrass steppe of the Comanche National Grassland in Baca County, CO. The results of this study showed that the expansion of black-tailed prairie dog colonies into burned areas of the shortgrass steppe was twice the expansion rate into unburned areas. The authors also noted that the study was conducted during a period of colony expansion associated with drought conditions, which further allowed them to conclude that burning in the shortgrass steppe can encourage colony expansion, even under dry conditions (Augustine *et al.,* 2007).

These previous studies have shown that interaction of fire with shortgrass steppe is important for prairie dog colony expansion because it discourages the growth of dense and tall vegetation—areas in which prairie dogs have a difficult time colonizing (Garrett and Franklin, 1988; Wolff, 1999). Augustine et al. and others (Knapp *et al.,* 1999) also suggest that mammalian herbivores are attracted to post-fire growth that is of enhanced forage quality, and this may be another factor that enhances prairie dog expansion into burned areas.

Kiowa and Rita Blanca National Grasslands Site Description

In 1960, Congress designated 136,562 acres of New Mexico land in Mora, Harding, and Union Counties as the Kiowa National Grassland, and 77,183 acres of land in Dallam County Texas and 15,639 acres of land in Cimarron County Oklahoma as The Rita Blanca National Grassland (USDA Forest Service). These Grasslands, one of twenty publicly owned National Grasslands administered by the USDA Forest Service, encompass approximately 230,000 acres of numerous small government parcels that are intermingled with privately owned tracts of land. Although they are managed as one, the Kiowa and Rita Blanca Grasslands are separated into three geographic units—eastern and western parts of the Kiowa National Grassland in New Mexico, and the Rita Blanca National Grassland in Oklahoma and Texas (USDA Forest Service).

The Kiowa and Rita Blanca are semiarid, mostly treeless, grasslands dominated by grasses and forbs, and are characterized by large grazing mammals and burrowing animals. These grasslands are also home to a variety of arthropods, birds, and mammals that characterize the southern Great Plains and play important roles in ecosystem functioning of the shortgrass prairie (Ford and McPherson, 1996). Our study site, K46, lies within the shortgrass steppe of the eastern section of the Kiowa National Grasslands, which falls entirely within Union County, New Mexico. The steppe habitat is the most extensive habitat type in these grasslands, and is characterized by relatively level plains with undulating hills that are covered by mid-grass prairie and shortgrass steppe vegetation (Ford and McPherson, 1996). For northeastern New Mexico, annual precipitation is approximated at 15 inches with a bimodal distribution in precipitation occurring with an increase in rainfall in April and a second pulse, associated with a monsoon effect, occurring in July and August. Temperatures average 70 °F between June and September in the summer months and 35°F during the winter months (Hazlett *et al.*, 2009; Ford and McPherson, 1996).

Previous Research on Study Site K46

Research on a long-term experimental fire research site, K46, on the Kiowa National Grasslands has shown that there are significantly different responses by plant and animal species to the season and frequency of fire. The 18-year study was initiated in 1995 by Brockway to examine the effects of prescribed fire in the Shortgrass steppe in northeastern New Mexico (36°31' 20" N, 103° 3' 30"W), during the growing season and the dormant season at three, six, and nine year intervals (Ford, 2007). Although this region has been altered by grazing, fragmentation, and fire suppression, it is still dominated by mixed grass or short grass communities (Brown, 1994; Ford, 2007). Thus far, the study has shown differential responses (positive, negative or unaffected), by small mammals to fire, based largely on life history requirements. Mammals that responded negatively to fire were those that live and forage in dense vegetation and use plant debris for their nests. In this situation, fire removes both their food source and habitat—which elicits a negative response (Kaufman *et al.*, 1990; Ford, 2007). In contrast, those mammals that respond positively to fire are those that inhabit open areas, feed on insects that are attracted to new vegetation growth, and live in burrows, which offer protection from the fire (Ford, 2007).

Ford and Johnson (1997), researchers from the USDA Forest Service Rocky Mountain Research Station, examined the effects of the dormant and growing-season burns on biological soil crusts and perennial grasses on K46, the long-term experimental fire research site on the Kiowa National Grasslands. Through their analysis, the authors found that growing-season burns reduced fire severity and had less of an impact on soil crusts; however, burning during the growing-season negatively impacted grass cover for up to two years after the fire. The dormant season fire had a larger impact on biological soil crusts, but the grass cover recovered in as little as two months after the burn. Based on these results, the researchers were able to conclude that the Shortgrass steppe is able to recover from fire within three to 30 months, depending on the season. The authors also note that the Shortgrass steppe was in a drought during the course of this study, and warn that weather patterns must be taken into consideration when deciding on an appropriate return interval for prescribed burns, which may affect the recovery time of the vegetation and soils after a burn. These findings provide a strong basis for predictions regarding which fire treatment will most facilitate prairie dog colony expansion.

Direct Observation and Aerial Survey Methods

Methods for estimating the area inhabited by prairie dogs vary. Two common methods involve the use of aerial or satellite imagery and mapping software to trace polygons around the colony. The first method involves connecting the outermost burrow entrances to create a polygon around the perimeter of the colony. This method can be both time-consuming and difficult because the outermost burrow entrances tend to have small mounds, and the vegetation is often higher in comparison to the central portion of the colony (King, 1955; Hoogland, 1995). A second method for estimating the area involves tracing a polygon around the *clip-zone,* the central area surrounding a colony site where vegetation is clipped low, either for consumption or to enhance predator detection. Tracing the clip-zone can be difficult during periods of drought because grazing is especially heavy, and it is hard to discern between bare ground that is created by drought and bare ground that is created by heavy grazing and clipping (King, 1955; Hoogland, 1995).

Of the two methods, connecting the outermost burrow entrances often yields more accurate estimates; however, tracing the clip-zone is often quicker and more visible in aerial and satellite imagery (Hoogland, 1995). For smaller areas, such as national parks, national wildlife refuges, and Native American reservations, the boundaries of prairie dog colonies can be delineated, on foot, by marking the outermost burrow entrances with a Global Positioning System (GPS) receiver. Although this method is the most accurate, it is also the most time consuming and not possible in areas where access is not permitted (Hoogland, 2006).

By viewing ASCS black and white aerial photos, Cheatheam (1973), was the first to utilize aerial photographs to census prairie dog colony abundance. Cheatheam assessed the effectiveness of using aerial photos to survey prairie dog colonies in the Texas Panhandle by ground verifying, contacting landowners, and by examining inhabited areas by flying low to the ground. The results of this study showed that 88-94% of the colonies that were detectable in the aerial photos were actually present on the ground, although some limitations to this method were found. First, small colonies between 0.5-4 ha, have little vegetation removed, and are harder to detect in aerial photos. Second, some of the colonies detected on the photos were found to be inactive, due to disease or other factors, when they were ground verified. Despite these limitations, Cheatheam found aerial photograph analysis to be a cost effective and time saving method for estimating large prairie dog populations. In contrast, Sidle et al. (2012) found that aerial surveys without ground-truthing overestimated prairie dog numbers by 94% on Pawnee and Comanche National Grasslands.

Schenbeck and Myhre (1986) analyzed aerial photographs to assess pre- and post-treatment effects of zinc phosphide poison on a prairie dog town on the Buffalo Gap National Grassland in South Dakota. The pre-treatment photos were pre-existing black and white photos and post-treatment photos were color infrared (CIR) aerial photos. The researchers delineated the colonies by viewing the mounds and outlining them; transferred colonies to topographic maps using a zoom transfer scope; and measured colony area using a planimeter. This technique was found to be a cost-effective method for viewing overall population changes in black-tailed prairie dogs.

In 2010, researchers from the University of New Mexico Biology Department, utilized a digital orthophoto quarter quadrangle (DOQQ) survey method to survey and monitor the distribution of prairie dog colonies across eastern New Mexico. DOQQ panchromatic air photos collected in 1996 and 1997 were surveyed, and 24,400 ha of Black-tailed prairie dog disturbance was revealed—with 89% of towns still identifiable on the ground in a field check survey in 2003. To determine changes between the 1996-97 and 2005, gains and losses of prairie dog colonization were identified and major shifts in the spatial distribution were determined. The results of their comparison between the 1996-97 and 2005 DOQQs allowed the authors to determine that the DOQQ survey method is most beneficial for the detection, depiction, and the potential for spatial analysis of the distribution of towns over an area (Johnson *et al.*, 2010).

METHODS AND MATERIALS

Study Site Location

The Kiowa and Rita Blanca National Grasslands encompass approximately 93,100 hectares (230,000 acres) of Shortgrass prairie in the southern Great Plains (Fig. 1) In six counties within New Mexico, Texas, and Oklahoma, this grassland ranger district consists of numerous, small Government parcels that are intermingled with privately owned tracts of land (USDA Forest Service, 2012). Unit K46 (Fig. 2), the Rocky Mountain Research Station Kiowa Long-term Experimental Fire Research Site (36°31' 20" N, 103° 3' 30" W), occupies a total of 160 hectares (395 acres) of the Cibola National Forest in Union County, New Mexico (Ford, 2007). The northern boundary of K46 borders a tract of privately owned land that is used for agriculture, while the western boundary is bordered by a fence that separates the site from another grassland parcel. The eastern and southern boundaries of the study site are bordered by Country Road A077 and New Mexico State Road 411, respectively (Fig. 3).

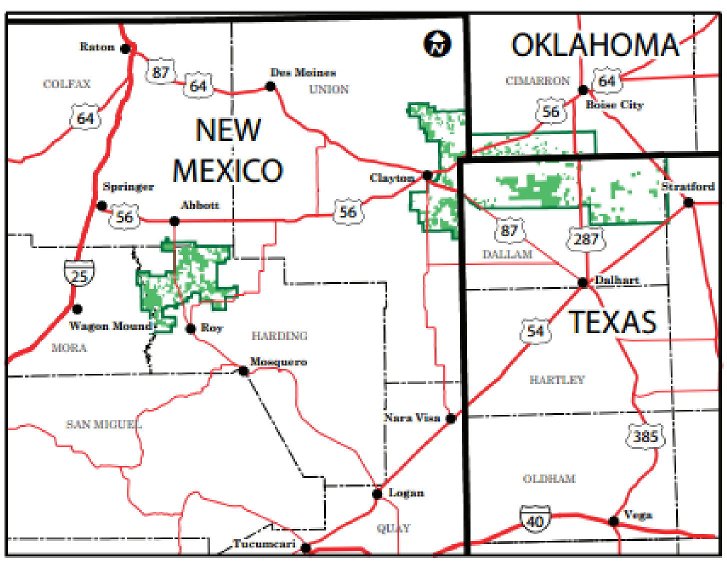

Figure 1 - USFS Map of the Kiowa and Rita Blanca National Grasslands

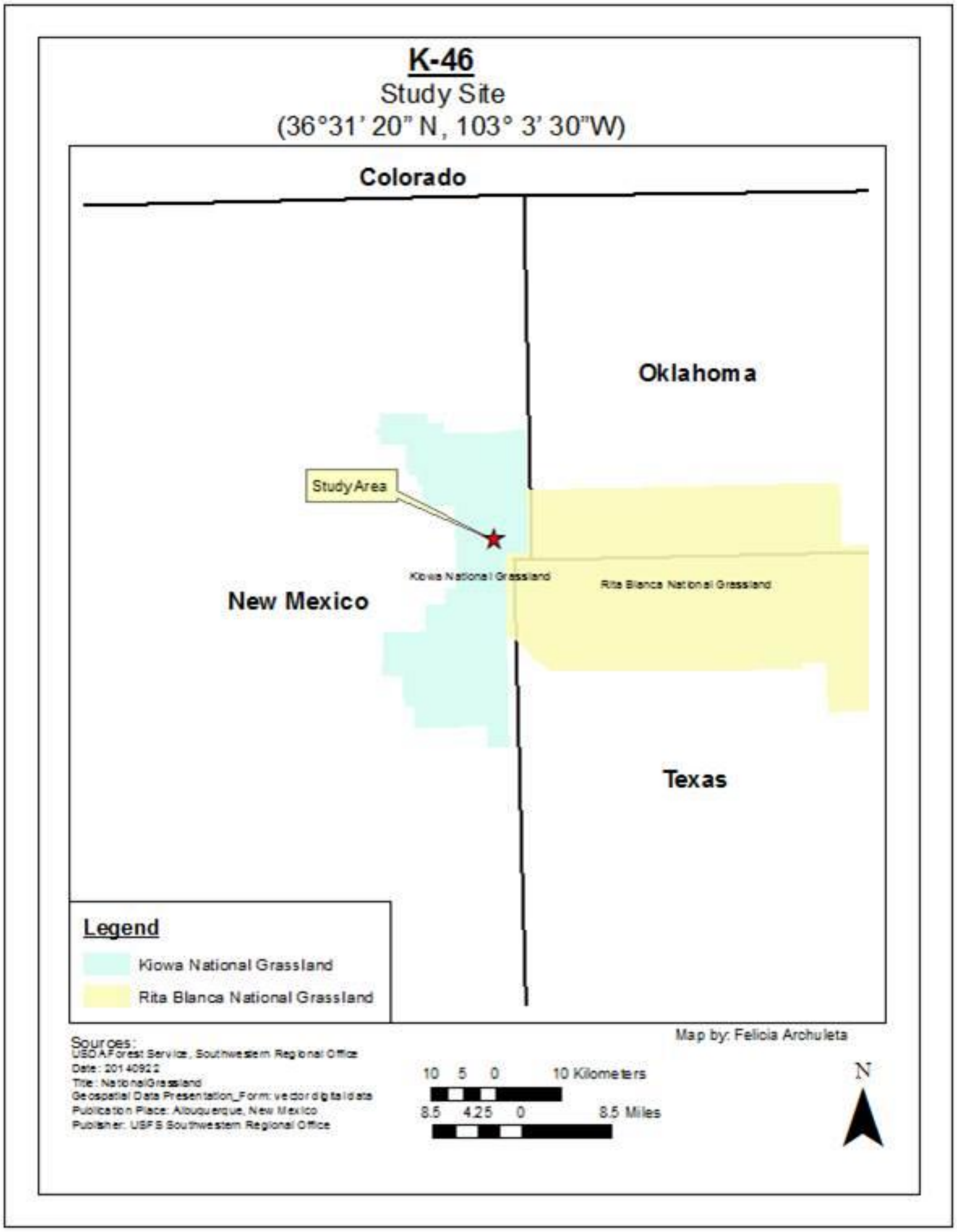

Figure 2 - Map of the Study Site Location. Map showing the study site location within the eastern Kiowa National Grassland (shaded area within New Mexico territory).

Figure 3 - Location Map of K46 and Boundaries. The northern boundary of K-46 borders a tract of privately owned land used for agriculture, while the western boundary is bordered by a fence that separates the site from another grassland parcel. The eastern and southern boundaries of the study site are bordered by Country Road A077 and New Mexico State Road 411, respectively.

Site Description

The most extensive grassland vegetation type on K-46 is Shortgrass steppe, which accounts for approximately 50 percent of New Mexico's grassland vegetation (Ford, 2006; Dick-Peddie, 1993). Although the study site was grazed by cattle until 1990, it has never been plowed and is relatively homogenous and flat with an elevation of 1472 m at the northwest corner to 1455 m at the southwest corner (Ford and Johnson, 2006). Biannual average temperatures range from 11 to 26^{o}C April through September, and from

3 to 12^{o}C October through March. The majority of the precipitation received occurs from May through September, with peak rainfall occurring in July. Mean annual precipitation (MAP), Fig. 8 in Appendix 4, was approximately 356 mm from 1931-1960; however, the total precipitation throughout the course of the study has been measured as low as 50 percent below MAP. Drought conditions, ranging from moderate to exceptional, existed in 2003 and again from 2011-2013 (Ford and Johnson, 2006).

Experimental Design

The experimental design is a completely randomized application of seven treatments and five replicates. Beginning in 1997, dormant and growing-season burns were planned to be performed at three, six and nine year intervals (Fig. 4). Growing season burns were applied in July, dormant season burns were applied in April, and control plots were left unburned (Brockway, 1995; Ford, 2006). The treatments were each replicated 4-5 times and were randomly assigned to 35-140m x 140m plots with 60m of unburned area separating the plots. Metal fence posts were set in the corners of each plot and labeled with the assigned plot number to designate the boundaries. ‘‘Black lines’’ were burned around the inside perimeter of each burn plot using drip torches, and the interior of each plot was burned using a strip headfire. (Ford, 2006).

Overall, five rounds of experimental fire treatments were completed, beginning in 1997 when the first treatments were applied. After the initial burn treatments, some burns had to be rescheduled due to drought and fire restrictions or due to too much rain. Further fire treatments were suspended indefinitely in 2013 due to drought. Throughout the course of the study, the 3 year, dormant season plots (3D) were burned 5 times, the 6 year dormant season plots (6D) were burned 3 times, and the 9 year dormant season plots

(9D) were burned twice. The 3 year growing season plots (3G) were burned 4 times, and both the 6 year growing season plots (6G) and the 9 year growing season plots (9G) were burned twice.

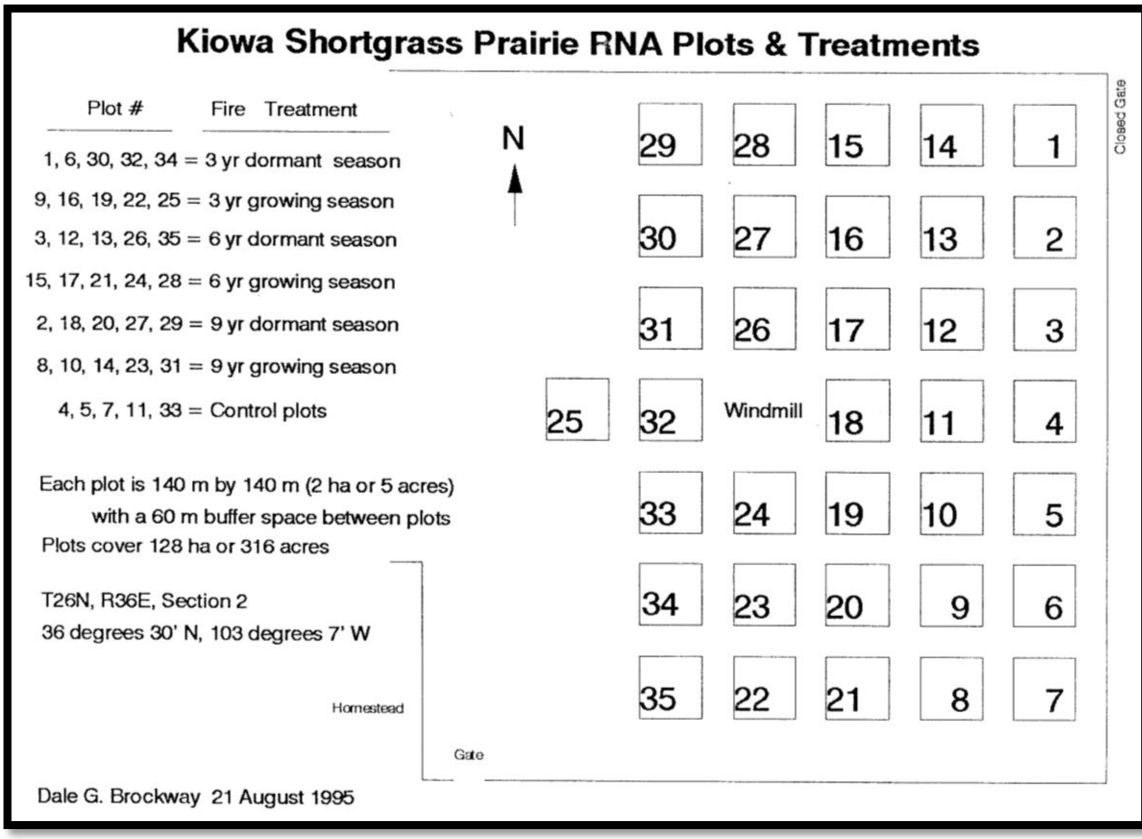

Figure 4 - Map of Designated Plot Numbers and Treatment Assignments

Survey Methods

To determine how the prescribed fire treatments have affected Black-tailed prairie dog colony expansion, we examined the location, size, and pattern of the colony within the study area over the course of eight years, 2005, 2006, 2009, 2010, 2011, 2012, 2013, and 2014. In order to make use of all available data, two well established survey methods were used to map the spatial location and size of the colony boundary on K46. The first method, direct observation, involves the use of a GPS receiver and direct observation to record the coordinates of the outermost burrow entrances of the colony. Although the direct observation method is the most accurate, data was not available for 2012 and 2013; therefore, an additional method involving visual interpretation of high resolution satellite imagery was employed to estimate the location and size of the colony boundary during these years. These survey methods are very well established, and were used to track the location, range, and movement of the colony on the research site, to better understand which, if any, treatment plots were preferred for colonization.

Direct Observation

Polygon layers (ArcView shapefiles) of the colony boundary on the study site were obtained from the USFS Kiowa and Rita Blanca National Grasslands. The USFS developed these files based on data that was collected by Jack Cully of the US Geological Survey Biological Survey at Kansas State University. To map prairie dog colonies, which were accessed and traversed with an ATV, Cully used a hand-held Trimble GeoExplorer3 GPS unit set to obtain positional readings every second. In order to show year-to-year changes in abundance of prairie dogs, only the active areas of each colony were mapped. Burrow entrances that were actively in use by the prairie dogs were distinguished from inactive burrow entrances by examining them for the presence of fresh digging, tracks, scat, and visual identification. The GPS coordinates of each of the active burrow entrances were recorded and uploaded to Environmental Systems Research Institute, Inc. (ESRI) ArcMap™ software to create a shapefile. The shapfiles that were created from the GPS locations were collected in 2005, 2006, 2009, 2010, and 2011. In addition, with the use of a hand-held Garmin GPSMAP 60Cx GPS unit, we delineated the 2014 colony boundary by walking the study area and recording the GPS locations of the outermost, active burrow entrances.

Image Analysis

In aerial and satellite imagery, Black-tailed prairie dog mounds can be seen as bright, roughly circular spots that typically are clumped spatially and surrounded by a light halo resulting from vegetation around the mounds being clipped by the prairie dogs. Images from 2012 and 2013, which were purchased from DigitalGlobe Inc., were examined in ESRI ArcMap™ and ERDAS Imagine software, one screen at a time, moving left to right, then down and right to left, to identify the boundary of the prairie dog colony on the research site. The colony boundary was designated by well-defined mounds and a definite contrast between the site and the surrounding landscape. A polygon was drawn around the boundary in each image by either tracing the clipped-vegetation halo surrounding the mounds, or by tracing the outermost burrow entrances. (Johnson *et al.,* 2010).

The colony boundary in the 2012 image, which was taken on September 10, 2012 by the Pleiades satellite, was identified by tracing a polygon around the *clip-zone,* the central area surrounding a colony site where vegetation is clipped low. Due to the exceptional drought conditions, the colony boundary in the 2013 image, which was taken on February 10, 2013 by the GeoEye satellite, was identified by connecting the outermost burrow entrances to create a polygon around the perimeter of the colony. This method of connecting the outermost burrow entrances visible in the image was used in lieu of creating a polygon around the clip-zone because it was difficult to identify bare ground created by the drought and bare ground created by grazing and clipping.

Mapping Analysis

A digital orthophoto quarter quadrangle (DOQQ) aerial image of the area, which was taken in 2009, was obtained from the New Mexico Resource Geographic Information System (RGIS) online repository and uploaded to ESRI ArcMap™. The boundaries of the treatment plots in this image were visible and could be distinguished from the surrounding vegetation. A polygon was traced around the boundary of each of the 35 treatment plots, plot number labels were applied, and the area of each of plot was calculated. An Arcview shapefile (Fig. 5) with each of the delineated treatments was created to serve as the “input feature” in our clip analysis.

Figure 5 - DOQQ Image Processing. This image shows the DOQQ image that that was processed to create a .shp file that represented the boundaries of each of the 35 treatments and served as the “clip feature” in our analysis

For each year’s representative colony boundary (2005, 2006, 2009, 2010, 2011, 2012, 2013, and 2014), we used the clip analysis function in ESRI ArcMap™, to create a new feature class containing a geographic subset of the colony boundary layer and the delineated treatment layer. By assigning the colony boundary polygon as the clip feature and the delineated treatment plot layer as the input feature, we were able to create a new feature class that contains only those portions of the prairie dog colony that fall within the boundaries of the treatment plots. If a treatment plot was overlapped by the colony boundary polygon, the area of overlap was clipped out and calculated in the new feature class (Fig. 6). We took the area of overlap in each treatment plot and we divided it by the respective treatment plot's total area and multiplied by 100 to get the percentage of coverage in each plot.

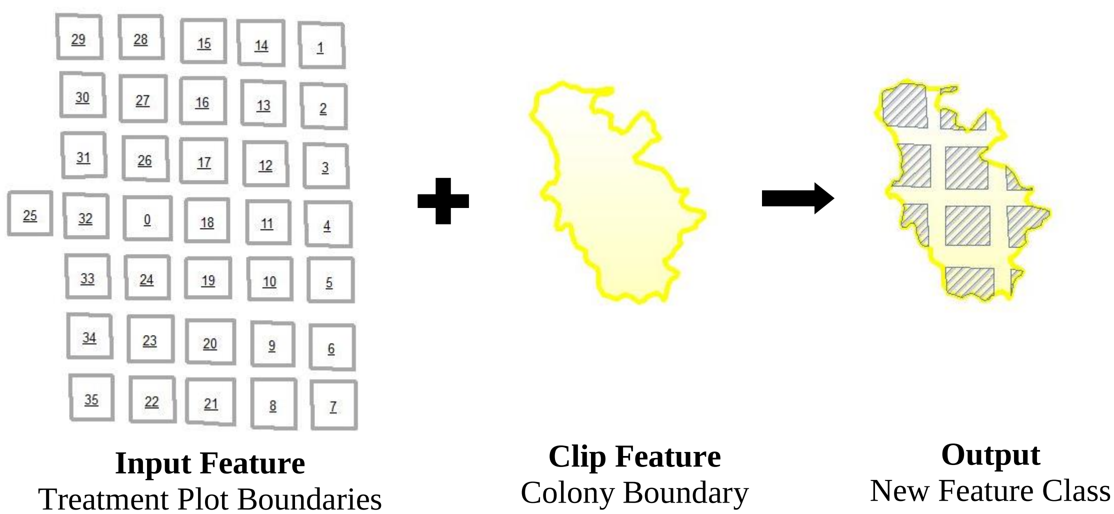

Figure 6 - Illustration of ESRI ArcMap^{TM} Clip Function. This image illustrates the clip function that was used to calculate the total area of overlap/coverage of the prairie dog colony on the treatment plots.

<u>Statistics</u>

Our experiment involves the manipulation of two independent variables with multiple groups. The independent variables are burn season (growing and dormant) and burn frequency (3, 6, and 9 years). Our statistical analysis was performed in order to determine how these two factors affected prairie dog colony expansion, which was our dependent variable. Our categorical data was coded and entered into IBM SPSS Statistics Software (Appendix 4). Upon running the descriptive statistics of the data, we determined that the data was not normally distributed. Attempts to transform the data and normalize it were not successful; therefore, we determined whether the assumptions of the Mann-Whitney U Test and the Kruskal-Wallis Test were met.

The Mann-Whitney U test is used to compare differences between two independent groups when the dependent variable is either ordinal or continuous, but not normally distributed. Since our independent variable, season, has two independent groups we used the Mann-Whitney U test to determine if the mean area covered by the colony on the experimental research site differs between the growing season and the dormant season burn treatments. The Kruskal-Wallis test is also a nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable. The other independent variable in our study, frequency, has three independent groups, so the Kruskal-Wallis test was used to determine if the mean area of coverage by the colony on the experimental research site differs between the three, six, and nine year burn frequency treatments.

RESULTS AND CONCLUSION

Results

Direct Observation and Image Analysis

The final maps and results from our mapping analysis of the prairie dog colony boundaries, which were acquired through direct observation and image analysis are in Appendix 1. The total area of the colony increased every year, with the exception of 2006—which decreased in size from the previous year (Table 1). The results of the colony boundaries that were delineated by direct observation from Jack Cully indicated that in 2005, 2006, 2009, 2010, and 2011 the colony covered approximately 183,016 m^2, 46,505 m^2, 220,497 m^2, 313,152 m^2, and 316,110 m^2, respectively. We also utilized the direct observation method to delineate the colony boundary in April, 2014—which was found to cover approximately 680,183 m^2. Moreover, through image analysis, we were able to delineate the colony boundary in the 2012 and 2013 satellite imagery. The results of this analysis indicated that the colony covered approximately 596,852 m^2 in 2012 and 621,528 m^2 in 2013.

Table 1 - Total Area (m^2) of the Prairie Dog Colony by Year

Year	**Total Area of Prairie Dog Colony (m^2)**
2005	183,016
2006	46,505
2009	220,497
2010	313,152
2011	316,110
2012	596,852
2013	621,528
2014	680,183

Descriptive Statistics and Normality Tests

Analysis that was performed using the clip-function in ArcMap™, gave us the total amount of overlap of the prairie dog colony on the individual treatment plots, results in Appendix 4. When the percentage of overlap was analyzed with the combined seasonal and frequency treatments, it was found that the mean percentage of coverage/overlap of the prairie dog colony was highest on the 9 year burn frequency plots that were burned during the dormant season. This analysis also indicated that the lowest mean percentage of coverage occurred on the 3 year burn frequency plots that were burned during the dormant season, Figure 15 in Appendix 2.

When the treatments were split by season, results shown in Table 2, there were 80 instances in which the prairie dog colony overlapped the growing season treatment plots, and 66 instances in which the colony overlapped the dormant season plots. The percent of coverage/overlap by the prairie dog colony was higher in the dormant season plots, with an average of 64.53 percent (SD = 37.40). The average coverage of the prairie dog colony on the growing season plots was 60.59 percent, (SD=36.76). The assumption of normality was tested via examination of the unstandardized residuals. Review of the Kolmogorov-Smirnov tests for normality, Table 3, indicate that the scores recorded for the percent of coverage/overlap of the prairie dog colony on the growing season plots, $D(80)=0.166$, $p<.001$, deviated significantly from a normal distribution. Scores for the dormant season, $D(66)=0.235$, $p<.001$, also deviated significantly from a normal distribution. The Shapiro-Wilk test results also indicated that both the growing and dormant season scores deviated significantly from normal with $p<.001$ for both.

When the treatments were split by burn frequency, results in Table 4, there were 42 instances in which the prairie dog colony overlapped the control plots, 27 in which the colony overlapped the three year burn plots, 39 for the six year burns, and 38 for the nine year burn treatments. Furthermore, the average percent of coverage/overlap by the prairie dog colony was 66.91 in the control plots, (*SD* = 33.03), which was only slightly higher than the average percent of coverage in the 9 year plots at 63.05, (*SD*= 40.14). The average percent of coverage was lowest in the 3 year treatments at 56.3 percent, (*SD*=41.29), and was slightly higher in the 6 year treatments at 60.97 percent, (*SD*=35.46). This analysis also indicated that the data for all four of the frequency treatments, was negatively skewed—indicating a build-up of high scores. The data also exhibited negative kurtosis for all of the frequency treatments. Furthermore, Kolmogorov-Smirnov tests for normality, in Table 5, indicate that the scores recorded for the percent of coverage/overlap of the prairie dog colony on the treatment plots deviated from a normal distribution for each of the frequency treatments. $D(42)=0.262$, $p<.001$, D(27)=.244, $p<.001$, D(39)=.146, $p=.036$, and D(38)=.227, $p<.001$ for the control, 3 year frequency, 6 year frequency, and 9 year frequency treatments, respectively. The Shapiro-Wilk test results also indicated that all of the burn frequency scores deviated significantly from normal.

Further review of the histograms (Appendix 2) and normal Q-Q plots (Appendix 3), also suggest a non-normal distribution of the data for all four frequency treatment types and both seasonal treatment types. The histograms all show a deviation from a normal bell-shaped distribution, and Q-Q plots all indicate that the scores deviate from the normal.

Table 2 - Descriptive Statistics with percentage of cover/overlap as the dependent variable and season as the independent variable

			Growing Season N=80		Dormant Season N=66	
			Statistic	Std. Error	Statistic	Std. Error
Percent Coverage	Mean		60.5988	4.11286	64.5273	4.60386
	95% Confidence Interval for Mean	Lower Bound	52.4123		55.3327	
		Upper Bound	68.7852		73.7218	
	5% Trimmed Mean		61.7639		66.1348	
	Median		67.5000		73.0500	
	Variance		1353.247		1398.907	
	Std. Deviation		36.78650		37.40197	
	Minimum		.00		.10	
	Maximum		100.00		100.00	
	Range		100.00		99.90	
	Interquartile Range		78.58		69.90	
	Skewness		-.352	.269	-.502	.295
	Kurtosis		-1.442	.532	-1.344	.582

Table 3 - Normality Tests with percentage of cover/overlap as the dependent variable and season as the independent variable

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Season	Statistic	df	Sig.	Statistic	Df	Sig.
Percent Coverage	Growing	.166	80	.000	.857	80	.000
	Dormant	.235	66	.000	.821	66	.000

Table 4 - Descriptive Statistics with percentage of cover/overlap as the dependent variable and frequency as the independent variable

		Control		3 year		6 year		9 year	
		N=42		N=27		N=39		N=38	
		Stat.	Std. Error	Stat.	Std. Error	Stat.	Std. Error	Stat.	Std. Error
% Cover	Mean	66.91	5.097	56.37	7.94	60.98	5.678	63.05	6.512
	95% C.I. for Mean Upper Bound	56.62		40.04		49.48		49.86	
	95% C.I. for Mean Lower Bound	77.21		72.71		72.47		76.25	
	5% Trimmed Mean	68.19		57.01		62.20		64.50	
	Median	67.20		61.50		69.20		83.55	
	Variance	1091		1704		1258		1611	
	Std. Deviation	33.03		41.29		35.46		40.14	
	Minimum	10.80		.20		.00		.10	
	Maximum	100.0		100.0		100.0		100.0	
	Range	89.20		99.80		100.0		99.90	
	Interquartile Range	59.63		86.80		67.10		78.52	
	Skewness	-.398	.365	-.103	.448	-.469	.378	-.544	.383
	Kurtosis	-1.29	.717	-1.88	.872	-1.16	.741	-1.51	.750

Table 5 - Tests of Normality with percentage of cover/overlap as the dependent variable and frequency as the independent variable

		Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Frequency	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Percent Cover	Control	.262	42	.000	.834	42	.000
	3 year	.244	27	.000	.800	27	.000
	6 year	.146	39	.036	.882	39	.001
	9 year	.227	38	.000	.787	38	.000

Data Transformation and Nonparametric Tests

Attempts to transform the data were not successful in normalizing the burn frequency and seasonality data; therefore, we chose to run non-parametric tests. The results of the nonparametric tests are displayed in Table 6, part a. For the independent variable season, an independent samples Mann-Whitney U Test was used to test whether the distribution of percent coverage of the prairie dog colonies was the same across the dormant and growing season treatments. The results indicated that there was not a significant difference in the distribution of percent coverage across categories of season, p=.516. Furthermore, an independent samples Kruskal-Wallis test was used to test whether the distribution of percent coverage of the prairie dog colonies was the same across frequency treatments. The results, part b. in Table 6, indicated that there was not a significant difference in the distribution of percent coverage across categories of frequency, p=.536.

Table 6 - Non-parametric Test Results. Non-parametric test results for the seasonal and frequency groups.

Independent Variable Group	**Null Hypothesis**	**Test**	**Significance**
a. Season	The distribution of % Cover is the same across categories of season	Independent Samples Mann-Whitney U Test	0.524
b. Frequency	The distribution of % Cover is the same across categories of frequency	Independent Samples Kruskal-Wallis Test	0.556

Conclusion

Based on the results of our mapping and clip analysis, as well as our nonparametric statistical tests, we conclude that there was not a significant difference in the percentage of coverage/overlap of the prairie dog colony amongst any of the burn treatments. When the two treatments groups, season and frequency, were combined, the 9 year burn frequency plots that were burned in the dormant season had the highest mean coverage. The lowest mean percentage of coverage/overlap of the prairie dog colony was on the 3 year burn frequency plots that were burned during the dormant season. When the two treatment types, season and frequency, were split, the results of the Mann-Whitney U test indicated that the percentage of coverage/overlap of the prairie dog colony was not significantly different amongst the seasonal treatments. Therefore, we retained on our null hypothesis: the distribution of percentage of coverage/overlap of the colony was the same across the dormant season and growing season plots. The Kruskal-Wallis test results for the frequency treatments were similar. There was not a significant difference in the percentage of coverage/overlap of the prairie dog colony amongst any of the frequency treatments. Once again, these results led us to retain our null hypothesis: the distribution of percentage coverage/overlap of the colony was the same across the frequency treatments—3 year burns, 6 year burns, 9 year burns, and control/unburned plots.

DISCUSSION

Discussion

Historically, the Black-tailed prairie dog was one of the most conspicuous and characteristic features of the Great Plains. It is estimated that prairie dog colonies once covered between 40 and 60 million ha of shortgrass prairies within their historic range—from southern Canada to northern Mexico, with portions in 12 states (Marsh, 1984). Today, the lands currently occupied by prairie dog colonies are thought to represent less than 2% of their historical range (Anderson *et al.*, 1986). Furthermore, recent estimates from the United States Fish and Wildlife Service suggest that the cumulative area occupied by prairie dogs is between 500,000 and 800,000 ha of 160 million ha of potential habitat in their former geographic range (USFWS, 2013). This considerable reduction of prairie dog populations can be directly attributed to human activities. Despite their ability to maintain a broad and relatively stable distribution throughout major climatic shifts during the Pleistocene, prairie dog population numbers and area of occupied habitat began to decline almost immediately after European settlement. Human persecution, habitat destruction, and sylvatic plague continue to pose a threat to the persistence of the black-tailed prairie dog.

The large-scale decline of the prairie dog populations has raised concerns, not only about the long-term survival and population viability of the prairie dogs, but also for the long-term survival and viability of the numerous grassland species that associate and depend on prairie dogs and their colony sites for survival. Agricultural politics and a lack of knowledge regarding the mechanisms for colony expansion have hindered the development of recovery plans that effectively manage for the persistence of prairie dog colonies. Previous studies have shown that manipulations of vegetation, through prescribed fire and brush removal, encourage and facilitate colony expansion. Numerous other studies suggest that the reestablishment of periodic fire is fundamental to the ecological restoration of grassland ecosystems. A lack of knowledge regarding the historic range of variability of the Southern Great Plains has hindered the development and implementation of prescribed fire regimes that can be used to effectively manage Shortgrass ecosystems.

Prior to reintroducing large-scale fire as a management tool, the appropriate fire season, frequency, and fire effects on ecosystem components need to be determined. Knowledge of prairie dog response to seasonality and frequency of fire may aid in the development and implementation of prescribed fire regimes that can be used to effectively manage Shortgrass ecosystems. Based on results from previous studies, we expected that prairie dog colony expansion would be directed towards plots that have been treated by prescribed fire during the dormant-season. In these studies, dormant-season burns resulted in a quicker recovery of grasses, when compared to growing-season burns. Although the results of our study suggested that there was not a significant difference in prairie dog colonization amongst our season and frequency treatment groups, we did see a higher average in the 9 year, dormant season plots.

Throughout the duration of the study (1995-Today) the research site, along with the entire state of New Mexico, has experienced periods of drought. Between 2011 and 2012, when the drought was classified as exceptional, there was a large exodus of the prairie dog population on to a neighboring site that had been recently burned and had a slight regeneration of new, green forage. Upon returning to the site in April 2014, I observed a healthy population on the site; however, I also observed that the colony boundary had expanded significantly since the last time it had been measured. Further inspection of satellite imagery confirmed that the colony perimeter now encompasses almost all of K46. When compared to the growth of the colony perimeter in previous years, this new colony perimeter grew larger and faster than what had previously been observed.

Changes in climate can alter fuel loads, available forage, and fire return intervals. These patterns must be taken into consideration when deciding on an appropriate return interval for prescribed burns, which may affect the recovery time of the vegetation and soils after a burn. Swetnam and Betancourt (1997) cited a phenomenon in which increased grass and fine fuel production during wet years are usually followed by large fire events and fewer fuels during dry years result in small fire events. This interaction of climatic variability and fire may explain why colonization amongst the fire treatments was not significantly different. Periodic drought, along with frequent burning, altered the fuel dynamics and available forage of the study site, which may have forced the prairie dogs to expand their colony in a way that allowed them to exploit any available forage. The need to survive and find available forage may be forcing the prairie dogs to expand into areas that they would not typically or preferentially inhabit.

Suggestions for Future Investigators

For future investigators, I suggest splitting the data between periods of drought occurrence and periods of normal precipitation, so that we may see if the effects of drought were muting the effects of the burn frequency and burn season on colonization patterns. Further research on the effects of season and frequency of prescribed fire on other grassland plant and animal species will also allow for the development of strategies in the use of prescribed fire as a tool to maintain ecosystem health and integrity. Additionally, a long term, large landscape scale investigation of effects of season and frequency of prescribed burns is needed to better understand how fire interacts with, maintains, and sustains shortgrass ecosystems.

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APPENDIX 1

MAPPING ANALYSIS- FINAL MAPS

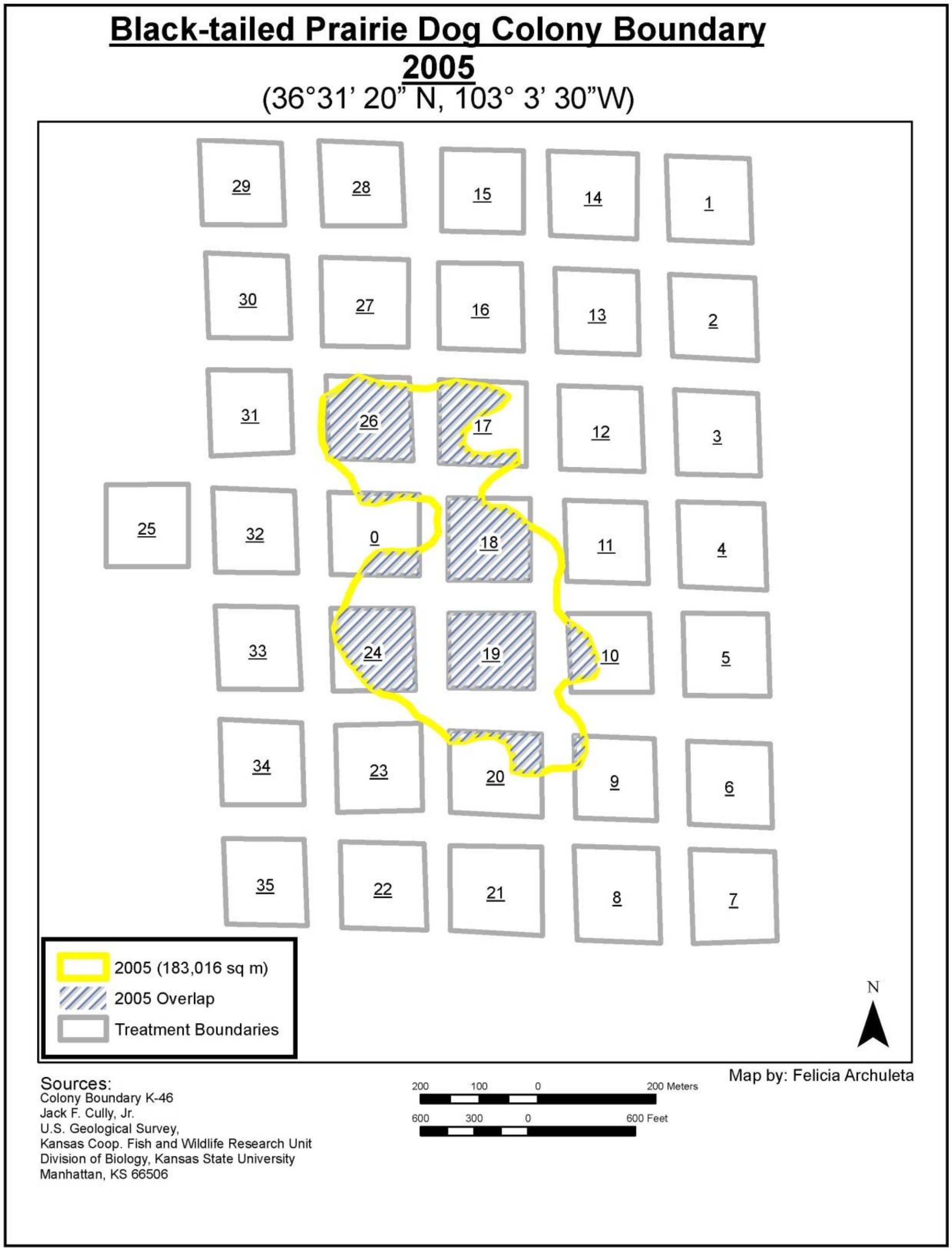

Figure 7 - Map of the 2005 Prairie Dog Colony Boundary. 2005 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray.

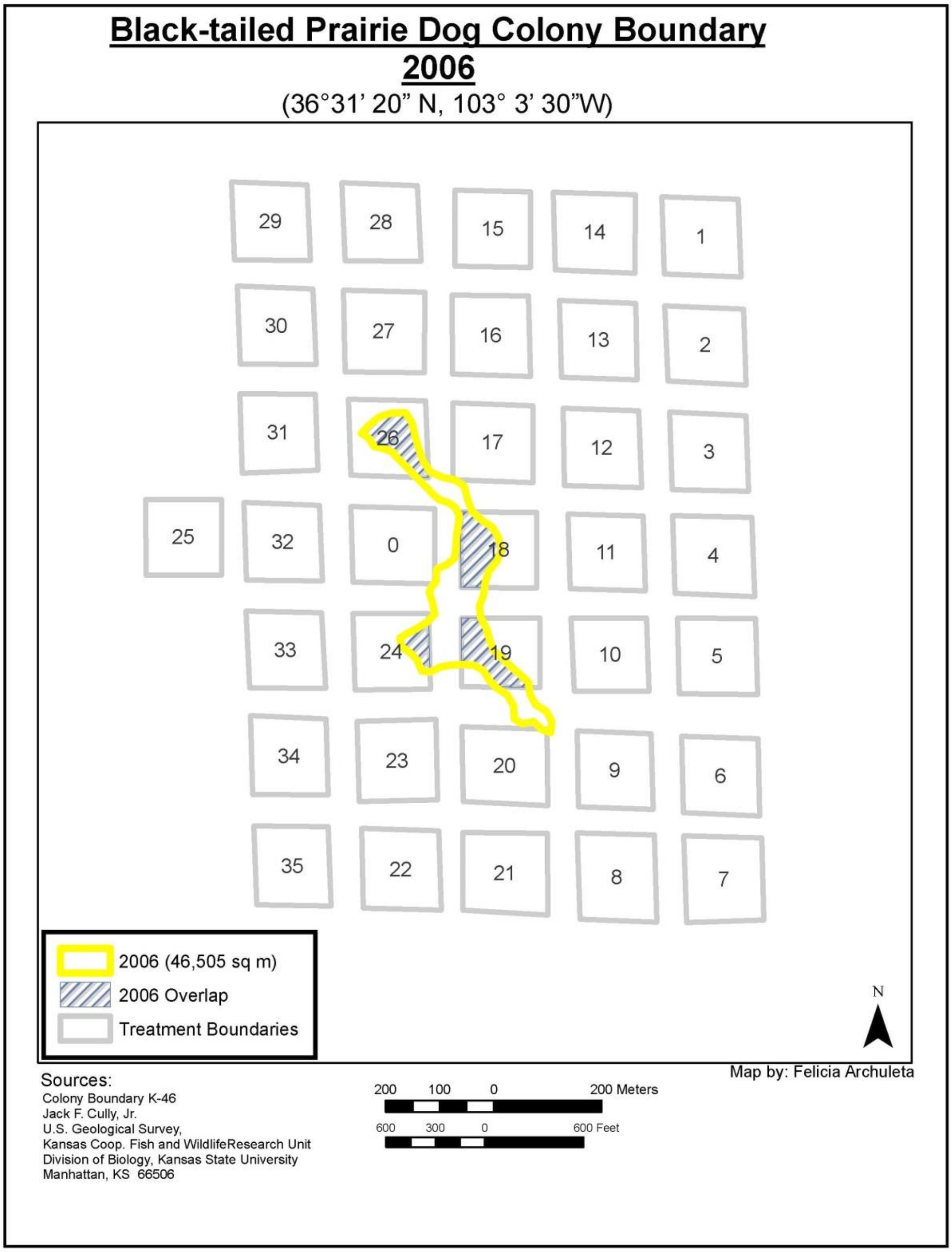

Figure 8 - Map of the 2006 Prairie Dog Colony Boundary. 2006 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

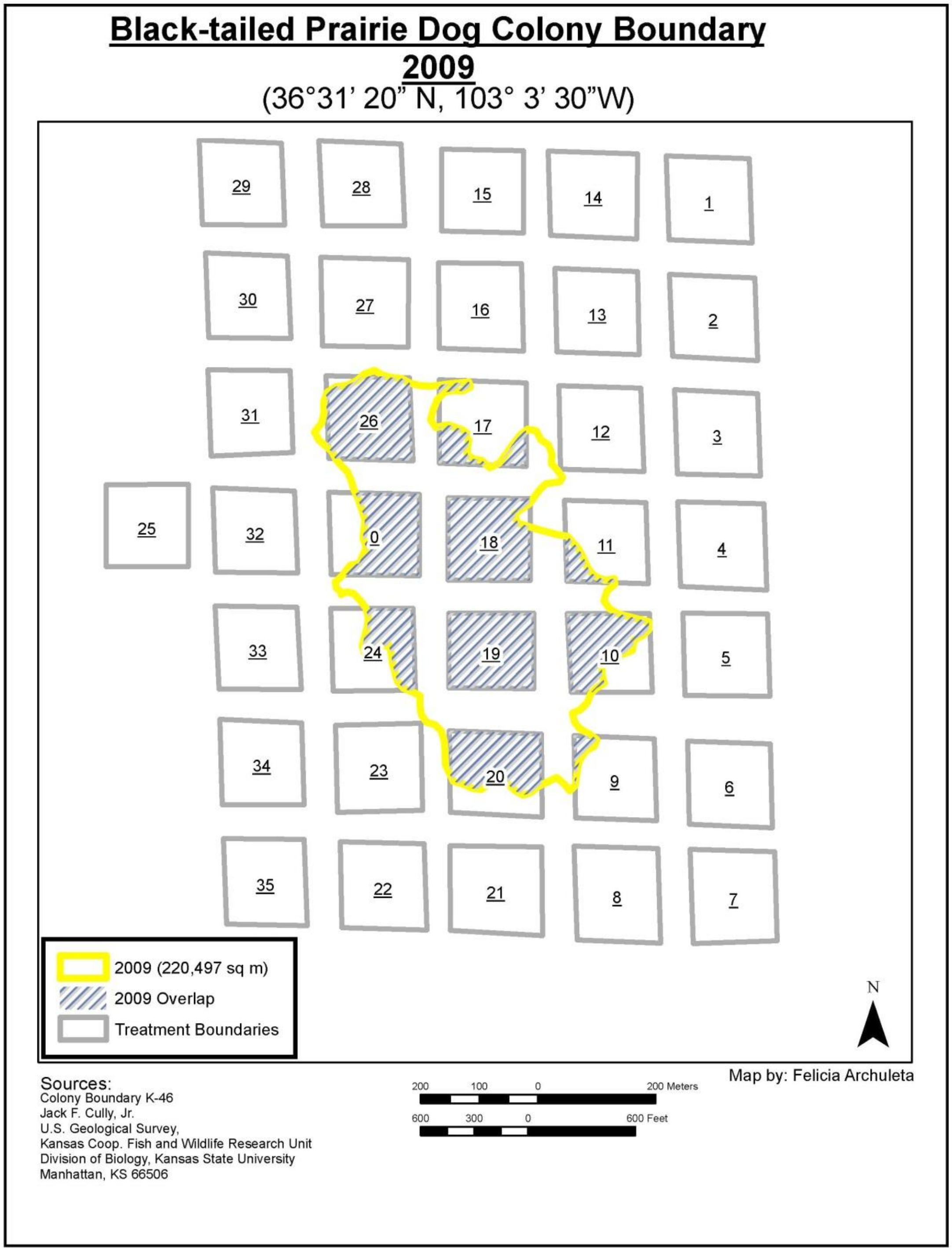

Figure 9 - Map of the 2009 Prairie Dog Colony Boundary. 2009 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

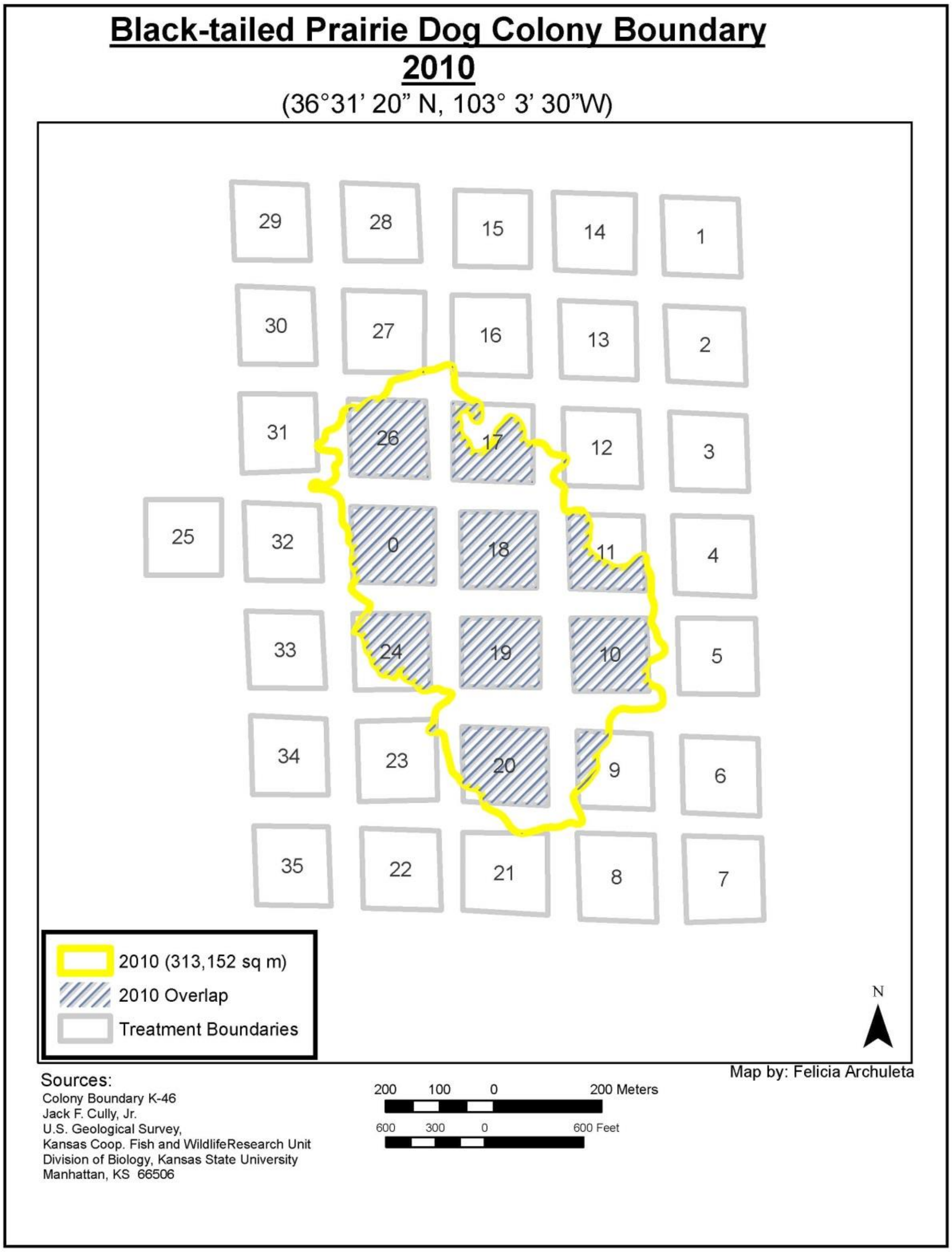

Figure 10 - Map of the 2010 Prairie Dog Colony Boundary. 2010 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

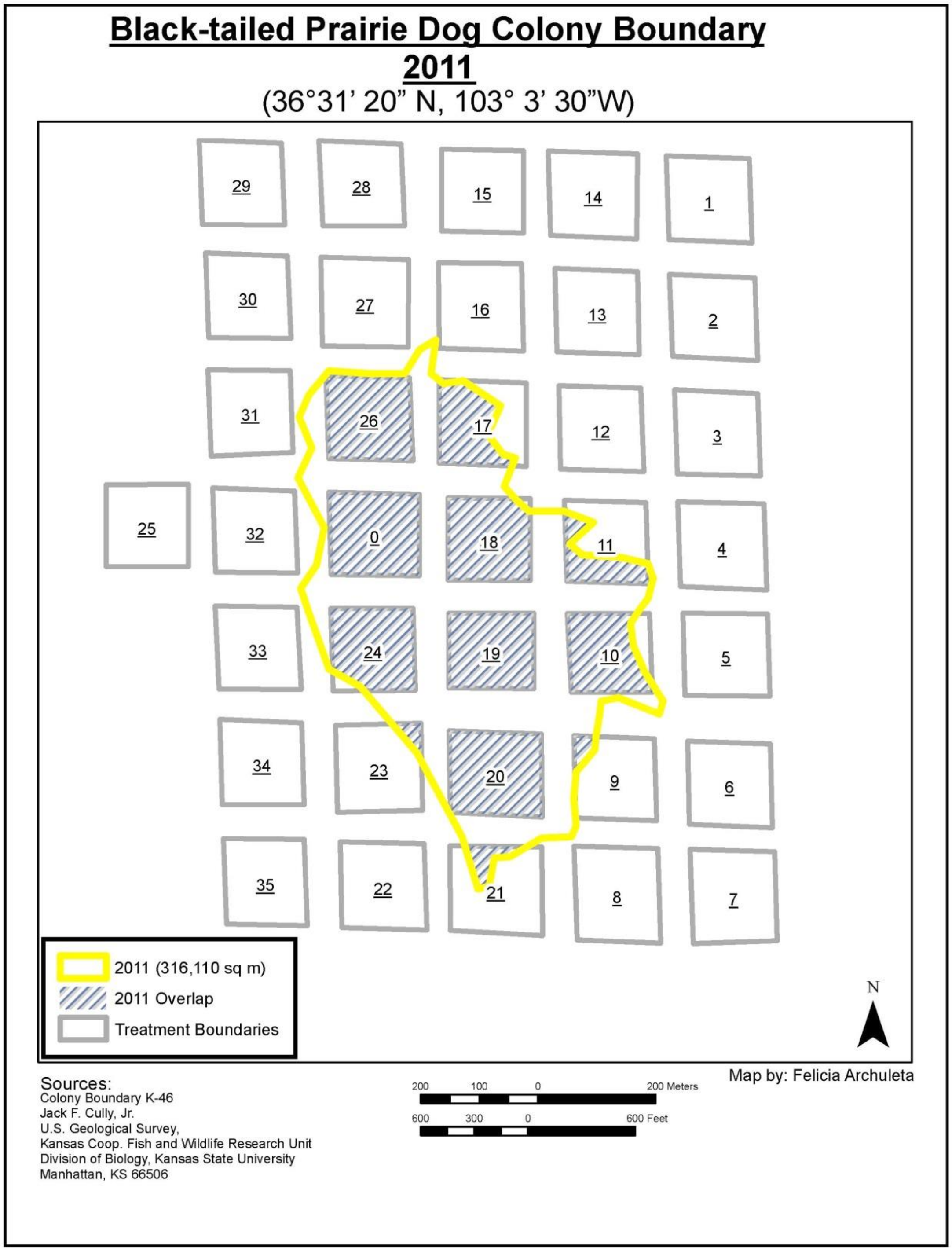

Figure 11 - Map of the 2011 Prairie Dog Colony Boundary. 2011 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

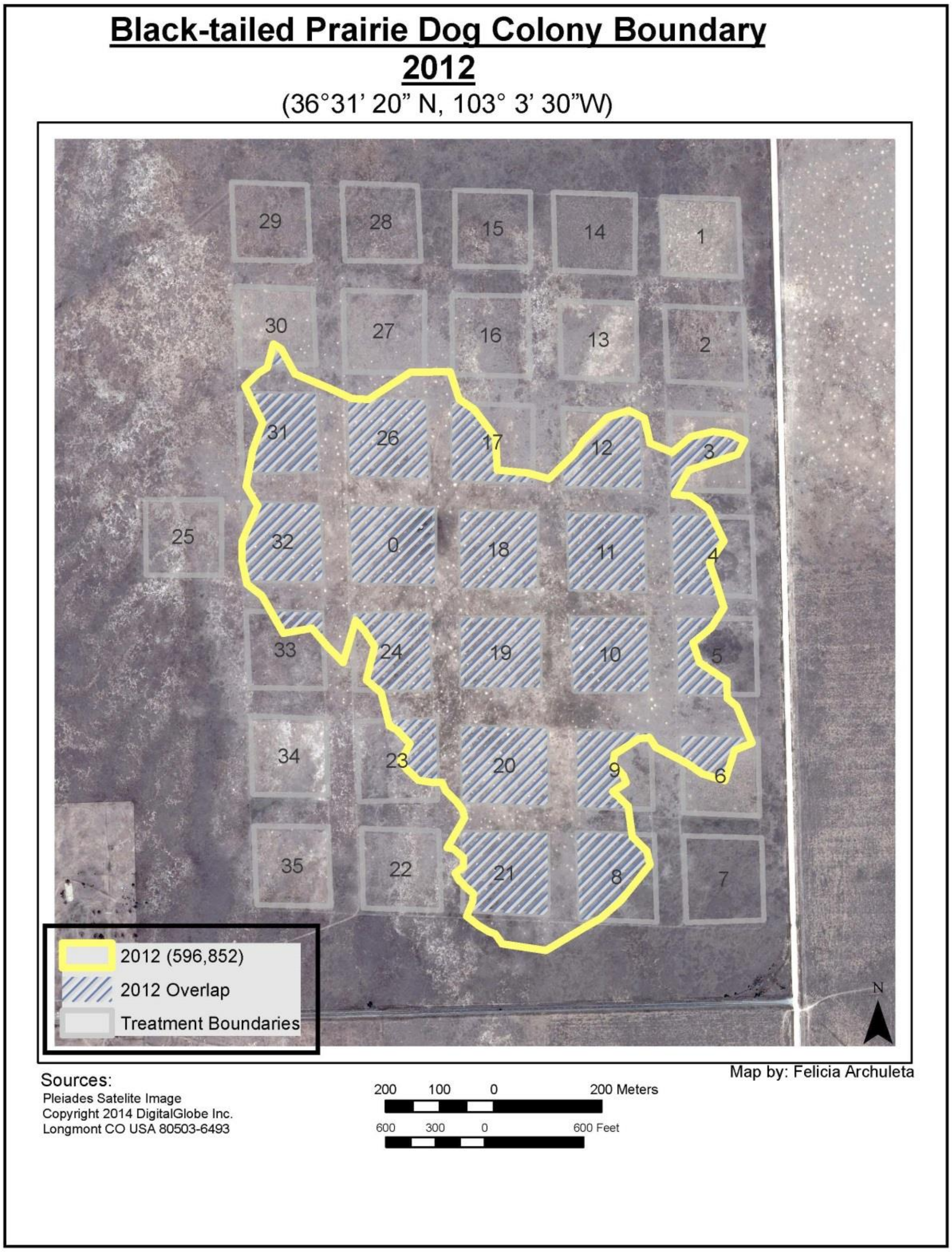

Figure 12 - Map of the 2012 Prairie Dog Colony Boundary. 2012 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

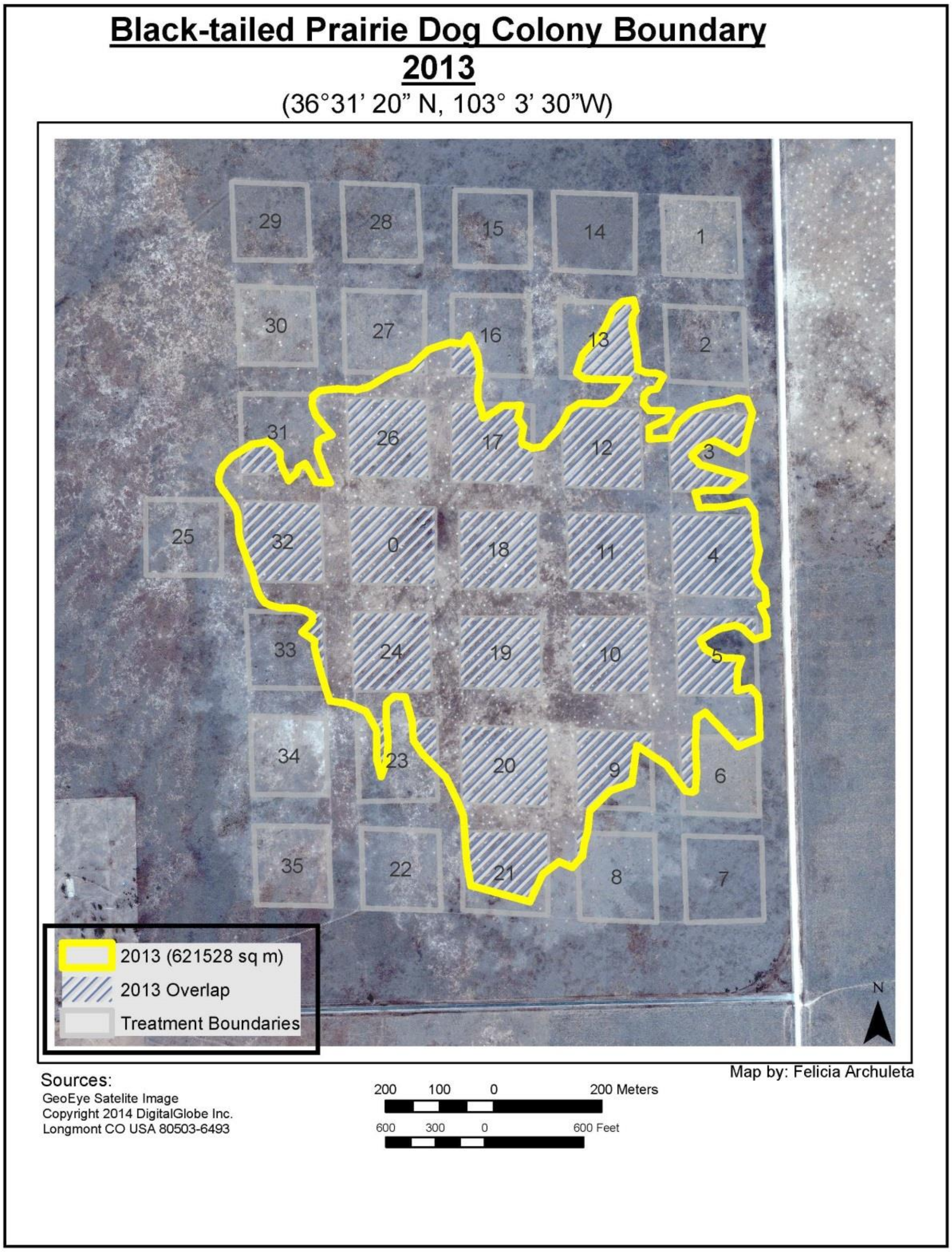

Figure 13 - Map of the 2013 Prairie Dog Colony Boundary. 2013 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

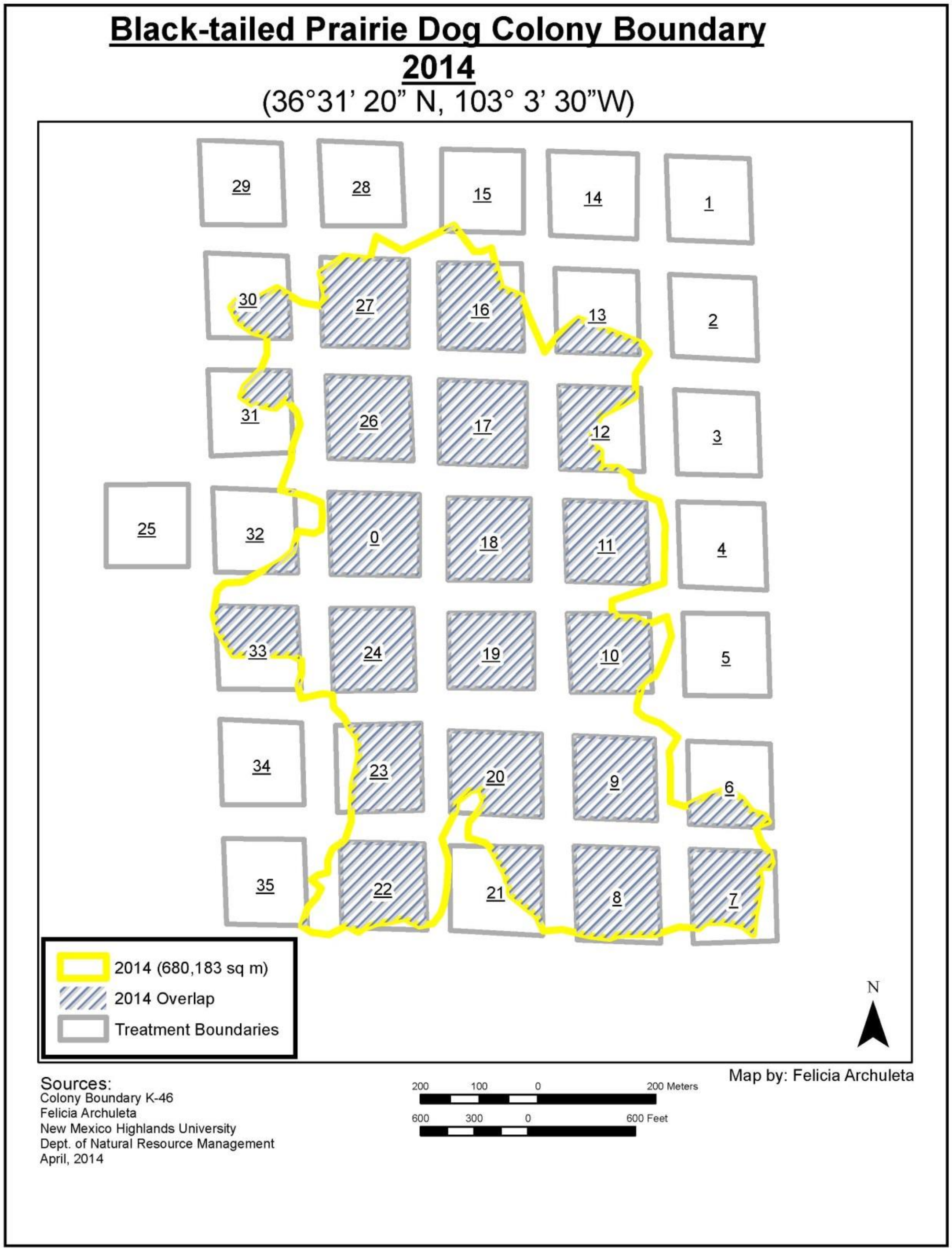

Figure 14 - Map of the 2014 Prairie Dog Colony Boundary. 2014 prairie dog colony boundary (yellow) overlaid on K-46 treatment plots with overlapping areas shaded in gray

APPENDIX 2

HISTOGRAMS

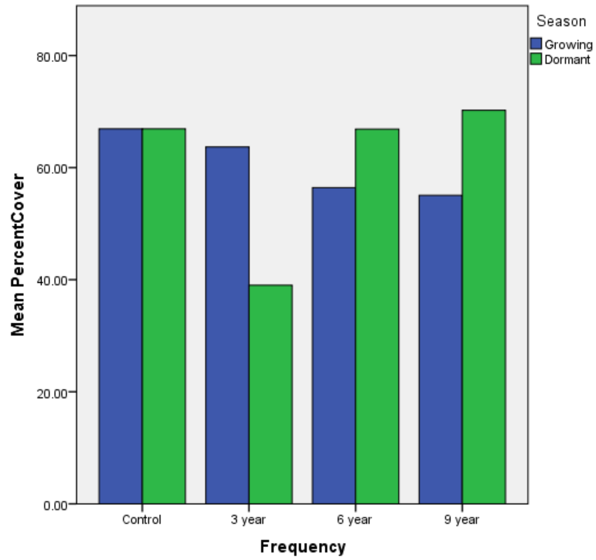

Figure 15 - Histogram of the mean percentage of coverage/overlap by frequency and season. Mean percentage of coverage/overlap of the prairie dog colony on the control, 3 year, 6 year, and 9 year burn frequency plots by season.

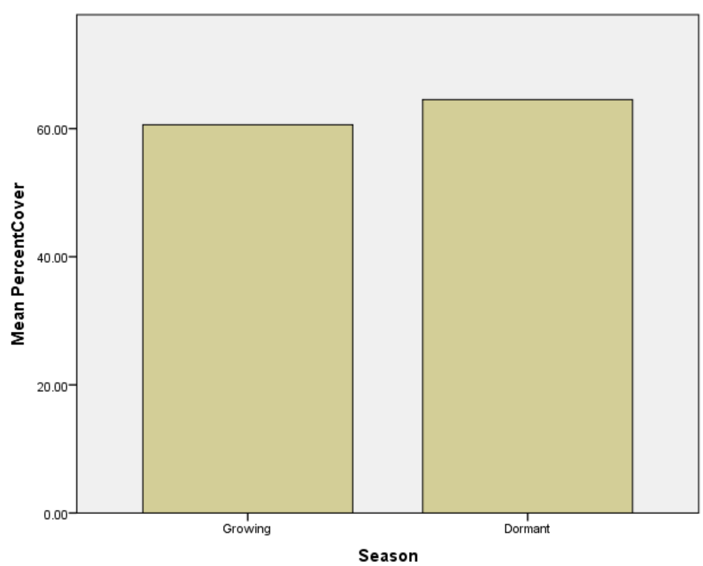

Figure 16 - Histogram of the mean percentage of coverage/overlap by season. Mean percentage of coverage/overlap of the prairie dog colony on the dormant and growing season.

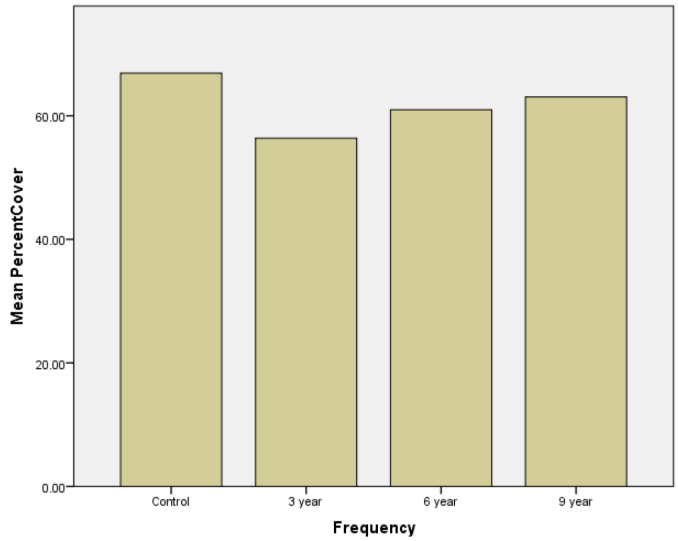

Figure 17 - Histogram of the mean percentage of coverage/overlap by burn frequency. Mean percentage of coverage/overlap of the prairie dog colony on the control, 3 year, 6 year, and 9 year burn frequency plots.

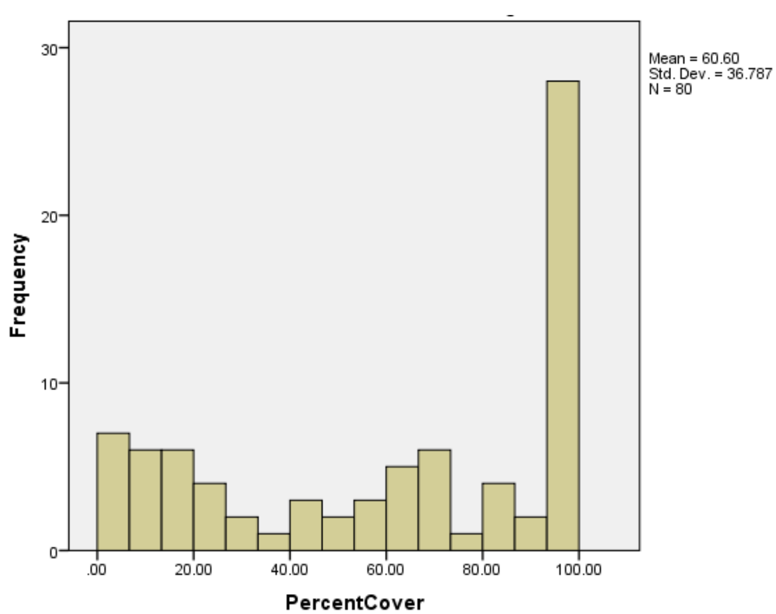

Figure 18 - Histogram of Growing Season Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the growing season plots.

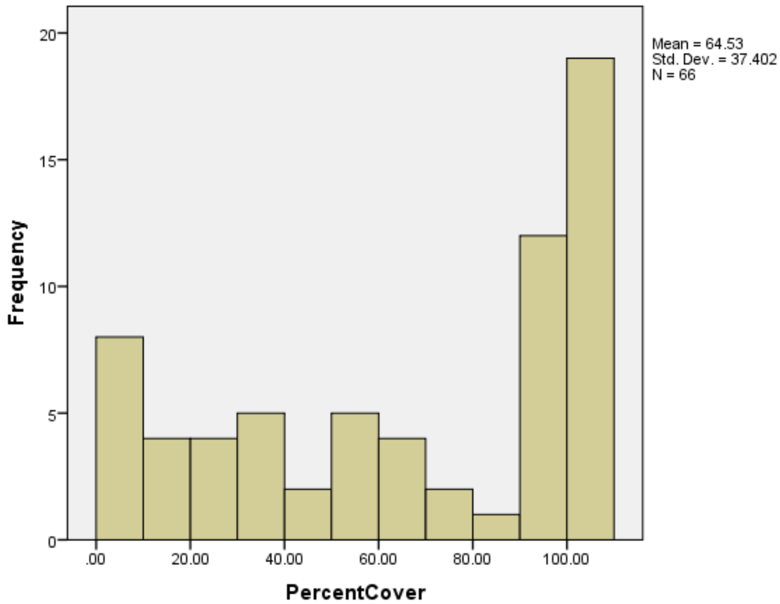

Figure 19 - Histogram of Dormant Season Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the dormant season plots.

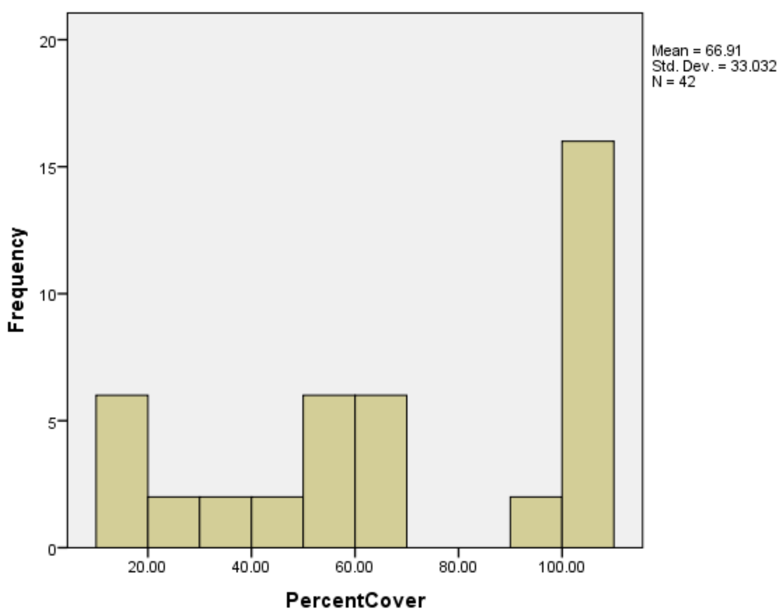

Figure 20 - Histogram of Control Plot Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the control plots.

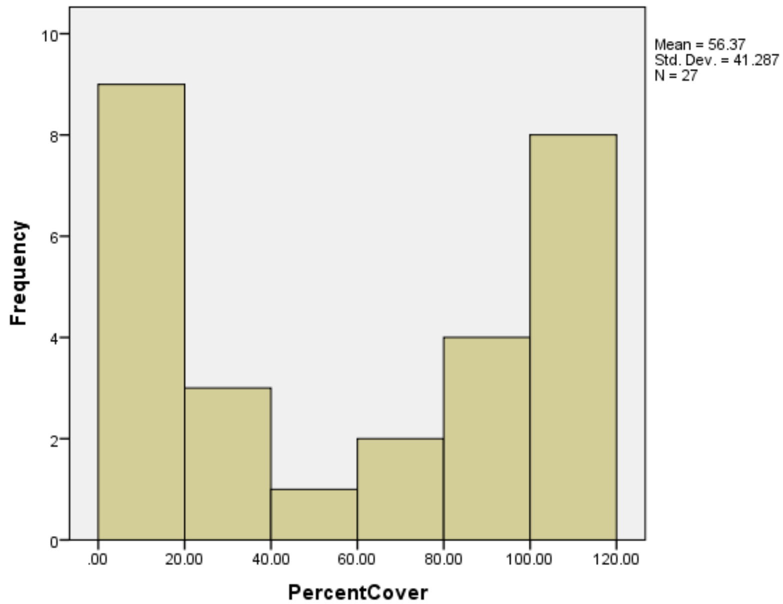

Figure 21 - Histogram of 3 Year Burn Frequency Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the 3 year burn frequency plots.

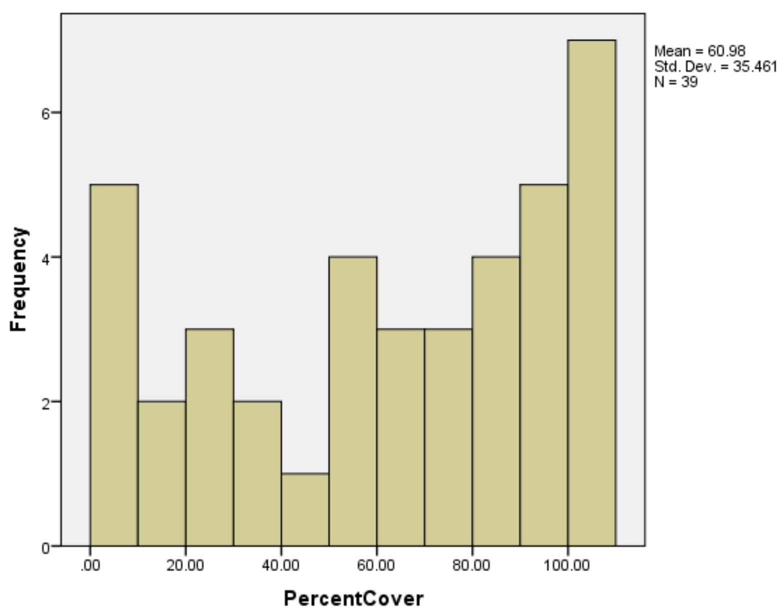

Figure 22- Histogram of 6 Year Burn Frequency Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the 6 year burn frequency plots.

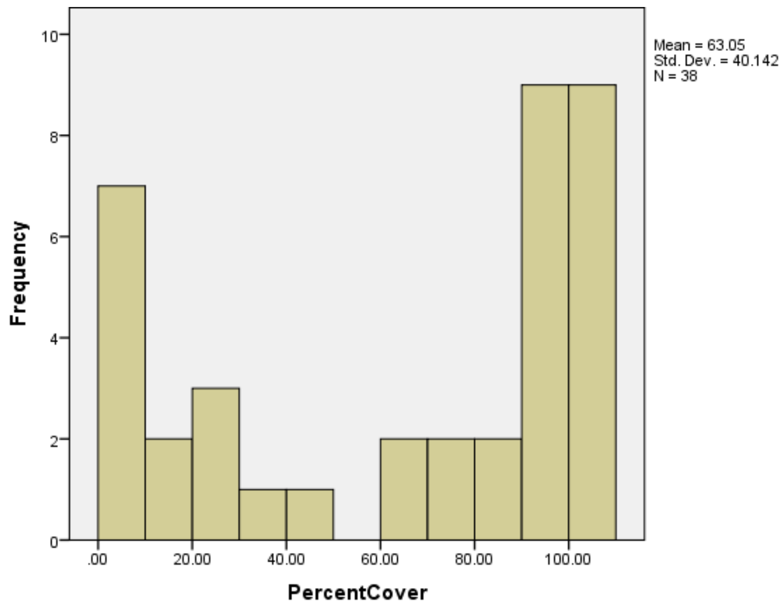

Figure 23 - Histogram of 9 Year Burn Frequency Data. This graph illustrates the non-normal distribution of the mean percentage of coverage of the prairie dog colony on the 9 year burn frequency plots.

APPENDIX 3

SCATTER PLOTS

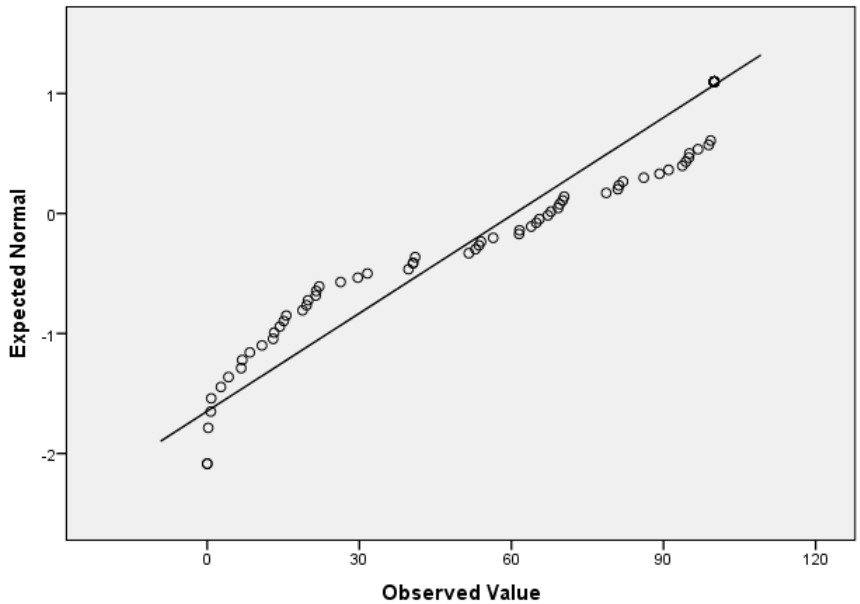

Figure 24 - Normal Q-Q Plot of Growing Season Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the growing season plots.

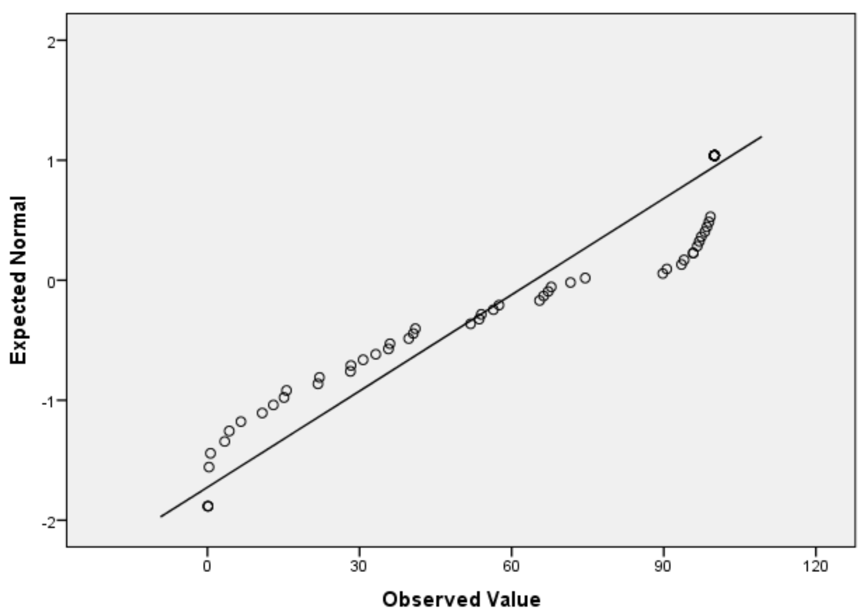

Figure 25 - Normal Q-Q Plot of Dormant Season Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the dormant season plots.

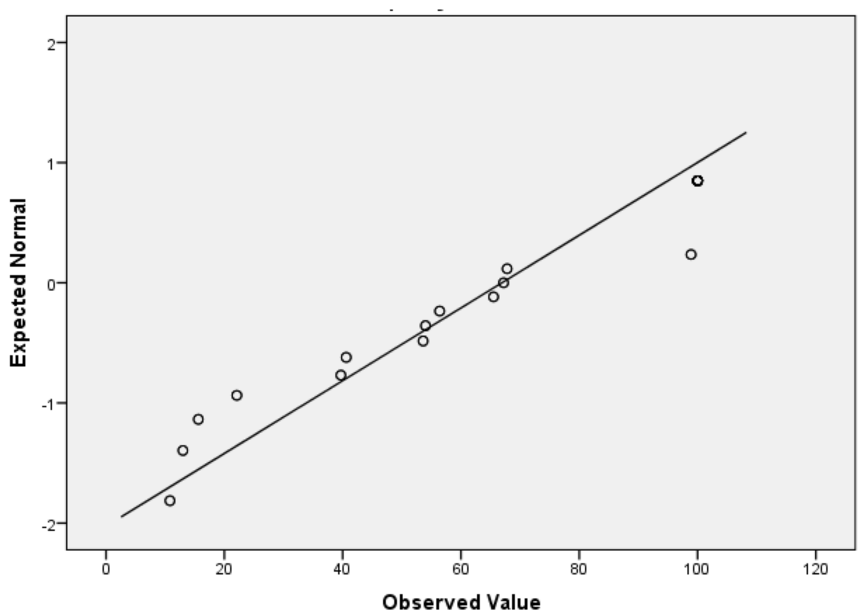

Figure 26- Normal Q-Q Plot of Control Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the control plots.

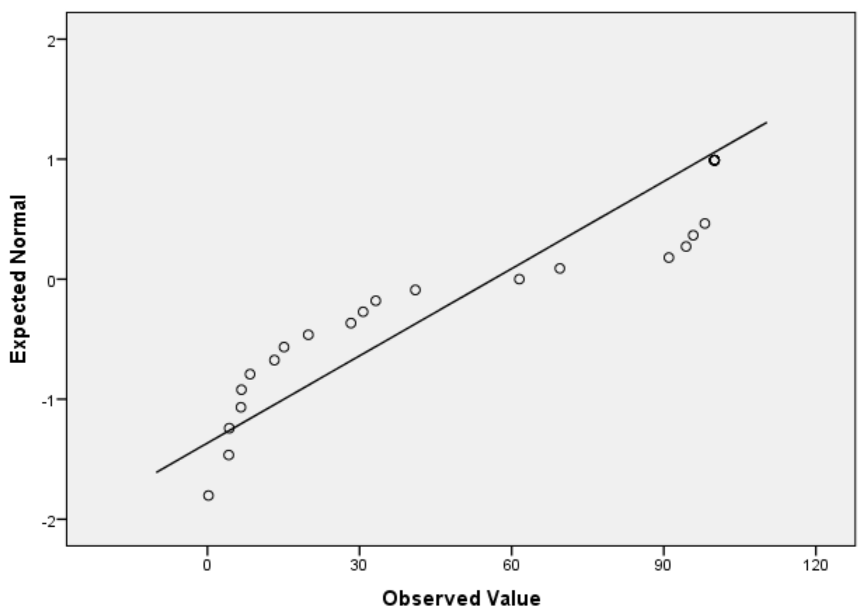

Figure 27 - Normal Q-Q Plot of 3 Year Burn Frequency Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the 3 year burn frequency plots.

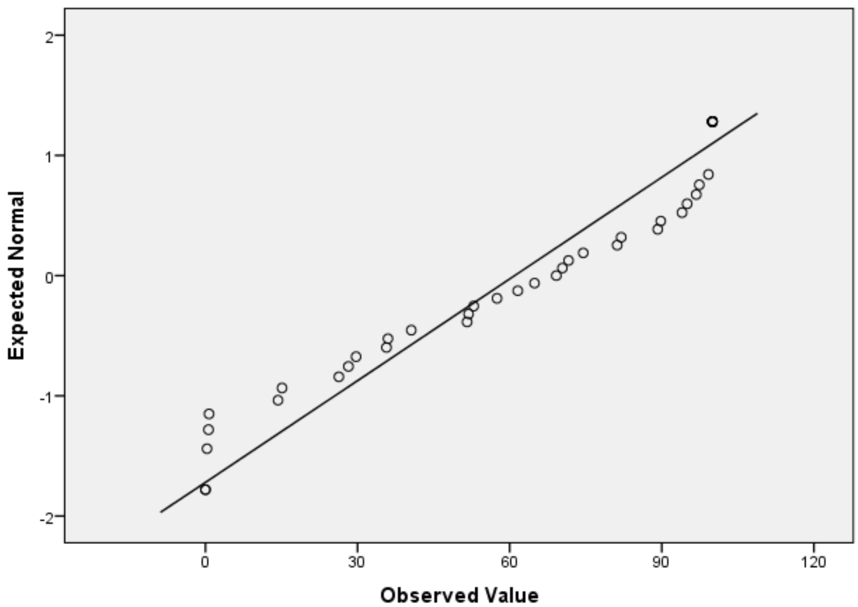

Figure 28 - Normal Q-Q Plot of 6 Year Burn Frequency Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the 6 year burn frequency plots.

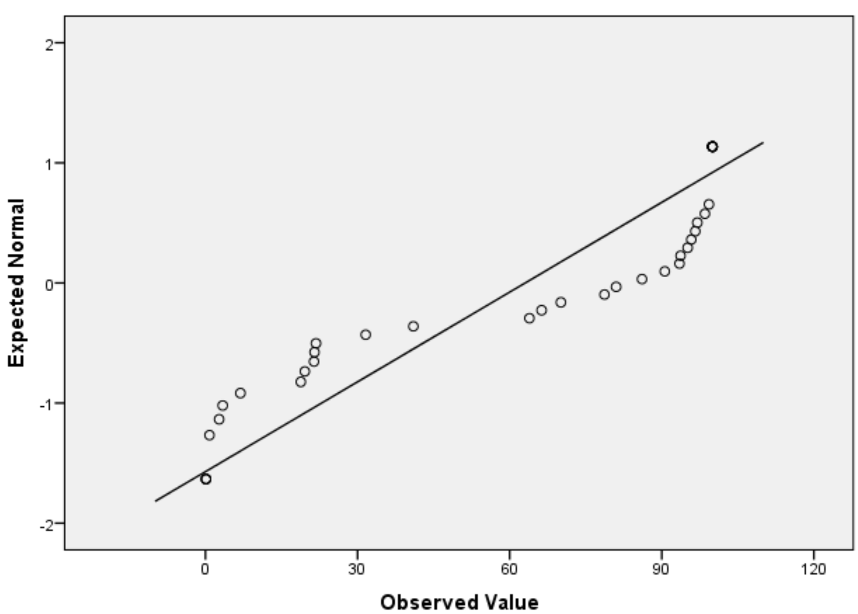

Figure 29 - Normal Q-Q Plot of 9 Year Burn Frequency Data. Normal Q-Q plot of the mean percentage of coverage of the prairie dog colony on the 9 year burn frequency plots.

APPENDIX 4

ANNUAL TEMPERATURE AND PRECIPITATION DATA

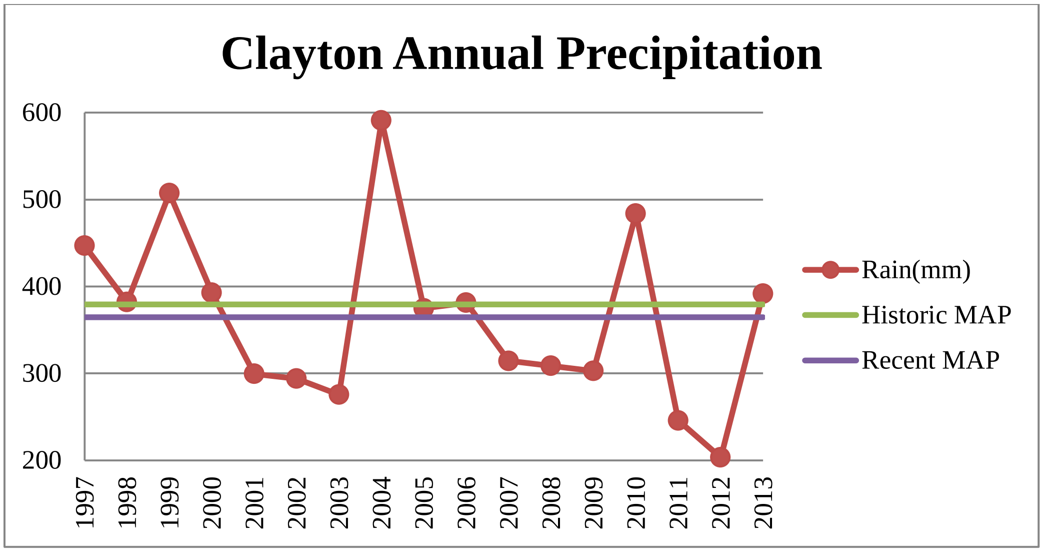

Figure 30 – Mean Annual Precipitation for Clayton, NM. This graph illustrates the mean annual precipitation recorded from 1997-2013 in Clayton, NM

Table 7 - Mean Annual Precipitation for Clayton, NM. This table lists the historic mean annual precipitation (MAP), recent MAP, and the MAP recorded from 1997-2013 in Clayton, NM.

Year	Rain(mm)	Historic MAP	Recent MAP	Rain(in.)
1997	446.786	379.31	364.43	17.59
1998	382.016	379.31	364.43	15.04
1999	507.238	379.31	364.43	19.97
2000	392.684	379.31	364.43	15.46
2001	299.466	379.31	364.43	11.79
2002	293.878	379.31	364.43	11.57
2003	275.59	379.31	364.43	10.85
2004	591.058	379.31	364.43	23.27
2005	374.904	379.31	364.43	14.76
2006	381.254	379.31	364.43	15.01
2007	314.452	379.31	364.43	12.38
2008	308.61	379.31	364.43	12.15
2009	302.768	379.31	364.43	11.92
2010	483.87	379.31	364.43	19.05
2011	245.872	379.31	364.43	9.68
2012	203.2	379.31	364.43	8
2013	391.6962	379.31	364.43	15.42111

APPENDIX 5

CODED DATA

DATA COLLECTED

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2005	26	18165.84	20221	89.8	1	D	2	6yr
2005	17	10852.03	21017	51.6	0	G	2	6yr
2005	0	4710.98	21319	22.1	1	D	0	Control
2005	0	4710.98	21319	22.1	0	G	0	Control
2005	18	17718.43	19559	90.6	1	D	3	9yr
2005	24	15988.26	19690	81.2	0	G	2	6yr
2005	19	18471.00	18471	100.0	0	G	1	3yr
2005	10	3525.73	18720	18.8	0	G	3	9yr
2005	20	4773.47	21924	21.8	1	D	3	9yr
2005	9	810.21	19231	4.2	0	G	1	3yr
2006	26	7287.55	20221	36.0	1	D	2	6yr
2006	17	0.23	21017	0.0	0	G	2	6yr
2006	18	8012.56	19559	41.0	1	D	3	9yr
2006	24	2966.02	19690	15.1	0	G	2	6yr
2006	19	7580.98	18471	41.0	0	G	1	3yr
2006	20	19.96	21924	0.1	1	D	3	9yr
2009	26	19007.40	20221	94.0	1	D	2	6yr
2009	17	5527.05	21017	26.3	0	G	2	6yr
2009	0	13966.55	21319	65.5	1	D	0	Control
2009	0	13966.55	21319	65.5	0	G	0	Control
2009	18	18887.85	19559	96.6	1	D	3	9yr

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2009	11	2490.11	19196	13.0	1	D	0	Control
2009	11	2490.11	19196	13.0	0	G	0	Control
2009	24	7986.76	19690	40.6	0	G	2	6yr
2009	19	18471.25	18471	100.0	0	G	1	3yr
2009	10	11970.71	18720	63.9	0	G	3	9yr
2009	20	14527.12	21924	66.3	1	D	3	9yr
2009	9	1283.29	19231	6.7	0	G	1	3yr
2010	27	19.47	22324	0.1	1	D	3	9yr
2010	16	31.89	21014	0.2	0	G	1	3yr
2010	26	19704.99	20221	97.4	1	D	2	6yr
2010	17	13649.05	21017	64.9	0	G	2	6yr
2010	12	52.33	20021	0.3	1	D	2	6yr
2010	0	21079.54	21319	98.9	1	D	0	Control
2010	0	21079.54	21319	98.9	0	G	0	Control
2010	18	19559.11	19559	100.0	1	D	3	9yr
2010	11	10368.43	19196	54.0	1	D	0	Control
2010	11	10368.43	19196	54.0	0	G	0	Control
2010	24	13869.90	19690	70.4	0	G	2	6yr
2010	19	18471.00	18471	100.0	0	G	1	3yr
2010	10	18592.32	18720	99.3	0	G	3	9yr
2010	23	177.15	21561	0.8	0	G	3	9yr
2010	20	21001.46	21924	95.8	1	D	3	9yr

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2010	9	3817.66	19231	19.9	0	G	1	3yr
2010	21	5.12	23109	0.0	0	G	2	6yr
2011	26	20222.50	20221	100.0	1	D	2	6yr
2011	17	12955.60	21017	61.6	0	G	2	6yr
2011	0	21319.00	21319	100.0	1	D	0	Control
2011	0	21319.00	21319	100.0	0	G	0	Control
2011	18	19263.30	19559	98.5	1	D	3	9yr
2011	11	7801.14	19196	40.6	1	D	0	Control
2011	11	7801.14	19196	40.6	0	G	0	Control
2011	24	18703.69	19690	95.0	0	G	2	6yr
2011	19	18471.00	18471	100.0	0	G	1	3yr
2011	10	16114.28	18720	86.1	0	G	3	9yr
2011	23	1483.30	21561	6.9	0	G	3	9yr
2011	20	21923.50	21924	100.0	1	D	3	9yr
2011	9	1618.11	19231	8.4	0	G	1	3yr
2011	21	3315.60	23109	14.3	0	G	2	6yr
2012	30	862.00	19865	4.3	1	D	1	3yr
2012	32	18995.00	19820	95.8	1	D	1	3yr
2012	33	3070.00	19686	15.6	0	G	0	Control
2012	33	3070.00	19686	15.6	1	D	0	Control
2012	31	16254.00	20065	81.0	0	G	3	9yr
2012	24	16141.00	19690	82.0	0	G	2	6yr

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2012	23	6818.00	21561	31.6	0	G	3	9yr
2012	6	6659.00	20068	33.2	1	D	1	3yr
2012	3	7166.00	20061	35.7	1	D	2	6yr
2012	12	14921.00	20021	74.5	1	D	2	6yr
2012	27	18.00	22324	0.1	1	D	3	9yr
2012	26	20220.00	20221	100.0	1	D	2	6yr
2012	0	21319.00	21319	100.0	0	G	0	Control
2012	0	21319.00	21319	100.0	1	D	0	Control
2012	4	11417.00	21307	53.6	0	G	0	Control
2012	4	11417.00	21307	53.6	1	D	0	Control
2012	5	8052.00	20290	39.7	0	G	0	Control
2012	5	8052.00	20290	39.7	1	D	0	Control
2012	8	15995.00	22820	70.1	0	G	3	9yr
2012	9	11826.00	19231	61.5	0	G	1	3yr
2012	10	18720.00	18720	100.0	0	G	3	9yr
2012	11	19196.00	19196	100.0	0	G	0	Control
2012	11	19196.00	19196	100.0	1	D	0	Control
2012	17	11121.00	21017	52.9	0	G	2	6yr
2012	18	19559.00	19559	100.0	1	D	3	9yr
2012	19	18471.00	18471	100.0	0	G	1	3yr
2012	20	21924.00	21924	100.0	1	D	3	9yr
2012	21	22379.00	23109	96.8	0	G	2	6yr

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2013	32	19445.00	19820	98.1	1	D	1	3yr
2013	33	2127.00	19686	10.8	0	G	0	Control
2013	33	2127.00	19686	10.8	1	D	0	Control
2013	31	3924.00	20065	19.6	0	G	3	9yr
2013	24	19690.00	19690	100.0	0	G	2	6yr
2013	23	4645.00	21561	21.5	0	G	3	9yr
2013	6	3035.00	20068	15.1	1	D	1	3yr
2013	3	14369.00	20061	71.6	1	D	2	6yr
2013	12	19867.00	20021	99.2	1	D	2	6yr
2013	13	10337.00	19928	51.9	1	D	2	6yr
2013	27	759.00	22324	3.4	1	D	3	9yr
2013	26	20221.00	20221	100.0	1	D	2	6yr
2013	0	21319.00	21319	100.0	0	G	0	Control
2013	0	21319.00	21319	100.0	1	D	0	Control
2013	4	21307.00	21307	100.0	0	G	0	Control
2013	4	21307.00	21307	100.0	1	D	0	Control
2013	5	13645.00	20290	67.2	0	G	0	Control
2013	5	13645.00	20290	67.2	1	D	0	Control
2013	8	625.00	22820	2.7	0	G	3	9yr
2013	9	13374.00	19231	69.5	0	G	1	3yr
2013	10	18720.00	18720	100.0	0	G	3	9yr
2013	11	19196.00	19196	100.0	0	G	0	Control

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2013	11	19196.00	19196	100.0	1	D	0	Control
2013	16	2776.00	21014	13.2	0	G	1	3yr
2013	17	18753.00	21017	89.2	0	G	2	6yr
2013	18	19559.00	19559	100.0	1	D	3	9yr
2013	19	18471.00	18471	100.0	0	G	1	3yr
2013	20	21924.00	21924	100.0	1	D	3	9yr
2013	21	15992.00	23109	69.2	0	G	2	6yr
2014	0	21319.00	21319	100.0	0	G	0	Control
2014	0	21319.00	21319	100.0	1	D	0	Control
2014	6	5675.00	20068	28.3	1	D	1	3yr
2014	7	15190.00	22410	67.8	0	G	0	Control
2014	7	15190.00	22410	67.8	1	D	0	Control
2014	8	21373.00	22820	93.7	0	G	3	9yr
2014	9	19231.00	19231	100.0	0	G	1	3yr
2014	10	17808.00	18720	95.1	0	G	3	9yr
2014	11	19196.00	19196	100.0	0	G	0	Control
2014	11	19196.00	19196	100.0	1	D	0	Control
2014	12	11512.00	20021	57.5	1	D	2	6yr
2014	13	5623.00	19928	28.2	1	D	2	6yr
2014	15	140.00	19578	0.7	0	G	2	6yr
2014	16	19133.00	21014	91.0	0	G	1	3yr
2014	17	21017.00	21017	100.0	0	G	2	6yr

Year	Plot #	Overlap Area (m2)	Plot Area (m2)	% Cover	Season Code	Season	Freq. Code	Frequency
2014	18	19559.00	19559	100.0	1	D	3	9yr
2014	19	18471.00	18471	100.0	0	G	1	3yr
2014	20	20498.00	21924	93.5	1	D	3	9yr
2014	21	6871.00	23109	29.7	0	G	2	6yr
2014	22	19902.00	21081	94.4	0	G	1	3yr
2014	23	16977.00	21561	78.7	0	G	3	9yr
2014	24	19690.00	19690	100.0	0	G	2	6yr
2014	26	20221.00	20221	100.0	1	D	2	6yr
2014	27	21646.00	22324	97.0	1	D	3	9yr
2014	30	6108.00	19865	30.7	1	D	1	3yr
2014	31	4287.00	20065	21.4	0	G	3	9yr
2014	32	1314.00	19820	6.6	1	D	1	3yr
2014	33	11103.00	19686	56.4	0	G	0	Control
2014	33	11103.00	19686	56.4	1	D	0	Control
2014	35	115.00	20102	0.6	1	D	2	6yr

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Thinking Like a Grassland: Challenges and Opportunities for Biodiversity Conservation in the Great Plains of North America☆

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ABSTRACT

Fauna of North America's Great Plains evolved strategies to contend with the region's extreme spatio-temporal variability in weather and low annual primary productivity. The capacity for large-scale movement (migration and/or nomadism) enables many species, from bison to lark buntings, to track pulses of productivity at broad spatial scales (> 1 000 km^2). Furthermore, even sedentary species often rely on metapopulation dynamics over extensive landscapes for long-term population viability. The current complex pattern of land ownership and use of Great Plains grasslands challenges native species conservation. Approaches to managing both public and private grasslands, frequently focused at the scale of individual pastures or ranches, limit opportunities to conserve landscape-scale processes such as fire, animal movement, and metapopulation dynamics. Using the US National Land Cover Database and Cropland Data Layers for 2011–2017, we analyzed land cover patterns for 12 historical grassland and savanna communities (regions) within the US Great Plains. On the basis of the results of these analyses, we highlight the critical contribution of restored grasslands to the future conservation of Great Plains biodiversity, such as those enrolled in the Conservation Reserve Program. Managing disturbance regimes at larger spatial scales will require acknowledging that, where native large herbivores are absent, domestic livestock grazing can function as a central component of Great Plains disturbance regimes if they are able move at large spatial scales and coexist with a diverse array of native flora and fauna. Opportunities to increase the scale of grassland management include 1) spatial prioritization of grassland restoration and reintroduction of grazing and fire, 2) finding creative approaches to increase the spatial scale at which fire and grazing can be applied to address watershed to landscape-scale objectives, and 3) developing partnerships among government agencies, landowners, businesses, and conservation organizations that enhance cross-jurisdiction management and address biodiversity conservation in grassland landscapes, rather than pastures.

Introduction

In his eloquent essay "Thinking Like a Mountain," Aldo Leopold discussed his experiences in the mountains of the southwestern United States, where he had "watched the face of many a newly wolf-less mountain, and seen the south facing slopes wrinkle with a maze of new deer trails …," leading him to "suspect that just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer" (Leopold 1949). Here, we apply a similar perspective to the grasslands of central North America, arguing that "thinking like a grassland" entails recognition that grasslands live in mortal fear of anthropogenic activities that eliminate the disturbance regimes essential to sustaining grassland ecosystems. The loss of these disturbances, such as fire and grazers, ultimately leads to landscape-scale homogenization and loss of biodiversity. We examine challenges and opportunities for biodiversity conservation across the Great Plains that center on the capacity for fire and fauna to move across broad, spatially diverse landscapes and for prairie dogs to

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play their keystone role (Fuhlendorf et al. 2009; Davidson et al. 2012; Fuhlendorf et al. 2017). In this paper, we first review the paleoecology of Great Plains flora and fauna since the last ice age and discuss how large-scale movements of some species, as well as metapopulation dynamics of others, contribute to their persistence in the Great Plains. We then present an analysis of the contemporary degree of grassland fragmentation across the Great Plains, to illustrate the scale, distribution, and extent of grassland alteration by croplands, woody plant encroachment, and urban expansion. Finally, we conclude with a discussion of recent successes and potential opportunities for defragmentation of these grasslands. Large, connected landscapes are critical to restoring ecosystem integrity, natural disturbance regimes, and biodiversity of the Great Plains; here we aim to illuminate both the current magnitude of Great Plains grassland fragmentation and ways forward to reconnect these grasslands.

Great Plains Paleoecology

The central grasslands of North America emerged from the last glacial period ~12 000 yr ago (Walker et al. 2009), as glaciers that covered modern-day Canada and portions of the northern United States retreated and substantial shifts in climatic conditions began to shape the flora and fauna of the region. Before this glacial retreat, today's southern Great Plains supported hardwood forests in the east and coniferous parklands in the west, intermingled in a patchy mosaic with sagebrush shrublands (Porter 1983). During the glacial retreat, many North American large mammals became extinct for reasons we do not debate here and extensive grasslands supporting lower-quality forage replaced the former mosaic of plant communities. The shift from the Pleistocene to the Holocene (~14 000−10 000 yr ago) entailed dramatic climatic changes that reorganized ecosystems and gave rise to floral and associated faunal communities that coevolved over the next 12 000 yr. These communities experienced another dramatic change in ecosystem organization initiated by the Homestead Act in 1862, which encouraged the first large-scale conversion of grasslands and landscape fragmentation.

From ~12 000 to 8 000 yr ago, drought-resistant grasslands expanded and lake levels declined across the Great Plains, favoring C_4-dominated grasslands in the south and mixed C3/C4 grasslands farther north (Baker et al. 2000; Woodburn et al. 2017). Drier conditions 9 000−8 500 yr before present (BP) eliminated upland and riparian forests in the eastern Plains and increased C_4 grass dominance, with the driest conditions likely occurring 8 500 to 5 800 yr BP (Baker et al. 2000; Mandel et al. 2014). Bison *(Bison bison)* evolved as the primary large grazer in the region and declined in body size during the early Holocene, ultimately reaching their modern form in the Great Plains ~6 500 yr ago (Hill et al. 2008; Lewis et al. 2010). Black-tailed prairie dogs (*Cynomys ludovicianus;* hereafter, BTPDs) occupied the nonglaciated portions of the Great Plains throughout the last glacial maximum and expanded into the northern Great Plains as the glaciers receded ~12 000 yr ago, at which time they had already reached their modern body size (Goodwin 1995). Genetic analyses of the mountain plover *(Charadrius montanus),* which nests on BTPD colonies, indicate their population underwent a significant expansion during this period of glacial retreat (Oyler-McCance et al. 2005), coincident with the northward expansion of BTPD. Fossil remains show other grassland birds currently endemic to the Great Plains including lark buntings *(Calamospiza melanocytes),* longspurs (*Calcarius* spp.), western meadowlark *(Sturnella neglecta),* and upland sandpipers *(Bartramia longicauda)* already occurred in their modern form in the central Great Plains ~26 000 yr BP (Downs 1954; Emslie 2007). Over the past 2 700 yr, plant communities of the Great Plains have resembled those present at the time of European settlement but experienced periodic extreme droughts that were likely similar to or more severe than the drought of the 1930s (Baker et al. 2000). Collectively, these paleoecological studies indicate the flora, fauna, and associated disturbance regimes that are the focus of conservation efforts in the Great Plains have been present and interacting for thousands of years. As we move into a new era of climate changes (USGCRP 2017) layered on all of the other anthropogenic alterations that Great Plains grasslands have experienced since European settlement, conserving the region's flora and fauna is clearly a major challenge.

Movement and Metapopulations

North America's Great Plains once rivaled Africa's Serengeti. Large, migratory herds of herbivores, including bison, elk *(Cervus elaphus),* deer (*Odocoileus* spp.), and pronghorn *(Antilocapra americana),* moved at varying and largely unquantified spatial scales across North America's prairies in the millions (Samson et al. 2004; Sanderson et al. 2008). Through grazing, browsing, trampling, wallowing, and defecating, large herbivores altered vegetation composition, habitat structure, soils, nutrient cycling, and fire regimes, creating heterogeneous landscapes that included suites of grassland species that associate with open and intensively grazed habitats (Knapp 1999; Fuhlendorf and Engle 2001; Sanderson et al. 2008; Derner et al. 2009). Opportunities exist for livestock to continue to provide the ecological functions that sustain heterogeneity and many components of Great Plains biodiversity, although domestic livestock in the Great Plains are typically constrained to move over far smaller spatial scales than native herbivores did in the past (Towne et al. 2005; Derner et al. 2009; Allred et al. 2011). In addition, bison have been restored to limited portions of their historic range (Sanderson et al. 2008). Efforts to restore native wildlife populations are unlikely to be successful from an ecological and functional perspective without providing large, connected landscapes that support migratory movements so that animals can track resource availability (Berger 2004; Samson 2004; Fuhlendorf et al. 2017a).

Movements of Great Plains fauna occur at a wide range of spatial scales in response to spatiotemporal variation in weather, seasons, fire patterns, and vegetation dynamics. The Great Plains encompass a temperature gradient extending across nearly 3 000 km from north to south and a precipitation gradient extending nearly 1 500 km from northwest to southeast (Lauenroth et al. 1999). In any given location, precipitation and temperature fluctuate dramatically over temporal scales from days to seasons, years, and decades (Knapp and Smith 2001; Chen et al. 2018). This large geographic area and extreme temporal variability combined with the limited vertical structure of the vegetation create a challenging environment shaping the regions' fauna over ecological and evolutionary time scales. As a result, many species depend on the capacity for large-scale movements (over hundreds to thousands of kilometers) to track resources and avoid inclement weather. Bison, elk, and pronghorn, the historically most abundant large herbivores on the Great Plains, are all well known for their ability to undertake long-distance migrations to track forage resources (Lott 2002; Berger 2004).

For many bird species, multiple scales and patterns of mobility are an important component of their strategies for survival in the Great Plans. Birds of conservation concern that migrate from breeding grounds in the Great Plains to overwintering locations farther south include passerines such as McCown's and chestnut-collared longspurs, Sprague's Pipit *(Anthus spragueii),* grasshopper, Henslow's and Baird's sparrows (*Ammodramus savannarum, A. bairdii,* and *A. henslowii*), and lark buntings (Rosenberg et al. 2016), grassland-breeding shorebirds such as mountain plovers, upland sandpipers and long-billed curlews *(Numenius americanus)* (Page et al. 2014; Pierce et al. 2017), and raptors such as burrowing owls *(Athene cunicularia),* ferruginous

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hawks *(Buteo regalis),* and golden eagles (*Aquila chrysaeitos;* Watson et al. 2018). Individuals of some migratory species may return to consistent locations within their breeding grounds year after year, but recent studies show substantial capacity for within- and among-year movements in response to spatially variable resources or habitats. For example, dense concentrations of breeding lark buntings track those portions of the Great Plains with recent high precipitation (Wilson et al. 2018). Mountain plovers may move > 2 km in just the first 2 d after a brood hatches (Knopf and Rupert 1996) and > 20 km between two successive nesting attempts in a given breeding season (Skrade and Dinsmore 2010). Once brood rearing is complete, they migrate long distances from breeding grounds to late-summer staging grounds in the southern Great Plains (Pierce et al. 2017). Other migratory shorebirds move opportunistically to recently burned areas during migration (Hovick et al. 2017). Similarly, individual ferruginous hawks exhibit long-distance, post-breeding movements within the Great Plains to track availability of prey resources (Watson et al. 2018). All of these examples emphasize the importance of large-scale mobility for survival and persistence of many Great Plains organisms.

Even for sedentary species that both breed and overwinter within year-round territories (e.g., < 10 km^2), extensive, connected landscapes can be critical for maintaining populations. Local extirpations of a species can occur as a result of multiple factors, including shifting habitat conditions as vegetation responds to disturbances (e.g., wildfires or woody plant encroachment locally eliminating nesting habitat for prairie grouse; Fuhlendorf et al. 2017), disease outbreaks (e.g., epizootic plague affecting local BTPD populations; Cully et al. 2010), or extreme weather events (e.g., hail and ice storms or heat waves killing local breeding bird populations; Ross et al. 2016; Carver et al. 2017). Recolonization of an area that experienced a local extirpation depends on metapopulation dynamics, which require connectivity and dispersal among portions of the landscape operating as population sinks versus sources (Hanski 1994).

One keystone species that has experienced dramatic declines throughout its range and relies strongly on metapopulation dynamics for persistence in the western Great Plains is the BTPD. BTPDs occur in complexes of spatially distinct colonies that typically support hundreds to thousands of individuals, and these colonies are interconnected via occasional dispersal (Hoogland 2006; Davidson et al. 2012). BTPD colonies are well-known to create habitat for numerous associated species, such as burrowing owls and mountain plovers, and they attract large herbivores, such as bison and cattle, that prefer the higher quality forage found on their colonies during periods of rapid plant growth (Kotliar et al. 2006; Bayless and Beier 2011; Augustine and Baker 2013). A diverse array of predators also rely on prairie dogs as a primary food source, including multiple raptor species, American badgers *(Taxidea taxus),* coyotes *(Canis latrans),* and the endangered black-footed ferret *(Mustela nigripes)* (Goodrich and Buskirk 1998, Cook et al. 2003; Biggins and Eads 2018). Since the introduction of sylvatic plague to North America in the early 1900s, BTPD populations have been regulated by periodic plague outbreaks that cause dramatic (> 95%) local population collapses (Cully et al. 2010). Field research linked with population modeling analyses reveal how BTPD persistence over broad landscapes depends on metapopulation dynamics, as populations in varying phases of collapse or recovery from plague exchange individuals and genetic diversity (Antolin et al 2006; Snall et al. 2008; Savage et al. 2011; George et al. 2013). As a result, associated species that rely on prairie dog colonies for habitat also depend on the metapopulation dynamics that sustain prairie dogs over broad spatial and long temporal scales.

Metapopulation dynamics are also increasingly recognized as essential to the persistence of sedentary bird species, such as the Lesser Prairie-Chicken *(Tympanuchus pallidicinctus),* which has experienced dramatic population declines and range contraction within the increasingly fragmented landscapes of the southern Great Plains. For example, prairie chicken populations can undergo steep declines in response to extreme drought (Ross et al. 2016) or woody plant encroachment (Fuhlendorf et al. 2017b), while landscapes containing more connected patches of grasslands, including those restored through the Conservation Reserve Program (CRP), can serve as population sources (Spencer et al. 2017). Although Prairie-Chickens are frequently sedentary, occupying year-round home ranges, Global Positioning System telemetry reveals they undertake occasional long-distance movements, which can connect populations across distances of ~5–25 km (Earl et al. 2016). Analyses to project long-term persistence of Lesser Prairie-Chickens rely on metapopulation models and emphasize the need to sustain connectivity among regions and core areas containing source populations in order to conserve the species (Hagen et al. 2017). These examples illustrate that even for birds and mammals, in which long-distance movement is not central to their strategy for living in the Great Plains, population dynamics occur across broad landscapes and extend far beyond the typical size of individual pastures or ranching operations.

Grassland Loss and Fragmentation

Today, extensive portions of the US Great Plains have been converted into some of the most productive croplands in the world. Conversion of native grassland to cropland combined with additional losses to woody plant encroachment, urban expansion, and energy extraction are widely recognized as major challenges for grassland species conservation (Samson et al. 2004; Williams et al. 2011). Widespread grassland to cropland conversion was precipitated by the Homestead Acts beginning in 1862 and new technologies like central pivot irrigation, with varying economic forces and national policies driving continued conversion for more than a century (Wright and Wimberly 2013). Samson et al. (2004) estimated that by 2003, tallgrass, mixedgrass, and shortgrass provinces of the Great Plains were reduced to 13%, 29%, and 52% of their historic extent, respectively. More recent analyses suggest that 22.1 million ha (54.7 million acres) of grassland were converted to cropland in the northern Great Plains during 2009–2017 (2018 Plowprint Report). At the same time, beginning in the 1980s, extensive amounts of cropland have been restored back to grasslands of varying composition through the Conservation Reserve Program in the United States and the National Soil Conservation Program in Canada. Although these restored grasslands can in some cases provide valuable wildlife habitat and serve to reestablish grassland connectivity, their value is often limited due to the dominance of non-native grasses and lack of diverse forb communities. Here, we use recent data layers compiled by the National Agricultural Statistics Service (NASS) on cropland distribution (2011–2017) combined with the 2011 National Land Cover Database (NLCD) to quantify the current status of Great Plains grasslands in terms of amount and distribution.

Methods

Quantifying Rangeland Loss and Fragmentation in the Great Plains

To define subregions of the Great Plains, we used a revised version of Kuchler's (1964) map of the potential natural vegetation of the United States. The map was digitized from the 1979 physiographic regions map produced by the Bureau of Land Management, which added 10 physiognomic types. All analyses are based on data sources specific to the United States; hence, we only analyze the portion of the Great Plains occurring in the United States. Similar contemporary analyses are needed for the Canadian

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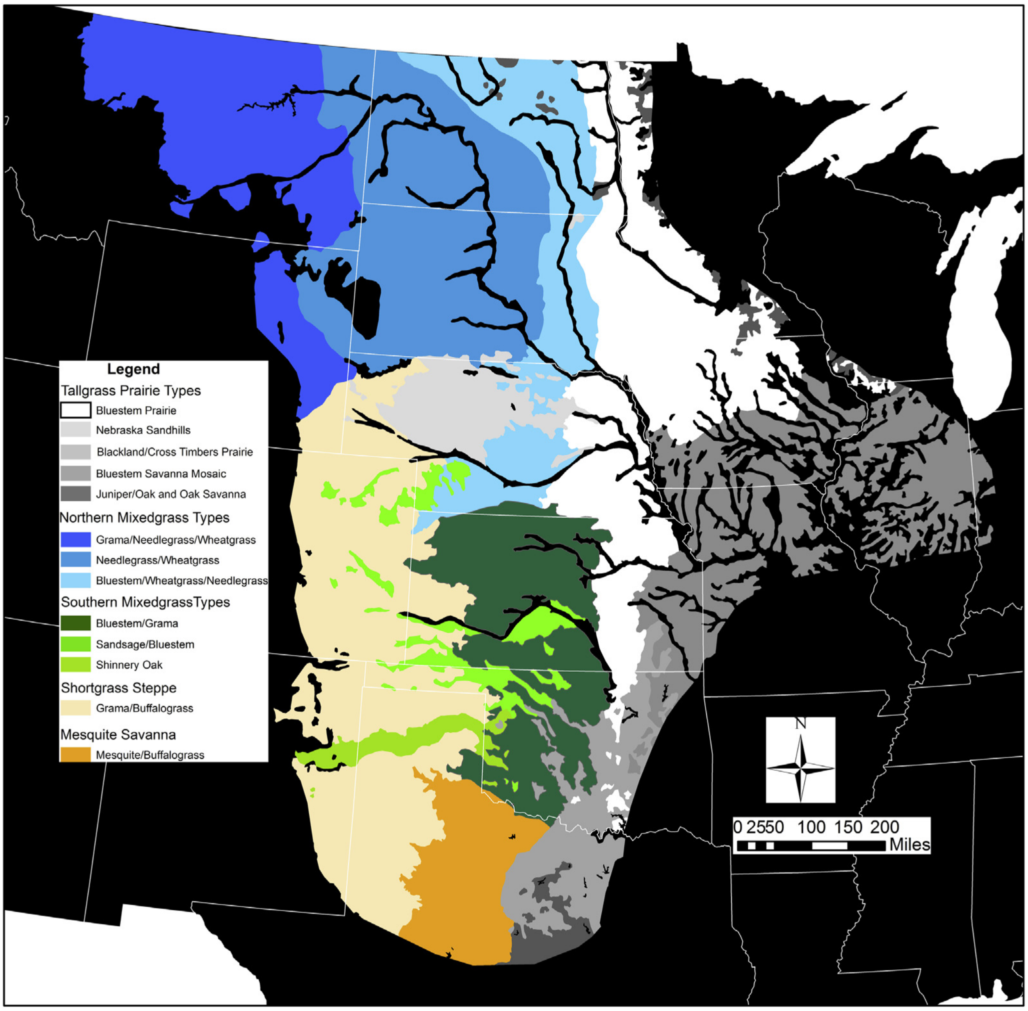

Figure 1. Potential natural vegetation of US portion of the North American Great Plains, adapted from Kuchler (1964).

portion of the Great Plains, but for a relatively recent and comprehensive overview of anthropogenic alterations to the Canadian Great Plains, see Williams et al. (2011). We extracted all of the grassland, shrubland, savanna, and forest communities in the US Great Plains from the revised Kuchler natural vegetation map (Fig. 1). Following Lauenroth et al. (1999), we refer to the northern portion of Kuchler's "Shortgrass Prairie" region (the grama/needlegrass/wheatgrass community) as "Northern Mixed Grass" types and the southern portion (the grama/buffalograss community) as "Shortgrass Steppe."

We sought to quantify the current amount of rangeland in the US Great Plains converted due to 1) woody plant encroachment; 2) urban, exurban, and other forms of development (e.g., energy infrastructure); and 3) cultivation of cropland. At the time of this analysis, the most contemporary measure of land cover across the United States was the 2011 NLCD (Homer et al. 2015). One limitation of the NLCD is that some grasslands with high rates of productivity, such as herbaceous wetlands or grasslands along riparian zones, are misclassified as cropland. A second limitation is the inability to capture cropland conversion occurring after 2011 (Lark et al. 2015). Beginning in 2009 (and retroactively for 2008), the US Department of Agriculture−NASS has annually produced a Cropland Data Layer (CDL) for the United States from satellite imagery, which maps individual crop types at a 30-m spatial resolution. Since 2009, methods were refined and improved, such that caution is recommended in using early years of CDLs for any analysis of land cover change (Lark et al. 2015, 2017). At the same time, using as many years of CDL data as possible can assist in identifying classification errors and delineating individual field boundaries (Lark et al. 2017). We used the annual CDLs from 2011 to 2017 to map the distribution of cropland in the Great Plains as follows. After constraining each layer to the boundaries of the Great Plains (see Fig. 1), we generated a layer with all cropland types (excluding grassland, grass-based pasture, and hay) in one class and all noncropland as a second class for each of the 7 yr. For each pixel, we calculated the number of years (out of 7) that it was classified as cropland. Pixels classified as cropland for $\geq$ 2 yr were classified as cropland in our final 7-yr integrated CDL layer (iCDL). This procedure eliminated pixels that likely were misclassified in 1 yr due to factors such as variable phenology of grasslands but still retained pixels with crop rotations that may result in classification as noncropland in some years. As a final step, we applied a minimum area filter, where any contiguous cluster of $\leq$ 10 cropland pixels (i.e., 0.9 ha) was reclassified as noncropland. This step was important for screening out small strips of productive grassland along pond edges or lowlands that were misclassified in the CDL as cropland, common in certain landscapes such as the Sandhills of Nebraska. Note that our approach seeks to quantify the amount and distribution of all grasslands, regardless of whether or not they have a history of being plowed and then restored, and hence differ from the approach of Olimb et al. (2018) and the Plowprint Report produced by the World Wildlife Fund (2019).

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Table 1
Estimated extent of 5 major ecoregions of the US Great Plains, subdivided into 14 vegetation communities as mapped by Kuchler (1964; see Fig. 1). For each community, we present the estimated percent of the landscape in each of 10 land cover types based on an integration of cropland data layers (2011–2017) with the 2011 National Land Cover Database (see Fig. 2).

	Potential natural vegetation (km^2)	Percent of potential natural vegetation occurring as:								
		Cropland	Forest	Water	Developed	Barren	Grassland	Shrubland	Pasture/ Hay	Developed open space	Uncertain grass/crop
Tallgrass prairie types										
Bluestem Prairie	259 802	68.5	3.5	1.7	1.4	0.0	14.1	0.0	2.8	4.2	3.8
Bluestem Savanna Mosaic	186 969	11.0	21.4	1.7	3.3	0.2	41.3	5.1	8.1	5.6	2.3
Blackland and Cross Timbers Prairie	83 275	9.1	1.1	1.1	0.2	0.1	86.5	0.0	0.3	0.9	0.7
Juniper/Oak and Oak Savanna	31 581	58.8	10.9	0.8	3.7	0.1	4.0	0.2	13.6	4.2	3.7
Nebraska Sandhills	58 439	29.4	16.2	3.2	1.3	0.1	24.2	13.1	3.6	4.6	4.3
Northern mixed-grass types										
Grama/Needlegrass/Wheatgrass	202 299	22.4	4.3	0.4	0.2	0.3	53.9	14.7	0.2	0.8	2.7
Needlegrass/Wheatgrass	246 531	32.5	2.0	1.5	0.4	0.9	53.2	4.4	1.2	1.9	2.0
Bluestem/Needlegrass/Wheatgrass	134 408	62.7	1.4	2.0	0.6	0.0	23.6	0.0	3.7	3.4	2.6
Southern mixed-grass types										
Bluestem/Grama	150 323	46.4	2.6	0.8	1.2	0.1	37.4	3.1	0.5	3.5	4.3
Sandsage/Bluestem	42 569	35.9	1.1	0.6	0.5	0.2	49.5	4.2	0.9	3.2	4.0
Shinnery	22 061	5.8	0.9	0.3	0.6	0.3	48.7	40.8	0.0	1.5	1.1
Shortgrass steppe										
Grama/Buffalograss	299 951	34.9	1.1	0.2	1.2	0.1	46.8	9.5	0.5	2.7	3.2
Desert savanna										
Mesquite/Buffalograss	68 800	23.6	2.8	0.4	0.7	0.4	20.4	47.2	0.1	3.1	1.3
Mesquite savanna	10 578	7.9	2.8	0.3	0.9	0.0	7.7	76.8	0.0	3.3	0.2
Total	1 797 586	40.6	4.4	1.0	1.2	0.2	36.3	7.5	2.9	3.0	3.0

We merged the iCDL layer with the 2011 NLCD, using NLCD to classify all "noncropland" pixels in the iCDL layer into one of nine land cover types (Table 1): 1) Forest (a combination of Deciduous, Evergreen, and Mixed Forest and Wooded Wetlands); 2) Open Water; 3) Developed Land (a combination of Low-, Medium-, and High-Intensity Developed land from NLCD); 4) Barren Land; 5) Grassland; 6) Shrubland; 7) Improved Pasture/Hay; 8) Developed Open Space (primarily rural roads); and 9) Uncertain Grass/Cropland (hereafter UGC). The UGC category consisted of lands classified as cropland in the NLCD, but as noncropland in the iCDL, and represented 3% of the total area of the Great Plains (Table 1). Given the more contemporary methods used to create the 2011–2017 CDLs, as well as their reliance on methods designed to specifically identify croplands, the UGC category likely represents lands misclassified as cropland by NLCD, including productive and/or restored grasslands, such as lands enrolled in the CRP. We refer to this fusion of NLCD and iCDL as fNLCD-CDL.

We used the fNLCD-CDL product to analyze rangeland fragmentation in the Great Plains based on two sets of assumptions concerning which land cover categories constitute "rangelands" and which cover types fragment rangelands. For each analysis, we used the fNLCD-CDL to calculate the distance from each rangeland pixel to the nearest fragmenting land cover type, with all non-rangeland pixels set to a value of zero. We then calculated the total area within each of the 14 vegetation subregions (see Fig. 1) consisting of rangeland occurring at varying distances from fragmenting land cover types.

In the first analysis (the "best case scenario"), we assumed that 1) rangelands consist of grasslands, shrublands, improved pasture/hay, and the UGC category; 2) fragmenting land cover types consist of cropland, forest, and developed land; and 3) the remaining land cover types (developed open space, open water, and barren lands) are not rangeland but also do not fragment rangelands. In the second analysis (the "worst case scenario") we assumed that 1) rangelands consist only of grasslands and shrublands; 2) fragmenting land cover types consist of cropland, forest, developed land, developed open space, improved pasture/hay, and UGC; and 3) open water and barren lands are not rangeland but do not fragment rangelands. The "best case" scenario was intended to provide an index of current rangeland fragmentation for organisms that may be capable of inhabiting land cover types dominated by any type of grass and are not strongly impacted by rural roads (e.g., pronghorn antelope) and optimistically assumes that discrepancies in cropland mapping by NLCD versus iCDL represent primarily restored grassland (e.g., CRP fields) or simply grasslands misclassified as cropland. The "worst case" scenario is intended to provide an index of rangeland fragmentation for organisms that do not inhabit grasslands dominated by non-native plant species and pessimistically assumes the additional lands classified as cropland by NLCD are indeed croplands.

Results

The fNLCD-CDL product estimates that 43.7% of the Great Plains still consists of grasslands and shrublands, with the remainder consisting of 40.6% cropland, 4.4% forests, 3.0% UGC, 3.0% developed open space, 2.9% improved pasture or hay fields, 1.2% developed land, 1.0% water, and 0.2% barren land, with important regional and subregional variation in the extent of rangeland loss to cropland, forests, and developed land (Table 1; Fig. 2; maps accessible at https://gpsr.ars.usda.gov/greatplainslandcover/).

Tallgrass prairie vegetation types have undergone the most extensive losses, particularly in the bluestem prairie and oak savanna mosaic types, where only 4.2–14.1% remain as grassland and shrubland. As much as 46% of the blackland and cross timbers prairie types and 37.3% of juniper and oak savannas remain as grassland or shrubland. At the same time, these types are highly fragmented by a combination of cropland conversion and forest encroachment, with < 1% of their total area occurring > 800 m (0.5 mi) from fragmenting land cover types. Similarly, only 1% of original bluestem prairie and none of the bluestem savanna mosaic occurs > 800 m from fragmenting land cover. A notable amount (2.3–4.3%) of all tallgrass prairie types other than the Nebraska Sandhills is classified as cropland by NLCD but not by iCDL, suggesting much of this could be restored grasslands. These landscapes also contain the greatest amount of developed open

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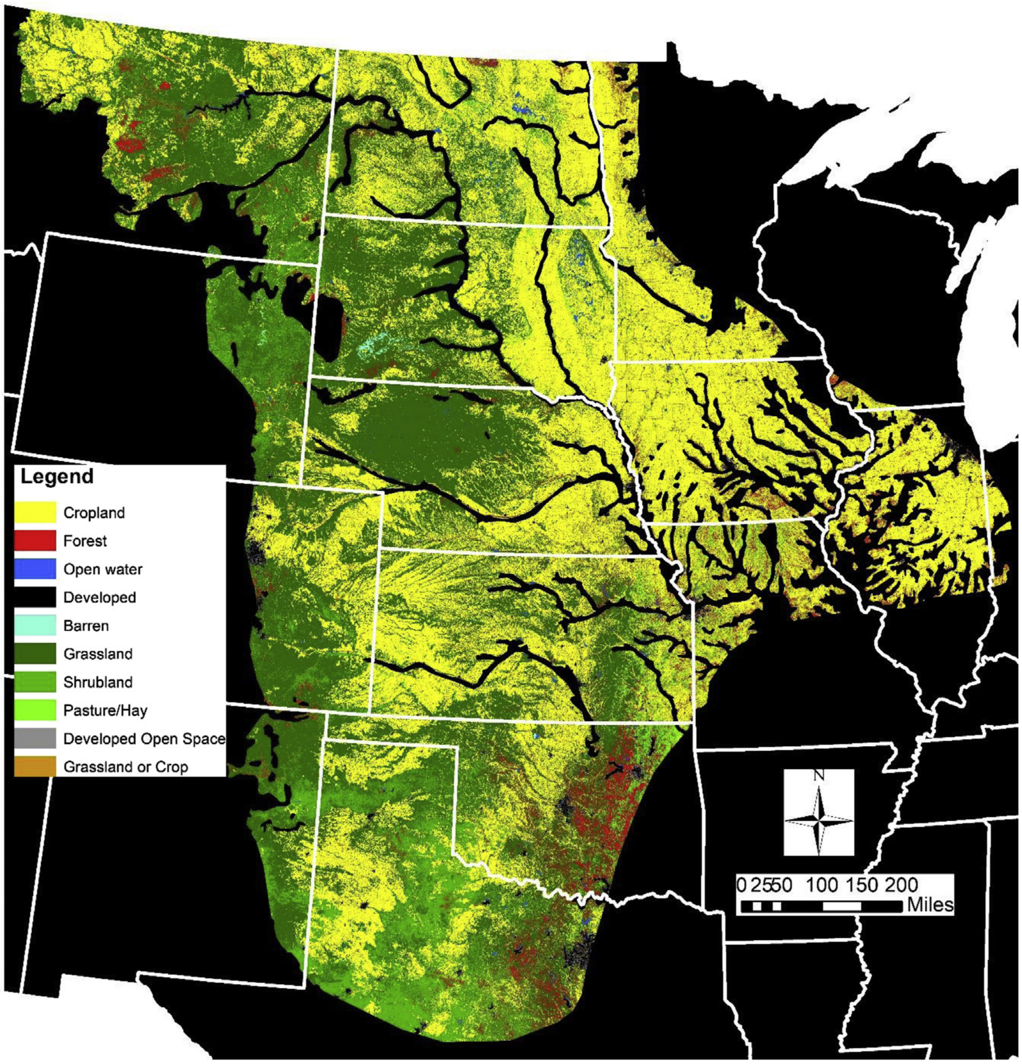

Figure 2. Land cover of the US portion of the North American Great Plains derived from a combination of the 2011 National Land Cov4.er Database (NLCD; Homer et al. 2015), and the 2011–2017 Cropland Data Layers (US Department of Agriculture–National Agricultural Statistics Service [NASS]). The orange cover type represents areas classified as non-cropland by NASS, but cropland by NLCD.

space, reflecting the dense network of rural roads. Outside of the Nebraska Sandhills, patches of contiguous rangeland that include areas > 1.6 km from a fragmenting cover type under the "best case" scenario are most widespread in the Flint Hills of Oklahoma and Kansas and in northeastern Oklahoma, with smaller and more isolated patches occurring in the counties of Archer, Clay, Jack, and Shackelford in Texas; Pontotoc and Murray in Oklahoma; Marshall, Roberts, and Grant in South Dakota; and Marshall in Minnesota. Portions of the Sheyenne National Grassland in Ransom County, North Dakota are > 800 m from fragmentation, but no part of this grassland was identified as > 1.6 km from fragmenting land uses, even under the "best case" scenario. In contrast to the remainder of the tallgrass prairie types, the Nebraska Sandhills are one of the least fragmented vegetation types within the entire Great Plains (Figs. 3–5). Portions of the southern and central Sandhills contain extensive, contiguous rangelands including areas > 6.4 km (4 mi) from any fragmenting land cover, and 50% of the entire region consists of rangelands > 800 m from any fragmenting land cover (Table 2; see Figs. 3–5).

In northern mixed prairie types, conversion to cropland has been especially severe in the eastern portion (bluestem/needlegrass/wheatgrass type), with only 23.6% (and potentially an additional 2.6%) in grassland (see Table 2 and Figs. 3–5) and only 1% occurring in patches > 800 m from fragmenting land cover. Encouragingly, at least 57.6% and 68.6% of the two more arid vegetation types remain in grassland (see Table 2), but only 11% of the needlegrass/wheatgrass type and 5% of the grama/needlegrass/wheatgrass types occur > 1.6 km from fragmenting land cover. Within these latter two vegetation types, the largest areas of contiguous rangelands in South Dakota are on and around Badlands National Park, Buffalo Gap National Grassland, and the Pine Ridge Indian Reservation; on the Cheyenne River Indian Reservation and adjacent private lands in Stanley County; and in Harding and Butte Counties north of the Black Hills. In Montana, contiguous mixed-grass rangelands > 1.6 km from fragmentation occur on intermingled private, state, and Bureau of Land Management (BLM)-administered lands across Phillips, Valley, Garfield, Rosebud, Custer, and Carter Counties. In Wyoming, contiguous rangelands > 1.6 km from fragmentation are most prevalent on and near the Thunder Basin National Grassland, plus extensive portions of Johnson, Campbell, and Converse Counties. The least fragmented mixed grass rangelands in North Dakota occur on and near the Little Missouri National Grassland and Theodore Roosevelt National

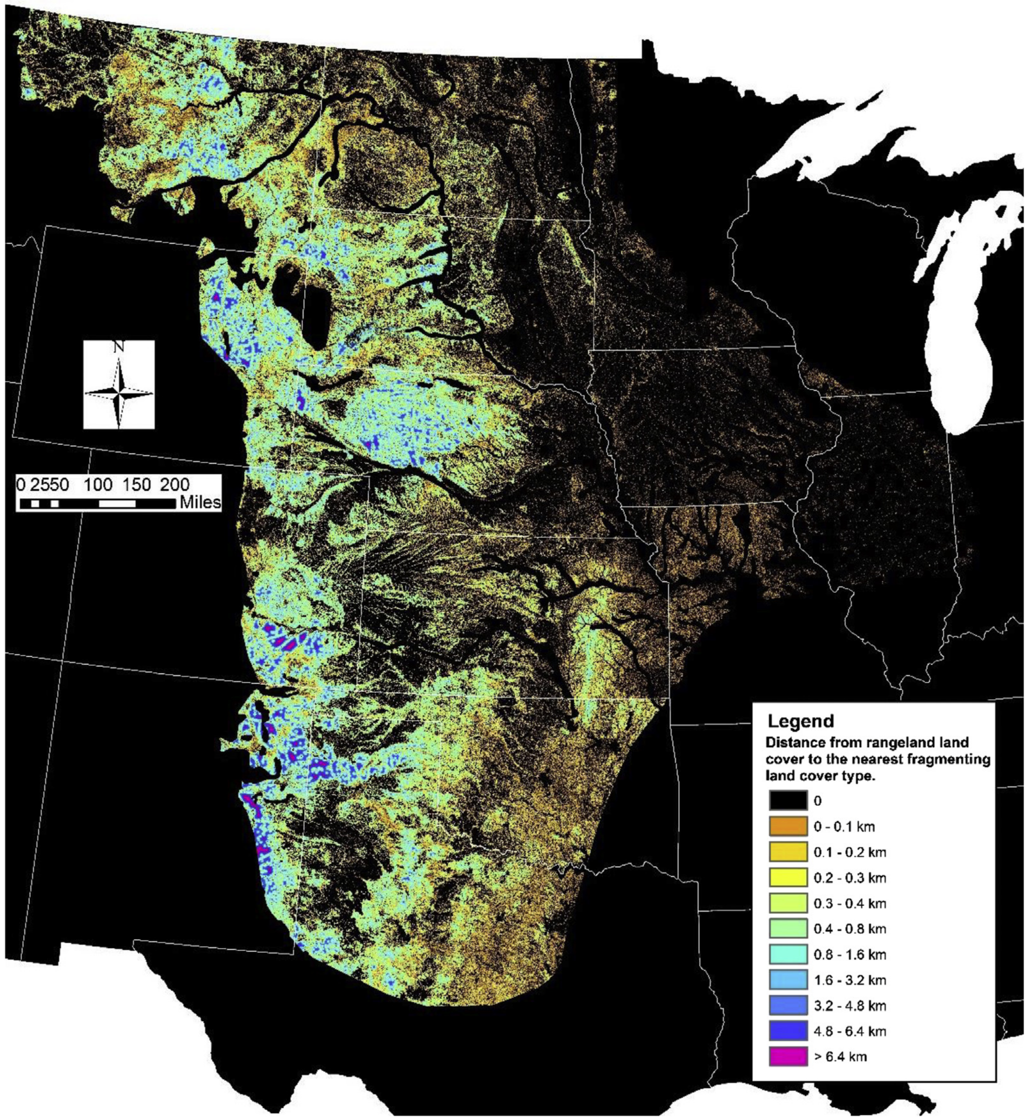

Figure 3. Variation in the degree of fragmentation of Great Plains measured in terms of distance to cropland, forest, or developed lands. This map depicts a "best case" scenario in which 1) croplands are mapped based only on the US Department of Agriculture—National Agricultural Statistics Service Cropland Data Layers (2011—2017), 2) all grass-dominated cover types including hay fields and improved pasture are considered rangelands, and 3) developed open space (as defined by the National Land Cover Database) are assumed to not be a fragmenting land cover type.

Park, but areas > 1.6 km from fragmenting land cover are relatively rare due to the prevalence of cropland near and forest within this landscape.

In the southern mixed prairie, > 40% of the bluestem/grama vegetation type is rangeland, but this region has been extensively fragmented by cropland and woody plant encroachment (see Figs. 3—5). Only 2% of the region occurs > 800 m from fragmenting land cover. Remaining contiguous rangeland within the bluestem/grama type is concentrated in south-central Kansas and on the border between Oklahoma and the Texas Panhandle, especially in Collingsworth County. We note that this region has been strongly affected by juniper encroachment (Scholtz et al. 2018), which our analysis does not fully capture because we included shrublands as rangeland, and only assessed woody encroachment via the development of forest. In contrast to the bluestem/grama region, extensive portions of the shinnery and sandsage/bluestem vegetation types persist as large, contiguous rangeland patches containing areas > 1.6 km from fragmenting land covers (see Figs. 3—4), due to sandy soils minimizing conversion to cropland. The shinnery type still retains 33% of the area as rangelands > 1.6 km from any fragmenting land cover, primarily along the Canadian River corridor in the Texas Panhandle. Large, contiguous areas of sandsage/bluestem occur on and around the Comanche National Grassland in southeast Colorado and across intermingled private and state lands in northeastern Colorado. In the mesquite savanna vegetation types, large patches of rangeland > 1.6 km from fragmentation (which comprise ~5% of the total landscape) occur primarily on privately owned lands in the western half of the region (see Figs. 2—4).

In the shortgrass steppe (grama/buffalograss type), at least 56% remains as rangeland, with 13% in areas > 1.6 km from fragmenting land cover. Large, unfragmented rangelands occur in southeastern Colorado, northeastern New Mexico, the western fringe of the shortgrass steppe in east-central New Mexico, and in Andrews County, Texas (see Figs. 2—4). Portions of these landscapes are associated with the Comanche, Kiowa, and Rita Blanca National Grasslands and BLM-administered lands in New Mexico, but most is privately owned. A smaller region of shortgrass rangeland

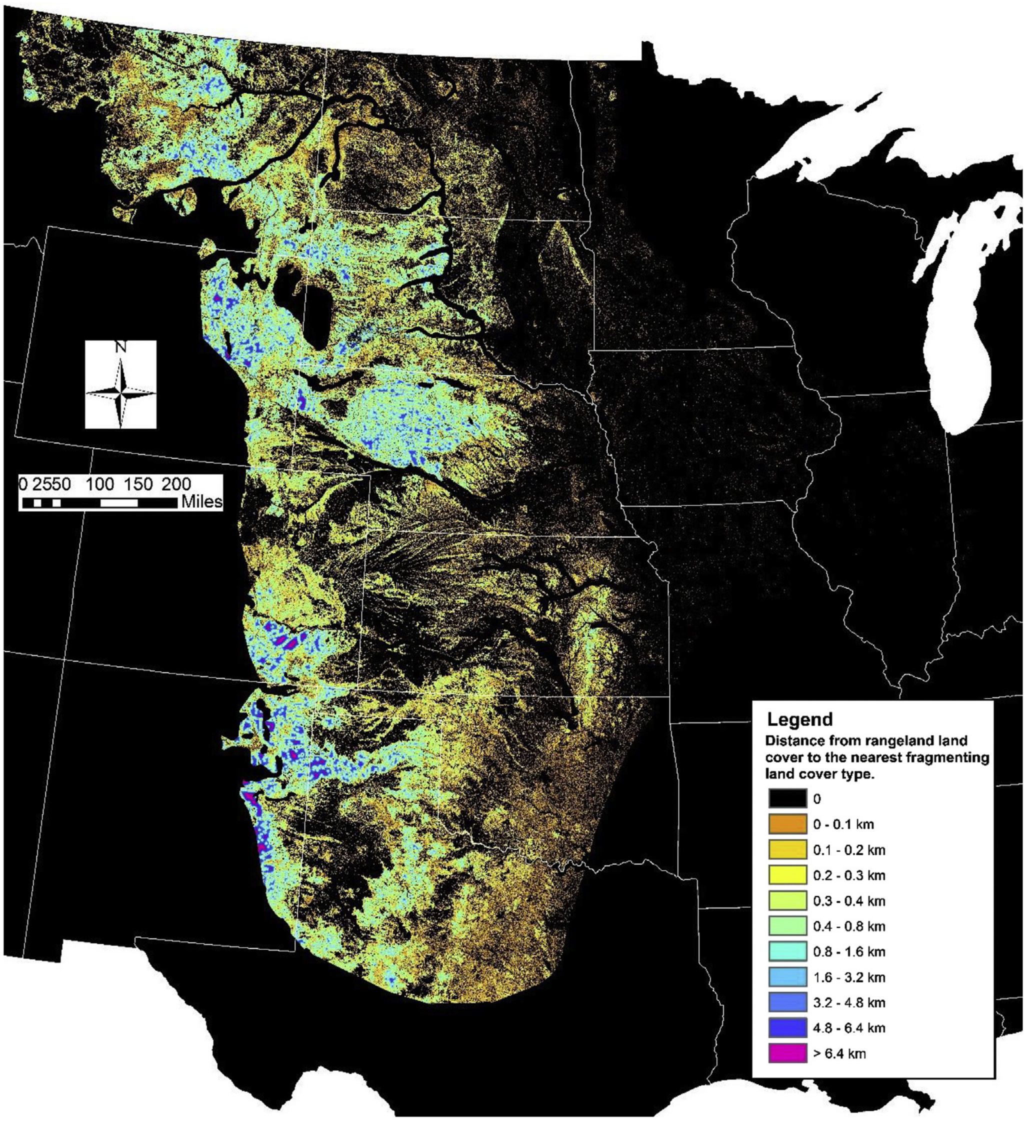

Figure 4. Variation in the degree of fragmentation of Great Plains measured in terms of distances to cropland, forest, or developed lands. This map depicts a 'worst case' scenario in which 1) croplands are mapped based on the US Department of Agriculture–National Agricultural Statistics Service Cropland Data Layers (2011–2017) and the 2011 National Land Cover Database (NLCD), 2) hay fields and improved pasture are not included as rangelands, and 3) developed open space (as defined by NLCD) is included as a fragmenting land cover type.

containing areas > 1.6 km from fragmentation occurs on and around the Pawnee National Grassland in Colorado and adjacent private lands surrounding Cheyenne, Wyoming.

The contrast between our "best case" and "worst case" scenarios was most notable in the tallgrass prairie (other than the Nebraska Sandhills), as well as in the bluestem/needlegrass/wheatgrass type of the northern mixed prairie, the bluestem/grama and sandsage/bluestem types of the southern mixed prairie, and in the shortgrass steppe (grama/buffalograss) (see Table 2). The estimated amount of rangeland in the tallgrass prairie types decreased by 7–17% when improved pasture and hay and UGC categories were excluded from the definition of rangeland, and the amount of rangeland > 800 m from fragmenting land cover declined by > 50%. The latter change was due to the inclusion of rural roads as a fragmenting land cover in the "worst case" scenario. Finally, the amount of shortgrass steppe as rangeland increased by 3.6% under the "best case" scenario, and the amount of rangeland > 800 m from fragmentation declined by a third (see Table 2).

In addition to the direct loss and fragmentation of rangelands by land conversion, the conservation of pattern and process in rangelands (sensu Fuhlendorf et al. 2012) is compromised by the complex land ownership patterns that characterize much of the region. Landownership boundaries within contiguous areas of rangelands can impede movements of both fire and grazers, via fences (Jakes et al. 2018) and via differences in management objectives and practices among landowners. A full quantification of these sources of fragmentation is beyond the scope of this paper, but we illustrate the complexity of land ownership patterns in Weld County, Colorado (Fig. 6), which is one of the largest counties in the western Great Plains and encompasses the Pawnee National Grassland. Although the majority of Weld County consists of large contiguous areas of rangeland (see Fig. 6a), these contiguous areas are characterized by a highly complex land ownership pattern, which affects wildlife populations. For example, black-tailed prairie dogs are controlled on the lands represented in black and on many of the private lands of varying colors in Figure 6b, whereas control

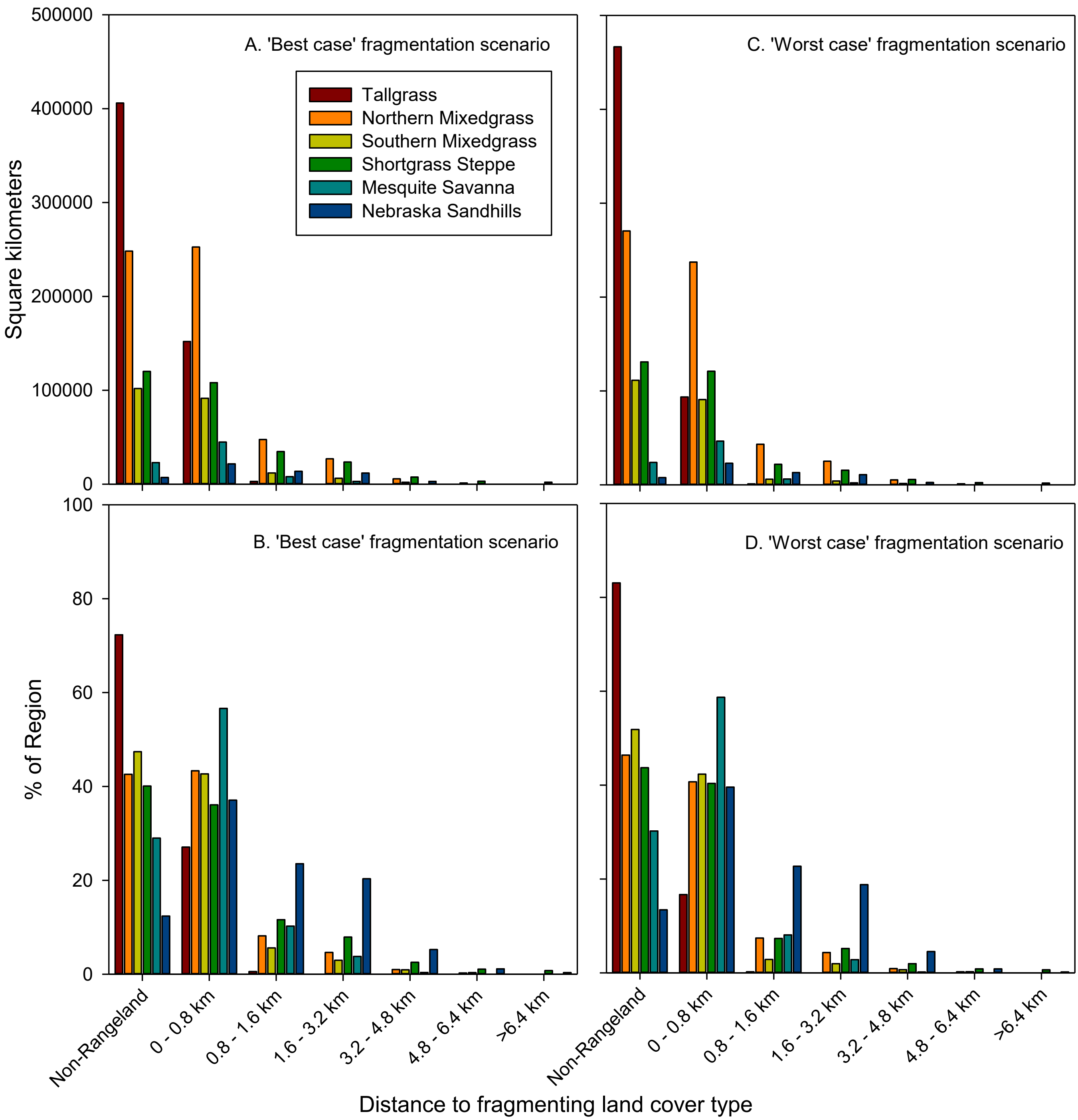

Figure 5. Variation in the degree of fragmentation of US Great Plains rangelands based on two different assumptions concerning which land cover types cause fragmentation. In both cases, we calculated the total area in each ecoregion within varying classes of distance to cropland, forest, or developed lands, but the two different scenarios made different assumptions about how croplands are mapped and which land cover types constitute "rangelands" (see Figs. 3 and 4 and methods for details).

is limited or prohibited on lands depicted in light blue (Pawnee National Grassland).

Discussion

Grassland Loss and Fragmentation

Previous analyses have reported on the extreme degree of grassland conversion in the Great Plains, particularly in the eastern ecoregions (e.g., 13.4% of the tallgrass prairie [excluding Nebraska's sandhills] remaining; Samson et al. 2004; see also Comer et al. 2018). These estimates expressed grassland loss in terms of "percent of historic vegetation remaining," where lands converted to cropland but then restored to grassland and lands managed as pasture or hay fields were considered to be converted grassland. Our analyses show substantially more grassland and shrubland remaining in many of these ecoregions. For example, we estimate that 35.1% of tallgrass prairie (excluding the Nebraska Sandhills) currently occurs as grassland or shrubland, and an additional 2.8% remains in the "uncertain grass or crop" category (see Table 1). At

Table 2
Percentage of total area in each of 14 major vegetation types in the US portion of the Great Plains (see Fig. 1) estimated to occur as nonrangeland or as rangeland of varying distances to a fragmenting land cover type (see Figs. 3 and 4). Numbers to the left of each slash symbol show results from a “best case” scenario (see Fig. 3), and numbers to the right of each slash symbol are the estimate from a “worst case” scenario (see Fig. 4), which made different assumptions about the definition of rangeland cover types and the definition of fragmenting land cover types (see methods).

Potential natural vegetation type	Percentage of area occurring as rangeland of varying distances to fragmenting land cover types						
	Nonrangeland	0.01-0.8 km	0.81-1.6 km	1.61-3.2 km	3.21-4.8 km	4.81-6.4 km	> 6.4 km
Tallgrass prairie							
Bluestem Prairie	79.3/85.9	19.8/13.7	0.8/0.3	0.2/0.1	0/0	0/0	0/0
Bluestem Savanna Mosaic	78.5/95.8	21.4/4.2	0.1/0	0/0	0/0	0/0	0/0
Blackland and Cross Timbers Prairie	43.2/53.6	55.9/46.1	0.8/0.2	0/0	0/0	0/0	0/0
Juniper/Oak and Oak Savanna	54.8/62.7	44.9/37.2	0.3/0.1	0/0	0/0	0/0	0/0
Nebraska Sandhills	12.4/13.4	37.1/39.5	23.5/22.7	20.3/18.8	5.2/4.5	1.1/0.9	0.3/0.2
Northern mixedgrass							
Grama/Needlegrass/Wheatgrass	28.5/31.4	47.6/46.1	13.0/12.2	8.3/7.9	2/1.8	0.5/0.5	0.1/0.1
Needlegrass/Wheatgrass	39.2/42.3	48.0/46.0	7.9/7.2	4.1/3.7	0.7/0.7	0.1/0.1	0/0
Bluestem/Needlegrass/Wheatgrass	70.1/76.4	28.4/22.9	1.3/0.6	0.2/0.1	0/0	0/0	0/0
Southern mixedgrass							
Bluestem/Grama	54.6/59.5	42.6/39.6	2.4/0.8	0.3/0.1	0/0	0/0	0/0
Sandsage/Bluestem	41.5/46.3	44.7/50.3	10/2.6	3.5/0.6	0.3/0.1	0.1/0	0/0
Shinnery	9.4/10.5	38.8/45.1	19/17.4	20/17.4	8.5/6.4	3.1/2.3	1.1/1
Shortgrass steppe							
Grama/Buffalograss	40.1/43.7	36.1/40.4	11.6/7.3	7.9/5.2	2.5/1.9	1.1/0.8	0.8/0.6
Mesquite savanna							
Mesquite/Buffalograss	31.1/32.5	55/57.1	10/7.8	3.6/2.6	0.3/0.1	0/0	0/0
Mesquite savanna	15.3/15.5	66.9/69.2	11.8/10	4.9/4.3	0.9/0.7	0.2/0.2	0/0

the same time, our fragmentation analysis for tallgrass prairie shows that aside from the Nebraska Sandhills, at most 0.2% of tallgrass prairie occurs in locations > 1 600 m (1 mi) from a fragmenting land cover type, similar to the conclusions based on minimum dynamic areas of remaining prairie (see Fig. 1 in Samson et al. 2004). Thus, our land cover analyses (see Tables 1 and 2) reveal that more of the eastern Great Plains remains in rangeland cover than previously thought, but that remaining rangelands still predominantly occur in small, highly fragmented patches that likely contain substantially altered plant species composition relative to the historic condition. Fragmentation of this magnitude clearly has the potential to alter movements and metapopulation dynamics of a broad range of fauna in the region. Linking these patterns more directly to the ecology of specific species will require more detailed analyses of specific regions and landscape than we can provide here, but our land cover and fragmentation results are available to support such efforts (https://gpsr.ars.usda.gov/greatplainslandcover/). At broader spatial scales, we emphasize that even in the western Great Plains, where > 50% of the mixed-grass, shortgrass, and mesquite savanna regions persist as rangeland, the spatial distribution of rangelands is still highly fragmented. In both northern and southern mixed grass, < 6% of the

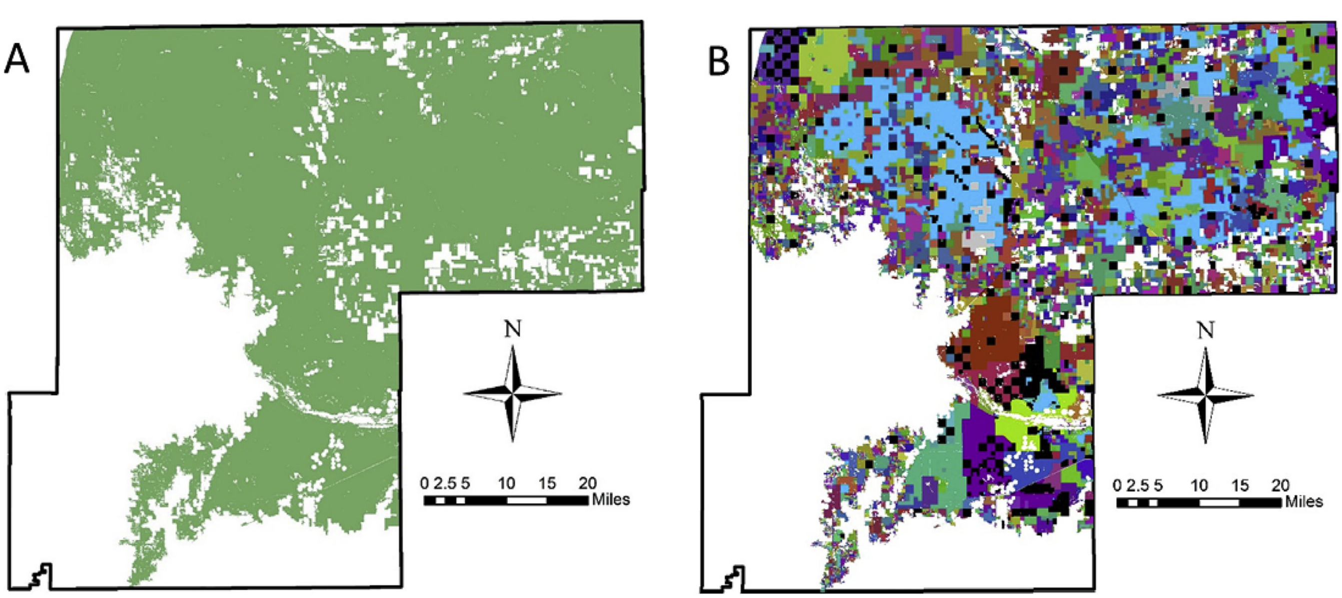

Figure 6. The distribution of large, contiguous areas of rangeland in Weld County, Colorado when viewed as a single land cover type (*green polygons* in map A) or when viewed in terms of individual landowners (*polygons of varying colors* in map B). In map B, each color represents a different landowner, where *light blue* represents federal ownership (Pawnee National Grassland) and *black* represents lands owned by the state of Colorado. Although the northeastern portion of Weld County appears to contain the largest contiguous block of rangeland, this portion of the county contains a complex mosaic of landowners. In contrast, some of the largest contiguous blocks of rangeland under a single ownership are located in the northwestern and southcentral portion of the county. Land ownership patterns are a potential additional source of fragmentation for some native species. For example, black-tailed prairie dogs are controlled on the lands represented in *black* and on many of the private lands of varying colors, whereas lands depicted in *light blue* are managed in the opposite manner.

Table 3
Amount and percentage of area of each of 9 National Grasslands occurring > 800 m (0.5 mile) from a property boundary.

National grassland	State	Total area (ha)	Area (ha) > 800 m from property boundary	% of Area > 800 m from property boundary
Buffalo Gap	SD	265 102	98 007	37.0
Little Missouri	ND	451 319	142 859	31.7
Sheyenne	ND	33 200	8 554	25.8
Thunder Basin	WY	224 005	56 023	25.0
Rita Blanca	OK/TX	38 119	8 900	23.3
Comanche	CO	179 662	38 160	21.2
Grand River	SD	75 800	15 174	20.0
Pawnee	CO	77 954	9 468	12.1
Black Kettle	OK	13 464	46	0.3

entire landscape consists of rangeland > 1.6 km (1 mi) from a fragmenting land cover type. Only in the shortgrass steppe and Nebraska Sandhills do we begin to identify some larger, contiguous rangeland landscapes, with 12% and 27% of the region > 1.6 km from fragmenting land cover, respectively. These findings indicate that efforts to restore rangelands in a manner that enhances native plant diversity and does so in a spatial context that enhances connectivity among conserved and restored rangelands are central to conserving Great Plains biodiversity.

Differences between the results of our “best case” versus “worst case” scenario analyses also support this conclusion. For example, the estimated total extent of rangeland in the bluestem/needle/wheatgrass, bluestem/grama, and sandsage/bluestem vegetation types declined by 6.3%, 4.8%, and 4.9%, respectively, under our worst relative to best case scenarios. Furthermore, in all three aforementioned vegetation types, the amount of rangeland > 800 m from fragmentation was more than halved under the worst relative to best case scenario. These results indicate that the inclusion of the UGC category, which likely includes CRP and other restored grasslands, in the definition of “rangeland” substantially reduced fragmentation, such that both the amount and spatial location of restoration efforts are important in reconnecting existing rangelands. In addition, we note that improvements in remote sensing and ground-based mapping of rangeland composition and conservation value could reveal new opportunities to enhance landscape connectivity. Hereafter, we highlight several potential opportunities to reverse the pattern of rangeland loss and fragmentation illustrated in Figures 2 and 3.

Opportunities: Stitching Grasslands Back Together

Incentive Programs to Restore Grasslands and Native Wildlife

The CRP, signed into law as part of the Food Security Act of 1985, is the largest voluntary, private-lands conservation program in the United States and represents a key mechanism for grassland restoration in the Great Plains. CRP enrollment in the Great Plains reached a peak of 10.6 million ha (26.3 million acres, or 5.5% of the Great Plains) in 2007 and has since declined annually, with 6.7 million ha (16.5 million ac; 3.2%) of the Great Plains enrolled in 2017. Although we have not conducted a spatial analysis, the 3.2–4.5% of the Great Plains enrolled in CRP over the past decade likely comprises much of the area mapped as “uncertain grassland or cropland” by the fNLCD-CDL product (see Table 1) and likely contributes to the substantial difference in degree of rangeland fragmentation quantified by our best case versus worst case scenarios (see Table 2 and Figs. 3–4).

Over time, the focus of CRP has shifted from primarily a soil erosion and land retirement program to one that targets a combination of water quality improvement, soil erosion prevention, and wildlife habitat improvement on environmentally sensitive agricultural lands, via enrollment in a ten- or fifteen-year contract. The early days of CRP saw 9.4 million ha (23.2 million ac) enrolled in the Great Plains by 1990, most planted to grass monocultures, often using non-native grass species whose seeds could establish quickly and were inexpensive. Furthermore, these grasslands remained ungrazed and unburned in most years, in part due to the program’s focus on prevention of soil erosion, thereby suppressing the historic disturbance regime and limiting the value of CRP grasslands to native wildlife (King and Savidge 1995; McCoy et al. 1999).

Importantly, 46 different practices are now eligible for application to lands enrolled in either a general (competitive enrollment) or continuous (noncompetitive) signup nationwide, with priority being placed on the types that offer the highest diversity of native grasses, forbs, and shrubs. As of July 2018, 5.6 million ha (14.0 million acres) nationwide were enrolled in general CRP and an additional 3.3 million ha (8.1 million acres) were enrolled in continuous and other targeted contracts, with most of these acres being in the Great Plains. Thus, CRP practices have substantial potential to influence patch size and connectivity of rangeland habitats.

Recognizing opportunities for improvement to biodiversity, the CRP program later placed priority on enrollment offers that targeted establishing or improving stand diversity. Midcontract management practices (disturbance, such as high-intensity grazing, prescribed fire, or tillage, often followed by interseeding additional grass and/or forb species) were originally optional but have now become required practices. Such management can shift low-diversity CRP stands toward more diverse grasslands and enhance opportunities for grazing and fire to become functional processes within CRP grasslands. Unfortunately, the types of practices applied and the frequency of midcontract management varies substantially from state to state and often does not include prescribed burning (FSA 2018a). We suggest that a major opportunity for increased conservation of pattern, process, and biodiversity is the broader incorporation of fire and grazing into midcontract CRP management in all Great Plains states.

Another underused opportunity is transitioning of lands enrolled in CRP to working rangelands that will not be recultivated when CRP contracts expire. One recent advance is the CRP Grasslands signup opportunity, authorized by the 2014 Farm Bill, which allows landowners and operators to protect grassland, including rangeland and pastureland, while maintaining the areas as working lands through 14- or 15-yr contracts (FSA 2018b). CRP Grasslands emphasizes support for grazing operations to maintain and/or improve plant and animal biodiversity. Participants retain the right to conduct common grazing and haying practices within the parameters set forth in the conservation plan developed with assistance from NRCS. CRP lands with contracts nearing expiration are targeted for enrollment, and cost share is available for infrastructure such as fencing and water development to maintain the grass cover, which aids in incorporating these lands into a grazing program.

One example of an advance in grassland landscape restoration comes from a grass-roots effort, Preserving CRP Grassland Benefits in Western Nebraska, which could serve as a model for broader application in the Great Plains. This locally led effort sought to convert lands expiring from CRP in the early 2010s into grazed grasslands. At the time, 106 800 of the 154 600 ha of CRP in the Nebraska Panhandle were set to expire between 2009 and 2012, with no option for CRP contract renewal. Recognizing the threat that these lands could revert to cultivated cropland, the three Natural Resource Districts (NRDs) in the Panhandle, the Natural Resources Conservation Service (NRCS), the Nebraska Game and Parks Commission (NGPC), and several other conservation entities developed a partnership to promote the maintenance of expiring CRP as grassland using livestock grazing. Cost-share incentives for grazing infrastructure and education on grazing management were components. A Nebraska Environmental Trust Fund Grant was secured to help with these efforts. Even though CRP enrollment was reauthorized during the project, 8 321 ha (on 102 different projects) benefitted over a 6-yr period as producers chose to convert them to working grasslands rather than entering into another CRP contract.

The Lesser Prairie-Chicken is one species that has benefitted dramatically from CRP grasslands. One key to this success was the spatial targeting of CRP enrollments with appropriate vegetation diversity in counties with both existing Prairie-Chicken habitat and populations and where CRP could enhance connectivity and size of grassland patches (Spencer et al. 2017; Sullins et al. 2018). Recent work shows that annual survival of Prairie-Chickens is greater in landscapes with larger grassland patch size and greater patch richness, as well as in portions of those landscapes farther from fences (Robinson et al. 2018). Given that new enrollment of lands into the CRP program is limited, targeting enrollment in locations that increase grassland patch size is important (Robinson et al. 2018). In addition, as discussed by Spencer et al. (2017) “one approach to retain CRP fields as grassland, but in the face of reduced CRP contract enrollment, is to retain the primary land use of these as working grasslands (NRCS 2016).” The use of the Environmental Quality Incentives Program (EQIP) to share the costs of necessary infrastructure such as boundary fencing and water sources can enhance the conversion of these lands to working grasslands (NRCS 2016), while also recognizing the need to consider the potential effects of fencing density and type on wildlife (Patten et al. 2005; Jakes et al. 2018; Robinson et al. 2018). Similar efforts facilitated by nongovernmental organizations that address other grassland-breeding birds (e.g., Ducks Unlimited) enhance these types of transitions. Habitat modeling for other grassland birds can also help guide the selection of localities where transitions of CRP to working grassland should be emphasized (e.g., Lipsey et al. 2015; Niemuth et al. 2017). For example, spatial targeting of CRP enrollment in landscapes with existing tallgrass prairie can enhance habitat and abundance of Henslow’s sparrow, another grassland bird of conservation concern (Herse et al. 2017).

Another innovative application of the EQIP program is the NRCS Black-Footed Ferret Special Effort, which provided technical assistance and direct financial support to ranchers who agree to manage a portion of their land to maintain BTPD populations and allow the reintroduction of black-footed ferrets (BFFs). The program’s goal was to promote voluntary, incentive-based conservation of these species on private and tribal lands. This program was particularly valuable in that it changed the management objectives (and associated practices) on a property, without necessarily adding fragmenting infrastructure such as fencing. A key limitation is uncertainty in how to maintain contracts over longer time scales than a single contract. To the extent that such programs can be implemented across multiple adjacent landowners, or with landowners adjacent to other lands managed for prairie dog conservation, there is great potential to increase the size of grassland patches managed in a common framework. Continued modifications that allow the CRP and EQIP programs to address landscape-scale habitat needs of Great Plains fauna are needed, particularly through spatial targeting of key locations or landscapes in order to link together existing grasslands, rather than simply addressing field- or pasture-scale soil and water conservation.

Landownership Patterns and Cross-Boundary Management

The complexity of the land ownership pattern displayed for grasslands in Weld County, Colorado (see Fig. 6) is typical of many Great Plains counties. The coordination of management objectives across property boundaries and reductions in the ratio of boundary length to the area of properties managed for biodiversity conservation will clearly enhance the capacity for grazers and fire to move across broader landscapes and interact with the inherent variability in soils, topography, and weather patterns. Most public lands within the Great Plains currently occur in highly fragmented spatial patterns. For example, analysis of boundary patterns in nine National Grasslands managed by the US Department of Agriculture—Forest Service extending from North Dakota to New Mexico shows that only two (Buffalo Gap and Little Missouri National Grasslands) have > 30% of their land base occurring in areas > 800 m (0.5 mi) from a National Forest System property boundary (Table 3). This land ownership pattern creates major challenges for the conservation of controversial species such as BTPDs and mobile species such as elk, for which adjacent private and state lands can have nearly opposite management objectives.

Boundary management for BTPDs can be an especially significant source of conflict, as their colonies can frequently expand across distances of 800 m in 1–2 yr (Augustine et al. 2008), and management options to prevent such movement can be expensive and contentious (Luce et al. 2006; Miller et al. 2007). It is notable that the Buffalo Gap National Grassland currently has the greatest proportion of its land base occurring in contiguous blocks of grassland distant from property boundaries (see Table 3). This resulted from a program to conduct land exchanges (i.e., exchanges of National Forest System and private land of equal value) to reduce boundary complexity over the past 2 decades. This effort, combined with portions of Buffalo Gap National Gap occurring adjacent to the Badlands National Park and the Pine Ridge Indian Reservation, has facilitated the recovery of BTPD in this landscape and supports the most successful BFF reintroduction site in the Great Plains (US Fish and Wildlife Service 2013). Similarly, lands originally granted from the federal government to the states upon their creation were in the form of two sections (2.56 km^2 properties) within each township of the Great Plains, creating a fragmented state land ownership pattern. Ongoing efforts to conduct land exchanges in states such as Colorado have enhanced the development of landscape-scale Stewardship Action Plans for many properties and allowed for creation of Stewardship Trust Lands that are subject to a higher standard of care, planning, and management by both the State Land Board and lessees. Such plans and trust lands address habitat needs of species of conservation concern and enhance livestock and native grazer movement, as well as metapopulation dynamics of sedentary species, at spatial scales far larger than the original 2.56 km^2 properties.

Finally, the vast majority of Great Plains grasslands are privately owned and managed by people who care deeply about conservation of the land but also need to make a living. Managers of private rangelands often acknowledge the importance of wildlife conservation but place this as a far lower priority than livestock production (Kachergis et al. 2014; Sliwinski et al. 2018). Engaging these people to manage disturbance regimes at larger spatial scales will require acknowledging that domestic livestock grazing can function as an essential rather than a degrading component of Great Plains disturbance regimes. Programs and strategies to enhance livestock movement at greater spatial scales and increase spatio-temporal variability in grazing intensity can enhance contributions to wildlife conservation (Fuhlendorf et al. 2006; Derner et al. 2009; Toombs et al. 2010). Purchases of contiguous rangelands by nongovernmental organizations and/or establishment of conservation easements to consolidate private properties and connect existing public lands has also made important contributions to the conservation of native grazers (and in some cases increased utilization of prescribed fire) and has increased notably in use and scale nationwide over the past decade (Owley and Rissman 2016).

The need to coordinate management objectives and practices across property boundaries and jurisdictions to conserve Great Plains fauna has been recognized by many authors, organizations, managers, and agencies (e.g., Samson and Knopf 2004; Fuhlendorf et al. 2012; NRCS 2016). Yet cross-jurisdictional management remains a major challenge within a region that is predominantly private land intermingled with public lands managed by 11 states, 3 provinces, > 1 000 counties and administrative divisions, and at least 4 different federal agencies in the United States alone. Samson and Knopf (2004) proposed that establishment of more meaningful state and federal agency designs is necessary to advance Great Plains grassland conservation. In particular, they suggested that consolidation or realignment of federal agencies and improved state-federal collaboration would reduce conflicting approaches to species conservation and enhance conservation cost-effectiveness. Progress in this regard has been limited over the past 15 yr, but the history of efforts to conserve the Lesser Prairie-Chicken in the southern Great Plains suggests some opportunities to advance cross-boundary management efforts. In some cases, even small nature reserves or other public lands, when managed in a manner that includes effective outreach and interactions with surrounding private landowners, can serve as catalysts for landscape-scale conservation and directly enhance wildlife conservation (Miller et al. 2012). Success in such efforts relies on application of novel advances in the science and practice of engaging landowners. Outright purchase of private ranches and conversion to conservation-oriented operations can in some cases also produce valuable outcomes for wildlife conservation that include increasing the scale and pattern of grazing by both livestock and bison (e.g., Kohl et al. 2013), but such efforts will be enhanced where they are linked with an understanding of current economic, political, and cultural issues within the landscape (Miller et al. 2012; Davenport 2018).

The need for cross-boundary management frameworks in the Great Plains was formally recognized > 20 yr ago, when in 1997 the US Fish and Wildlife Service (USFWS) announced an initiative called the *High Plains Partnership for Species at Risk* (HPP). This initiative encouraged landowners, agricultural organizations, and conservation groups in actions to benefit the Lesser Prairie-Chicken and other declining wildlife species in the southern Great Plains. The initiative was born out of the five state wildlife agencies forming the Lesser Prairie-Chicken Interstate Working Group (LPCIWG), which developed a region-wide conservation strategy for this species and many other species associated with LPC habitat. The group worked with the Great Plains Partnership of the Western Governors' Association and received funding from the National Fish and Wildlife Foundation to coordinate a partnership of diverse stakeholders to advance region-wide, proactive, voluntary solutions to the decline of the Lesser Prairie-Chicken. The Initiative identified measures that would benefit the Lesser Prairie-Chicken and promote voluntary participation in habitat restoration projects, including a series of demonstration projects in Lesser Prairie-Chicken range, technical and financial assistance to landowners for habitat restoration and improvement projects, and research into the relationship between Lesser Prairie-Chicken habitat needs and range management practices.

From 1998 to 2003, momentum for this effort grew. Letters to the USFWS Director at the time highlighted the accomplishments, which included > 36 000 ha of conservation efforts across the five states within the range of the Lesser Prairie-Chicken. While initial efforts demonstrated interest by a broad spectrum of stakeholders, it lacked participation from the energy development and delivery sectors and eventually dissolved due to a lack of dedicated funding. Although conservation opportunities were directed at landowners, proponents did not engage with oil and gas companies, rural electrical cooperatives, and wind-power companies. Another limitation of the initiative was to clearly demonstrate how the funds invested would mitigate the need to list the Lesser Prairie-Chicken under the Endangered Species Act. Proponents did not present a strategic conservation plan that would clearly allow for other economically important industries to continue across the landscape and contribute to the conservation of the species. Finally, promotional materials about the effort displayed the action area as being the entire Great Plains, giving the impression that local actions would have minimal contribution to initiative goals while potentially restricting developmental activities.

Over the next decade, the LPCIWG transitioned from collecting information on Lesser Prairie-Chicken ecology, as it had done during the HPP, to evaluating conservation actions benefitting Lesser Prairie-Chickens. This ultimately led to the Lesser Prairie-Chicken Range-wide Conservation Plan (LPCRWP; Van Pelt et al. 2013) developed by the LPCIWG and collaborators, which incorporated several lessons from the HPP experience. One important modification was to evaluate the location and juxtaposition of potential habitat, with the intent that restoration would be implemented in the same habitat types being impacted by management or development activities and would enhance habitat connectivity. Also, measures were developed to ensure the quality of the habitat being managed or restored was equal to or better than the area being impacted. Finally, the LCPRWP conservation effort was depicted visually using the Western Association of Fish and Wildlife Agencies' Crucial Habitat Assessment Tool (CHAT), allowing land managers to target their activities and visualize the contribution to the broader landscape. Finally, there was recognition for the need for a shifting mosaic of grassland conservation efforts across the landscape to address changing precipitation patterns and prolonged droughts, instead of focusing investments on permanently protected areas, which could become unsuitable with changing climate. We suggest that efforts to restore working rangelands in portions of the Great Plains outside the LPC range be spatially targeted in a similar manner and use visualization tools that enhance communication of broader, landscape-scale conditions, and goals among agencies, landowners, businesses, and the public. The development of rangewide plans with similarly associated institutions as the LPCRWP for species such as BTPD and other prairie grouse (Greater Prairie-Chicken, Sharp-Tailed Grouse, and Greater Sage-Grouse) would be one potential means to enhance collaboration and coordination of grassland restoration in the remainder of the Great Plains. Consistent funding sources and commitments at federal, state, and local levels may help ensure such plans and institutions do not follow the fate of the HPP.

Management Implications

Across the Great Plains, conservation of native fauna is constrained by the loss and fragmentation of rangelands, as well as the limited spatial scales over which fire and fauna can move, interact, and influence Great Plains vegetation. Here, we quantified contemporary patterns of rangeland patch size and fragmentation across all the major historic grassland, shrubland, and savanna vegetation types in the US portion of the Great Plains (https://doi.org/10.1016/j.rama.2019.09.001). Our maps and analyses identify significant opportunities for landscape-scale conservation and restoration in the western half of the Great Plains. Continued restoration of marginal croplands to grassland, in spite of declining opportunities for enrolling lands in CRP, will depend on expanding innovative programs that transition existing CRP to working rangelands, managed with grazing and fire to support enhanced plant and habitat diversity. Most public land in the Great Plains remains highly fragmented and intermingled with private lands that often have conflicting goals for biodiversity conservation. Coordination of management objectives across broader landscapes, as has occurred in South Dakota on portions of Buffalo Gap National Grassland adjacent to the Badlands National Park and the Pine Ridge Reservation, is critically needed in additional portions of the Great Plains to facilitate conservation of the full suite of native grazers, including prairie dogs and their associated species. In addition, our land cover analyses identify many key areas of contiguous rangeland in predominantly private ownership, where conservation may be enhanced through voluntary incentive programs that provide compensation for harboring species or creating habitats that conflict with traditional livestock production objectives. The development of adequately funded institutions to facilitate cross-boundary management and restoration within broad landscapes could rely on lessons learned in the ongoing efforts to conserve landscapes for the Lesser Prairie-Chicken. All of these efforts rely on accelerating the slow but ongoing shift from thinking about and managing grasslands at the scale of individual pastures to focusing restoration and conservation efforts at the scale of dynamic grassland landscapes.

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Appendix A. Supplementary data

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TURNOVER RATES IN INSULAR BIOGEOGRAPHY: EFFECT OF IMMIGRATION ON EXTINCTION[1]

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Abstract. Demographic and genetic contributions from conspecific immigrants tend to reduce extinction rates of insular populations. The MacArthur-Wilson model of island biogeography is modified to provide for this effect of immigration on extinction, which we call the rescue effect. This new model predicts that when immigration rates are high relative to extinction rates, turnover rate is directly related to the distance between an island and the source of colonizing species. A field study of the distribution of arthropods among isolated plants supports the model.

Key words: Arizona; biogeography; colonization; extinction; insular biogeography; island; turnover.

INTRODUCTION

More than a decade ago MacArthur and Wilson (1963, 1967; *see also* Preston 1962) proposed a general model of insular biogeography. This model represents the number of species inhabiting an island as a dynamic equilibrium between opposing rates of extinction and colonization, which are functions of the size of the island and its distance from a source of dispersing species, respectively (Fig. 1). The model is attractive because it is elegantly simple and generates several robust predictions which can be tested with appropriate field observations and experiments. There have been numerous attempts to test the model and to use it to account for the distribution of diverse organisms among islands and insular habitats. Although some distributions that do not conform to the predictions have been reported (e.g. Barbour and Brown 1974; Brown 1971; Culver et al. 1973; Diamond 1972, 1973; Simpson 1974; Terborgh 1975), the majority of empirical analyses have supported the model. Thus Simberloff (1974) in a recent review stated "...the equilibrium hypothesis has been experimentally confirmed for oceanic islands, proved useful for interpreting many other insular situations, and spawned a mass of research which has given biogeography general laws of both didactic and predictive power."

The primary innovation of the MacArthur-Wilson (M-W) model was the suggestion that recurrent colonizations and extinctions create a dynamic equilibrium in which the number of species remains relatively constant while the identity of species varies over time. The model predicts that species are replaced at a rate inversely related to both island size and distance to a source of colonists (Fig. 1). Species turnover on islands has been reported (Diamond 1969; Simberloff 1976; Simberloff and Wilson 1969, 1970; Terborgh and Faaborg 1973; however, *see* Lynch and Johnson 1974, for a critique of the first and last papers), but the predicted relationship between turnover rate and island size and isolation has not been observed empirically. A rigorous test of these predictions is essential to support the M-W model, because a simple, intuitively attractive modification of the model predicts that turnover rate often will be directly related to insular isolation.

AN ALTERNATIVE MODEL

The M-W model represents extinction rate as a function of island size and colonization as a function of insular isolation; the interaction of these two independent and opposing rates determines the equilibrium number of species and turnover rate (Fig. 1). Realistically, however, the same parameters that affect colonization rate (e.g., proximity to a continent or other source of dispersing species) also similarly affect the rate of immigration of individuals belonging to species already present on the island. When this immigration rate is sufficiently high, it will reduce the extinction rate. This is primarily because demographic and genetic contributions of immigrants tend to increase the size and fitness of insular populations, thereby reducing the probability that they will become extinct. In addition, a high immigration rate also will have a statistical effect in reducing the apparent extinction rate simply by decreasing the probability that a given species will be absent during any census.

We suggest that this effect of immigration upon extinction, which we call the rescue effect, makes the M-W model inadequate to predict the relationship between turnover rate and isolation for many kinds of true islands, insular habitats, and isolated patches of resources. Whenever immigration rates are sufficiently high relative to extinction rates, islands that are closer to sources of dispersing species will have higher immigration rates, and hence lower extinction and turnover rates than more isolated islands. The rescue effect will be increased by the tendency (Diamond 1975) for those species that are present on an island to be good dispersers and hence have high immigration rates. When immigration and colonization rates are

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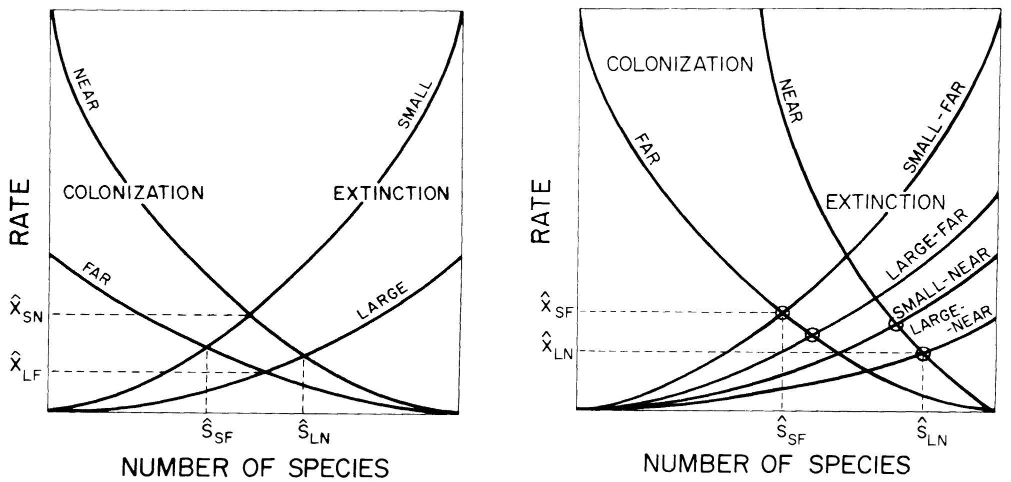

FIG. 1. Two models of equilibrium insular biogeography. Left, the MacArthur-Wilson model, which portrays extinction and colonization rates as functions of island size and isolation, respectively. Right, a modification of the M-W model which incorporates the rescue effect of immigration on extinction. In both models intersections of the curves can be extrapolated to the abscissa and ordinate to give equilibrial numbers of species ($\hat{S}$) and turnover rates ($\hat{X}$) respectively. Note that the two models predict the same relative order of numbers of species but different orders of turnover rates.

low relative to extinction rates, the rescue effect should be small and the turnover rate should be inversely related to insular isolation as predicted by the M-W model. Thus turnover rate as a function of increasing distance from a source of species should first increase, reach a maximum where colonization and extinction rates are both high, and then decrease (Fig. 2). On islands more distant from a source of colonists than the maximum turnover rate, the M-W model should correctly predict the relationship between turnover rate and insular isolation. However, for islands nearer a source (to the left of the peak in turnover rate in Fig. 2) a modification of the model is required. We present a model similar to that of MacArthur and Wilson, but which incorporates the rescue effect on the rates of extinction for islands of varying isolation and size (Fig. 1). In comparison to the M-W model, our model predicts the same effect of island size and isolation on equilibrium number of species, and the same effect of island size but the opposite effect of isolation on equilibrium turnover rate.

Turnover of Arthropods on Thistles

We were led to reexamine the M-W model and propose an alternative on the basis of a short-term study of the distribution of arthropod species among isolated thistle plants. In May 1973 we censused spiders and several orders of insects on individual plants of *Circium neomexicanum* near Portal, Arizona. Two large stands of thistles were censused twice, 5 days apart. Recolonization experiments also were performed by defaunating equal numbers of plants near to and far from other thistles supporting large arthropod faunas.

The results of this study confirmed the major predictions of the M-W model, except that turnover rate was directly related to insular isolation rather than inversely related as expected. The number of arthropod species increased with size of thistle plant and decreased with distance between plants (Tables 1 and 2). The faunas of the plants appeared to be in approximate equilibrium; the number of species remained similar between censuses although there were gains and losses of individual species on particular plants. Turnover rates were high, inversely related to size of plant

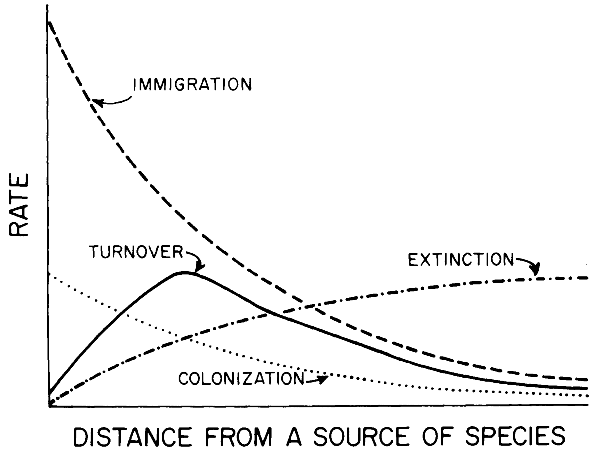

FIG. 2. A graphical representation of the relationship between the distance to a source of species and turnover rate at equilibrium. Note that rates of immigration and colonization decrease with insular isolation as suggested by MacArthur and Wilson; but, in contrast to their model, extinction rate increases with isolation because of the rescue effect. The result is that equilibrium turnover rate first increases and then decreases with distance from a source of species, and turnover is greatest where both colonization and extinction rates are high. The shapes of these curves are hypothetical and should vary with the characteristics of particular insular systems.

TABLE 1. Effects of plant size and isolation on the number and turnover of arthropod species on individual thistle plants. Note that all patterns conform to the predictions of the M-W model except for the relationship between turnover rate and isolation

	Corral site						Roadside site					
	16 May		21 May		16–21 May		18 May		23 May		18–23 May	
Size-isolation category[1]	No. of plants	$\bar{x}$ no. of species	No. of plants	$\bar{x}$ no. of species	No. of plants[2]	$\bar{x}$ turnover of species[3]	No. of plants	$\bar{x}$ no. of species	No. of plants	$\bar{x}$ no. of species	No. of plants	$\bar{x}$ turnover of species
Large-Near	15	3.00	28	3.82	16	0.67	9	5.78	12	5.25	9	0.29
Large-Far	6	1.67	9	3.78	7	0.78	9	3.67	9	4.44	9	0.42
Small-Near	59	1.61	46	1.89	56	0.78	22	3.23	19	2.21	21	0.69
Small-Far	6	0.67	3	1.33	3	1.00	15	1.27	15	0.80	11	0.91

[1] Categories are defined as follows: Large > 2.5 = number of fresh blossoms + (no. of old blossoms ÷ 2). Near > 8.0 = no. of plants within 12.5 m + (no. of plants 12.5–25 m ÷ 2) + (no. of plants 25–50 m ÷ 4).

[2] Plants that had not arthropods in both censuses were eliminated from calculations of turnover rates; otherwise, they would have given values of infinity.

[3] Turnover = (No. of species present only in first census + no. of species present only in second census) ÷ (total no. of species in first census + total no. of species in second census).

and directly related to distance between plants. Recolonization of defaunated plants was rapid. Within 24 h, 94% and 67% of the original number of species had recolonized the near and isolated plants respectively.

In this case the direct relationship between turnover rate and plant isolation probably was produced primarily by the statistical consequences of high immigration rates. The arthropods did not maintain breeding populations on the thistle plants, but visited them for short periods while searching for food or mates. Since several individuals of each of several common species often were present simultaneously on the same plant, high dispersal rates would reduce the possibility that a species would be present in one census but absent in another, thus producing a turnover. This statistical effect of immigration on extinction is similar only by analogy to the reproductive and genetic contributions of immigrant individuals that should reduce extinction rates of breeding populations on true islands or insular habitats.

DISCUSSION

There have been so few studies of equilibrial faunal turnover in insular systems that it is difficult to evaluate the general significance of the rescue effect and the validity of our model until additional empirical observations are made. The model is consistent with the observed turnover of arthropods on thistles, and also with the conclusions of Diamond (1969; but these have been challenged by Lynch and Johnson 1975) that the turnover rates for bird species on the Channel Islands of California are inversely related to the number of species present. Immigration rates were observed to be high in the former case and assumed to be so in the latter.

Simberloff and Wilson (1969, 1970) observed no significant correlations, either positive or negative, between turnover rates for arthropod species and distance from a source of species in their study of defaunated mangrove islands. It is not clear whether this was due to sampling problems, the fact that their systems were near the point where the relationship between turnover rate and distance from a source of colonists has zero slope, or the difficulty in distinguishing between recolonization and succession, on one hand, and turnover equilibrium, on the other. Although we know of no attempts to measure turnover directly on islands where immigration and colonization rates are very low, the fact that extremely isolated islands have a high proportion of endemics (MacArthur and Wilson

TABLE 2. Partial correlation analysis of the dependence of number of species and turnover rate on plant size and isolation. Values are partial correlation coefficients giving the effect of one independent variable (plant size or isolation) when the other is held constant. These results show the same pattern as Table 1, and indicate the statistical significance of the relationships

	Corral site			Roadside site		
Size/Isolation parameter	16 May No. of species	21 May No. of species	16–21 May Turnover of species	18 May No. of species	23 May No. of species	18–23 May Turnover of species
Plant size[1]	0.53**	0.57**	−0.33**	0.52**	0.62**	−0.64*
Plant isolation[1]	−0.28*	0.13	0.27*	−0.45**	−0.31*	0.32*

[1] As in Table 1 except that plant isolation is the reciprocal of the measure given there.

* $P < 0.05$.

** $P < 0.01$.

1967, Darlington 1957) suggests their turnover rates are lower than those islands somewhat nearer to continents. This is consistent with our prediction (Fig. 2) that as colonization rates decrease with increasing isolation, turnover rates should first increase and then decrease.

The rescue effect of immigration in reducing extinction and turnover potentially has two important consequences for insular biogeography and ecology. First, recolonization by conspecifics may be an important mechanism enabling some species to persist on islands. This may be particularly true of species that represent early stages in insular taxon cycles and are characterized by species-area curves of shallow slope (Ricklefs and Cox 1972, Scott 1972); examples are the supertramp and tramp bird species described by Diamond (1975). Previously it had been suggested that the persistence of insular populations might be explained largely in terms of life history features that reduced their probability of extinction (MacArthur and Wilson 1967, MacArthur 1972). The genetic contributions of frequent immigrants may delay or prevent the genetic differentiation of insular populations. There is evidence that the evolution of genetically distinct insular populations represents entry into the taxon cycle which almost inevitably ends with the extinction of endemic populations (Wilson 1961, Ricklefs and Cox 1972, Scott 1972). Second, the rescue effect suggests that the species composition of insular biotas should be more stable and deterministic than expected from the M-W model. High rates of immigration will tend to stabilize and prevent the extinction of species which are favored by suitable habitats, competitive superiority or absence of predators. Thus Brown (In press) has suggested that the primary importance of habitat in determining the number and identity of permanent resident boreal bird species inhabiting isolated mountain ranges in western North America (Johnson 1975) is owing primarily to high immigration rates. Low slope of the species-area curve and other evidence indicate that immigration is sufficient to maintain boreal bird populations wherever habitat is adequate.

In retrospect, the rescue effect is intuitively reasonable and seems likely to influence many insular distributions. The M-W model has received so much attention since it was presented more than a decade ago that it is interesting to ask why this potentially important exception went unreported for so long. We suggest two primary reasons; they testify to MacArthur's and Wilson's biological knowledge and intuition and provide interesting insight on the relationship between theory and empiricism in contemporary population biology. First, because the M-W model is so elegantly simple and most of its predictions correspond to the observations and intuition of ecologists and biogeographers, there was a tendency to accept the model before it had been tested rigorously. Second, the most easily checked predictions were tested repeatedly and the results usually supported the model (e.g., Culver 1970; Diamond 1969; Simberloff and Wilson 1969, 1970; Vuilleumier 1970, 1973); the few exceptions were readily explained without invoking a rescue effect (e.g., Abbott and Grant 1976, Barbour and Brown 1974, Brown 1971, Culver et al. 1973, Diamond 1972, 1973, Terborgh 1975). As a result the model was widely regarded as having been confirmed empirically before the crucial predictions about dependence of turnover rate on island size and isolation had been tested. The fact that we obtained conflicting data and were able to reconcile them with most of the existing data on insular species diversity and turnover by constructing an alternative model, demonstrates the necessity of testing all possible predictions and assumptions of such models to avoid "making the right prediction for the wrong reason" (Dayton 1973).

Careful analyses of turnovers of insular species populations are required to test and distinguish between current models of island biogeography. There are obvious reasons why such work has proceeded slowly. It is difficult to perform controlled experiments on a biogeographic scale, although Simberloff and Wilson (1969, 1970; Simberloff 1976) have had the imagination and practicality to do so with great success. An obvious alternative is to work with small-scale, analog systems that are easier to observe and manipulate (e.g., Cairns et al. 1969, Maguire 1971, Schoener 1974, Siefert 1975). Valuable insights may come from analyzing the dynamics of colonization and extinction on thistle plants or artificial sponges, but these must be regarded as hypotheses until they can be tested rigorously on a biogeographic scale.

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LETTER

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Support for the U.S. Endangered Species Act over time and space: Controversial species do not weaken public support for protective legislation

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Abstract
We used data from a 2014 survey (n = 1,287) of U.S. residents and recent polls to assess how public support for the U.S. Endangered Species Act (ESA) changed over time, and whether protecting controversial species affects support for the law. We assessed support for the ESA, trust in the U.S. Fish and Wildlife Service (FWS), and attitudes toward wolves across three regions with different experiences in conserving gray wolves through the ESA. We found: (a) ∼4 in 5 Americans support the ESA, whereas ∼1 in 10 oppose; (b) support for the ESA remained stable over the past two decades; (c) strong majorities (>68%) of individuals identifying with 8 special interest types support the ESA; and (d) no differences in support for the ESA, attitudes toward wolves, or trust in the FWS across regions. Results suggest that protecting species—even controversial predators—does not weaken support for protective legislation.

KEYWORDS
attitudes, Endangered Species Act, interest groups, politics, public opinion, public policy, wolves

1 | INTRODUCTION

Effective conservation of biodiversity depends on legislation designed to protect biodiversity. Likewise, achieving the goals of such legislation depends on political and social forces that affect its implementation (e.g., Chapron, Epstein, Trouwborst, & López-Bao, 2017). Widespread public opposition to such legislation, for example, could promote efforts to weaken protective legislation or thwart its implementation and enforcement. Thus, understanding factors that impact public support for such legislation is critical to meeting long-term conservation goals. To that end, we examine support for the U.S. Endangered Species Act, 1973 (ESA).

In 1973 the U.S. Congress passed the ESA to provide for the conservation of species (16 U.S.C. § 1531). The ESA passed with widespread bipartisan support, supplanting two prior laws deemed inadequate for conserving species (Enzler & Bruskotter, 2009; Freyfogle & Goble, 2009). The ESA explicitly acknowledges that numerous species were "rendered extinct as a consequence of economic growth and development" and sought to provide a means of mitigating these circumstances. However, it quickly became clear that any limitations on economic opportunities could be controversial. In the decades since its passage, the ESA has become a focal point in conflicts pitting species of conservation concern against economic interests (Goble, 2005; Meltz, 1994; Plater, 2004).

Accordingly, the idea that the ESA is increasingly controversial has become a common feature of environmental news media coverage. For example, in June of 2017, *National Public Radio* introduced a story about recovery of the Wyoming toad (*Anaxyrus baxteri*) asserting, "The Endangered Species Act is facing a growing number of calls for significant changes" (McKim, 2017), and that same month, *The Hill* reported that "the battle over the Endangered Species Act has reached a fever pitch" (Clark, 2017). This idea is echoed by conservation professionals. At a recent meeting of *The Wildlife Society* (a professional society that certifies wildlife biologists), Mathews (2017) asserted, "Over the past 10 years…the Act has seen declining public support, in part due to growing concern over states' rights, constraints on economic growth and development, and costs involved in protecting species and their habitat."

The empirical basis for claims that the ESA is increasingly controversial among the general public is unclear. This claim appears to emerge from interest groups and influential members of the U.S. Congress who manifest strong opposition to the Act. Congressional opposition is apparent, for example, in legislative proposals to amend the ESA directly, as well as the use of riders (bills attached to unrelated legislation) to block protections for certain species. Recent examples include an amendment to a defense bill in 2015 that blocked the listing of the greater sage-grouse (*Centrocercus urophasianus*) and a 2011 budget resolution rider that removed protections for gray wolves (*Canis lupus*) in the Northern Rocky Mountains. Recent analyses indicate that Congressional actions designed to weaken the Act or its implementation increased substantially over the past two decades (Pang & Greenwald, 2015).

Efforts to revise the ESA have not been limited to Congress, but also include administrative actions aimed at its implementation. For example, the FWS and National Marine Fisheries Service (NMFS) recently promulgated a new rule concerning the interpretation of the phrase "significant portion of its range" (Waples et al. 2015)—a key phrase in the Act that determines what constitutes endangerment (Vucetich, Nelson, & Phillips, 2006). This rule effectively redefines endangerment in a way that is likely to dramatically lower the standards for what counts as an endangered species and what is required for species recovery (Nelson, Vucetich, & Bruskotter, 2016). Importantly, the use of administrative policy and other nonlegislative mechanisms to weaken biodiversity protections is not limited to the United States, but may be an emerging global phenomena (Chapron et al., 2017).

These and other efforts to amend the ESA and revise associated administrative policy imply that some significant segment of the American public opposes such protections. But who—and why? One explanation lays blame on prolonged protection for controversial species. In November of 2015, 14 scientists wrote to the U.S. Secretary of the Interior (who is responsible for administering the ESA) expressing their belief that wolves no longer require ESA protections, and that continued listing "creates public resentments toward the species [wolves] and the ESA" potentially threatening the "integrity and effectiveness of the ESA" (Mech et al., 2015). Although plausible, the idea that the long-term protection of controversial species under the ESA undermines support for the law act is as yet untested.

1.1 | Research questions

Collectively these circumstances suggest: (i) support for the ESA among Americans may be declining and and (ii) listing/delisting of controversial species may be impacting support for the ESA. Our study seeks to interrogate these ideas using nationally representative surveys and polling data. Specifically, we address the following questions: (i) To what extent do Americans support or oppose the ESA? (ii) Has support for the ESA changed over time? (iii) To what extent is opposition to the ESA associated with one's identification with various special interests? Finally, (iv) we evaluate the idea that long-term listing of controversial species increases opposition to the ESA, negatively affects trust in agencies charged with its implementation (i.e., FWS, NMFS), and creates resentment toward the species being protected.

2 | METHODS

We commissioned a survey (n = 1,287) of adult residents of the United States conducted by the GfK Group. The study used GfK's Knowledge Panel®, which is composed of randomly selected panelists, that were selected via an address-based sampling method (Baker et al., 2010). GfK's sampling methodology is designed to improve population coverage, providing better representation of populations that have been traditionally harder to reach with surveys (e.g., young adults, minorities). For example, to alleviate problems in coverage associated with lack of internet access, GfK provides web-enabled devices and free internet services to panelists who lack internet access (for more details, see Supplementary Materials).

To test the idea that long-term listing of gray wolves has reduced support for the ESA and decreased trust in the FWS, we sampled three regions with different experiences in protecting gray wolves under the ESA, the: (i) Northern Rocky Mountains, (ii) Western Great Lakes Region, and (iii) remainder of the United States (Figure 1). Our goal was to obtain at least 400 responses per region. Because controversies about ESA protections of wolves also exist for Mexican wolves (*Canis lupus baileyi),* which reside in a small portion of New Mexico and Arizona, and red wolves (*Canis rufus*), which reside in a small portion of North Carolina, we filtered out cases from these three states (n = 23). We also removed cases from Alaska (n = 4), which has an unlisted population of

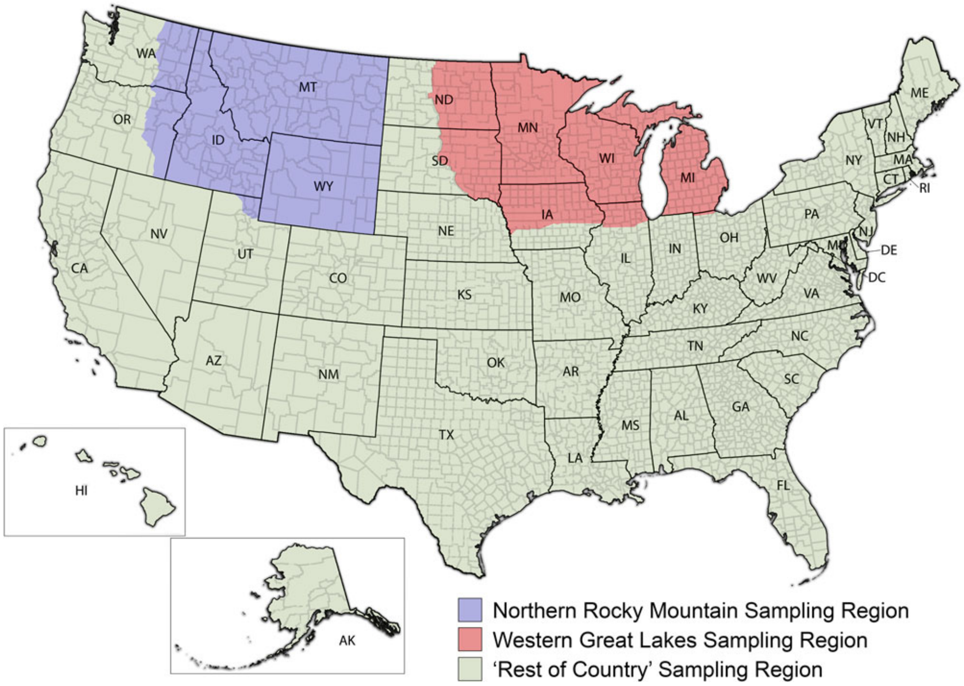

FIGURE 1 Sampling regions for the 2014 study were defined by gray wolf recovery zones (i.e., Northern Rocky Mountains, Western Great Lakes) delineated by the U.S. Fish and Wildlife Service

wolves, and Hawaii (n = 4), which has never been inhabited by wolves, when making comparisons across regional strata.

We collected responses using Qualtrics, an online survey platform. Over an 11-day period in February of 2014, GfK invited 2,020 panelists to participate in the study, which resulted in 1,287 completed questionnaires (response rate = 63.7%). For the present analyses, responses were weighted post hoc to represent the general U.S. population on several sociodemographic characteristics using benchmarks from the 2009–2011 American Community Survey, which is conducted by the U.S. Census Bureau. (For validity of weighting procedures to obtain accurate estimates from online samples, see Yeager et al., 2011.)

Additionally, we gathered basic response frequencies from previously published studies and public polling conducted at the national level. Although we found numerous studies and polls that reported on support for or attitudes toward the ESA, only four contacted nationally representative samples (see Supplementary Materials for details).

3 | RESULTS

3.1 | Trends in support for and opposition to the ESA

Our review identified two polls and two studies (including our own), spanning two decades (1995–2015) that explicitly address support for the ESA with nationally representative samples. Despite minor differences in response items, results appear remarkably consistent across these studies. Support varied from a low of 79% (±3 points, 95% CI) in 2014 to a high of 90% (±4 points, 95% CI) in 2015; opposition varied from a high of 16% (±4 points, 95% CI) in 1996, to a low of 7% (±4 points, 95% CI) in 2015 (Figure 2). Because of the differences in item wording and response categories, we refrained from conducting formal statistical tests. However, the margins of error surrounding the estimates of opposition in the oldest (1996) and most recent (2015) studies do not overlap—suggesting that opposition to the ESA has decreased over the past two decades.

3.2 | Support for the ESA among special interests and political ideologies

Next, we examined the extent to which individuals' identifications with various types of special interests are associated with support for the ESA. Results indicate that within all interest group types majorities (>68%) expressed support for the Act (Table 1). Support was higher than average (79%) among self-identified environmentalists, animal rights advocates, conservationists and wildlife advocates, and lower than average among self-identified gun rights advocates, farmers/ranchers, hunters, and property rights advocates. Those who identified as ideologically liberal expressed greater than average support for the ESA, whereas those who identified as ideologically conservative expressed less than average support for the ESA. Measures of interest group identification were weakly

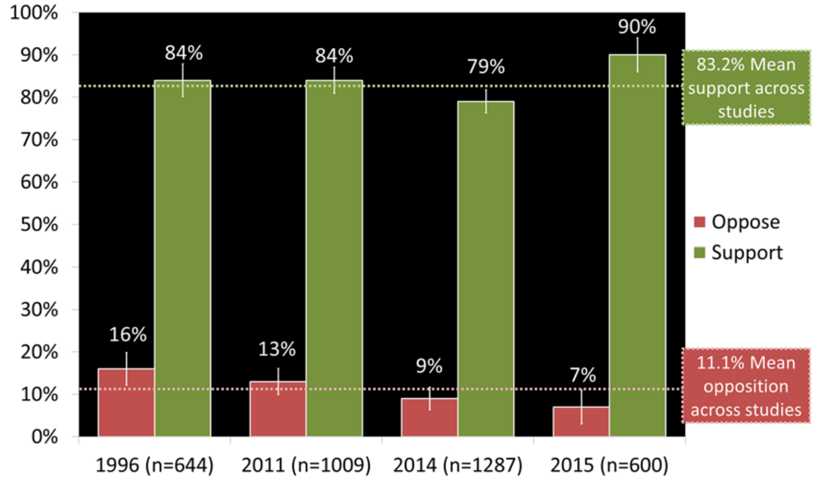

FIGURE 2 Americans' support for and opposition to the U.S. Endangered Species Act of 1973 (1996–2015). Error bars represent sampling error. For the 1996 study, the item used to assess support was, "In the best interests of the nation, the Endangered Species Act should be… Revoked, weakened to provide less protection to species, remain unchanged, strengthened to provide more protection to species." For the remaining studies, the item used to assess support was "As you may know, the Endangered Species Act is an environmental law established to protect all wildlife, plants, and fish that are in danger of extinction. Based on what you know, would you say that you strongly support, somewhat support, somewhat oppose, or strongly oppose the Endangered Species Act?" Note: In some cases support and opposition do not total 100% due to "neutral" or "don't know" response options

TABLE 1 Support for and opposition to the U.S. endangered Species Act[1] by Interest Group Identity and Political Ideology (2014)

Grouping variable	Support	Neutral	Oppose	Pearson's *R*
Interest group[2]				
Environmentalist ($n = 326$)	91.7%	4.9%	3.4%	0.33***
Animal rights advocate ($n = 225$)	90.2%	4.4%	5.3%	0.30***
Conservationist ($n = 344$)	88.4%	3.8%	7.8%	0.19***
Wildlife advocate ($n = 246$)	87.0%	4.5%	8.5%	0.22***
Gun rights advocate ($n = 380$)	71.3%	11.8%	16.8%	−0.20***
Farmer/rancher ($n = 289$)	71.3%	9.3%	19.4%	−0.07**
Hunter ($n = 222$)	73.0%	7.7%	19.4%	−0.15***
Property rights advocate ($n = 344$)	68.6%	10.2%	21.2%	−0.21***
Political ideology[3]				−0.29***
Liberal ($n = 276$)	89.5%	6.9%	3.6%	
Moderate ($n = 408$)	77.2%	19.4%	3.4%	
Conservative ($n = 570$)	73.7%	11.2%	15.1%	
All cases	78.5%	12.9%	8.6%	

[1]Data were weighted to represent the United States population using social and demographic benchmarks from the U.S. Census Bureau's American Community Survey; see Supplementary Materials for details.

[2]Respondents were asked "To what extent do you identify with each of the following groups." Response categories included: "not at all, slightly, moderately, strongly, very strongly." We classified individuals as belonging to a group if they selected "strongly" or "very strongly." Note that group response categories are note discrete (respondents were allowed to identify with multiple groups).

[3]Respondents were asked "When it comes to politics, please indicate which of the following you consider yourself?" Response categories included extremely liberal (1), liberal (2), slightly liberal (3), moderate/middle of the road (4), slightly conservative (5), conservative (6), and extremely conservative (7).

$^{**}p \leq 0.01$; $^{***}p \leq 0.001$.

to moderately correlated with support for the ESA (absolute Pearson's *R* values ranged from 0.07 to 0.33). Support was most strongly negatively associated with political conservatism ($r = -0.29$), and most positively associated with identification as an animal rights advocate ($r = 0.30$) and environmentalist ($r = 0.33$).

3.3 | Controversial listings and the ESA

We evaluated the idea that long-term listing of controversial species (a) reduces support for the ESA, (b) reduces trust in the agencies charged with administering the Act, and (c) generates animosity toward the species that is protected. If the

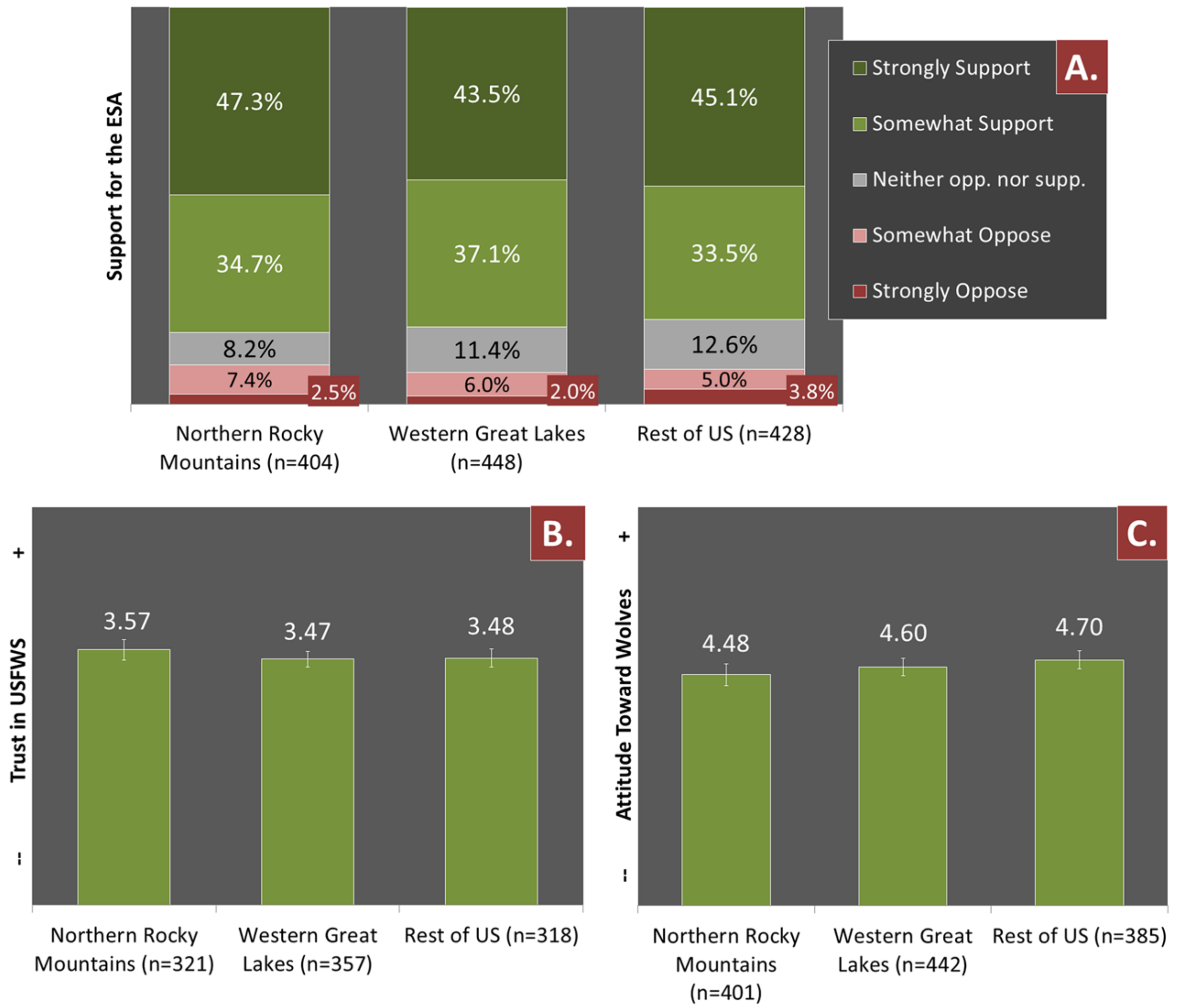

FIGURE 3 Mean levels of support for the U.S. Endangered Species Act, trust in the US Fish and Wildlife Service, and attitudes toward wolves, by sampling region. Trust in the FWS was assessed by averaging responses across four items that asked respondents the extent to which the agreed or disagreed that the U.S. FWS (i) "shares similar values as me," (ii) "takes similar actions as I would," (iii) "is trustworthy in their management of wildlife within the United States," and (iv) "is capable in the management of wildlife in the United States." Items were measured on a 5-point, bipolar scale ranging from "strongly disagree" (1) to "strongly agree" (5), and reliability was high ($\alpha = 0.92$) for the scaled measure. Attitudes toward wolves were assessed by averaging responses from four sets of paired adjectives with seven response categories. Respondents were prompted with the text, "Generally speaking I think wolves are…" and then asked to select the appropriate score ranging from 1 (harmful, unpleasant, worthless, bad) to 7 (beneficial, pleasant, valuable, good). Reliability for this 4-item scale was high ($\alpha = 0.92$). Note: analyses reported here excluded residents of Alaska, Arizona, Hawaii, New Mexico, and North Carolina

listing of controversial species contributed to the erosion of support for the ESA, then we should expect to find differences in support for the ESA across study regions (because these regions have different histories of ESA protections). Moreover, we might also expect regional differences in trust in the FWS and attitudes toward wolves. However, results of Fisher's exact tests indicate that neither opposition nor support for the ESA differed significantly across these geographic regions (fishers' exact = 9.78, 99% CI, p = 0.27–0.29; Figure 3). Likewise, one-way ANOVA tests indicate that neither respondents' (i) trust in the FWS nor their (ii) attitudes toward wolves varied across these regions (F = 1.271, df = 2, p = 0.30 and F = 2.22, df = 2, p = 0.11, respectively; see Figure 3).

4 | DISCUSSION

The news media in the United States consistently depicts the ESA as increasingly controversial. If that were the case, we would anticipate a polarized response in public polling (i.e., a bimodal distribution favoring the "strongly support" and "strongly oppose" response categories). However, our results find strong support for the ESA, which has persisted for at least the past two decades and transcends political ideology. Indeed, we found less than 10% of the population expressed opposition to the Act (Figure 1). These data do not support the assertion that the ESA is controversial; rather, they support the opposite conclusion.

Nevertheless, Congressional efforts to weaken the ESA appear to be increasing (Pang & Greenwald, 2015). Although recent efforts have thus far failed to amend the statute itself, the ESA has been meaningfully revised through Administrative rule-making, such as the recent adoption of a new policy for interpreting the phrase "significant portion of its range" that has profound implications for species listing and recovery (Greenwald, 2009; Nelson et al., 2016).

Given broad support for the ESA among the American public—support that transcends, for example, political ideology; it is tempting to conclude that efforts to weaken the ESA are driven by special interest groups. Indeed, various interest groups have expressed formal opposition to the ESA's protective provisions, citing, for example, restrictions on the rights of property owners or effects on agriculture. But our data indicate that individuals who self-identify with these special interests are largely supportive of the ESA. Thus, though interest groups continue to oppose the ESA, or at least some of its protective provisions, our data suggest that their opposition may not be broadly shared among their members.

Some insight into this disconnect is provided by research demonstrating that the leadership of interest groups tend to hold more extreme positions than their constituents (Nilsen et al., 2007). Additional insight is provided by a quantitative analysis of nearly 1,800 American policy issues, which led researchers to conclude that "economic elites and organized groups representing business interests have substantial independent impacts" on federal policy, "while average citizens and mass-based interest groups have little or no independent influence" (Gilens & Page, 2014, p. 564).

Similarly, a recent analysis of congressional voting behavior on environmental issues found that the odds of pro-environmental voting decreased significantly with each $10,000 that representatives received from "countermovement industries" (i.e., businesses at odds with pro-environmental legislation) (Ard, Garcia, & Kelly, 2017). In the specific case of the ESA, Plater (2004) argued that opposition to the Act may stem from an allegiance between groups who benefit from pork-barrel projects and individual congressmen who "gain power, votes, and campaign contributions by bringing infusions of federal taxpayer dollars into their local districts" (Plater, 2004, p. 302). Collectively, these studies suggest that environmental policy outcomes are unlikely to be driven by the opinion or interests of the general public; rather, these studies suggest that environmental policy is driven by narrow business interests and wealthy elites who benefit from less protective environmental policy.

Some scientists have suggested that continued protections for controversial species such as gray wolves or grizzly bears might erode support for the ESA or the species it protects. If so, one would expect to find less support for the ESA in places where such species were listed over long periods and where media attention has portrayed the species and/or ESA as controversial (e.g., Houston, Bruskotter, & Fan, 2010). However our data show that neither support for the ESA, trust in the FWS, nor attitudes toward wolves varied across regions where both the presence and listing status of wolves have varied. Although these data undercut the idea that controversial species are somehow responsible for reducing support for the ESA, it is important to recognize that the areas actually inhabited by wolves (i.e., part of wolf range) are among the least populated in the United States (Bruskotter, Vucetich, Enzler, Treves, & Nelson, 2014), a nation where more than four in five people reside in urban areas. Thus, it is possible that opposition to wolves occurs at a finer spatial scale (Treves, Naughton-Treves, & Shelley, 2013) than could be detected by the sampling scheme of our study, given that most residents within these regions reside in in urban areas where attitudes are typically more positive (Williams, Ericsson, & Heberlein, 2002). However, this concern is somewhat muted by recognizing that a large majority of people who self-identified with the interests of farming and ranching expressed support for the ESA. Moreover, some rural communities (e.g., native tribes) hold more positive views toward wolves (Shelley, Treves, & Naughton, 2011). In any case, the fair and just handling of opposition by small groups of people requires some care because all citizens—urban and rural—have a legitimate interest in the conservation of species (Vucetich, Bruskotter, Nelson, Peterson, & Bump, 2017).

In conclusion, our results suggest the ESA is commonly portrayed in a manner that is inconsistent with how the Act is viewed among the American public. Indeed our results show that support for the ESA generally was high—even among those who self-identify with the special interests who sometimes vehemently oppose ESA protections. Further, contrary to the predictions of some conservationists, protecting controversial species such as the gray wolf does not appear to undermine support for the ESA in regions where that species is protected. Our results have widespread application for conservation policy. Specifically, they suggest: (i) conservation professionals should not assume that protecting species—even where politically controversial—will undermine support for biodiversity conservation policies, nor support for those who administer such policies and (ii) concerted efforts by legislators to undermine or minimize policies should not be taken *prima facie* as an indication of public opposition—or even the opposition of those they purport to represent. Beyond conservation, our results may be of value to policy scholars who are interested in understanding why in some instances governments are more responsive to the special interests of a few, as opposed to the uncontroversial will of most citizens. The question, whose treatment is beyond the scope of this article, is what institutional or grass roots changes would work to reduce that lack of such responsiveness in general or in the special case of conservation policy.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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SPECIES ASSESSMENT FOR BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) IN WYOMING

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Introduction

Prairie dog colonies once stretched from southern Canada to northern Mexico, east of the Rocky Mountains (Hall 1981). Prairie dogs affect many ecosystem processes (Detling and Whicker 1987) and studies have suggested that prairie dogs are important for the maintenance of biodiversity in grasslands (Miller et al. 1994, Reading and Matchett 1997), increasing species richness or abundance of plants (Bonham and Lerwick 1976, Whicker and Detling 1988), arthropods (Agnew et al. 1987), and vertebrates (Agnew et al. 1986, Barko 1996, Ceballos et al. 1999).

Historically, prairie dogs were the target of widespread eradication programs (Anderson et al. 1986, Miller et al. 1996), which, along with land conversion, led to decline of the species to less than 2% of its original range, by conservative estimates (Miller et al. 1994, Mulhern and Knowles 1995). Competition between livestock and prairie dogs for forage has long been the justification for eradication programs (Collins et al. 1984). However, O'Melia et al. (1982) found no significant difference in weight gain between steers that grazed on or off prairie dog colonies. In fact, facilitation in the form of enhancement of forage quality for, and preferential grazing by, pronghorns (Krueger 1986), bison (Coppock et al. 1983b, Krueger 1986) and domestic cattle (Knowles 1986) have been shown for prairie dog colonies relative to uncolonized mixed grass prairie. Despite the obvious reduction in above-ground biomass available for grazers caused by prairie dogs (Coppock et al. 1983a), ungulates seek out prairie dog colonies to forage (Whicker and Detling 1988). The advantage to grazers comes in the form of enhanced crude protein (nitrogen) content of the newly regrowing shoots of previously clipped vegetation (Detling and Whicker 1987, Sharps and Uresk 1990). Likewise, prairie dogs may maintain an herbaceous cover in grasslands and prevent encroachment of woody species, improving rangelands for other grazers (Weltzin et al. 1997a, Weltzin et al. 1997b).

Natural History

Morphological Description

Black-tailed prairie dogs (*Cynomys ludovicianus*) are robust, stockily built ground squirrels. These animals are usually a buff brown with a grizzled black appearance (Figure 1). The last third of the tail is black tipped and 7-10 cm long. Adult *C. ludovicianus* usually weigh 0.8-1.5kg and reach a length of 31-41cm (including the tail; Clark and Stromberg 1987). The head is broad and rounded with relatively large eyes and small ears. The legs are short and powerful, each foot having 5 digits with well-developed claws for digging. The skull characteristics of black-tailed prairie dogs are described by Hoogland (1996) and Hall (1981), but in general the skull is broad and angular with large processes (Figure 2). Their body pelage molts seasonally (twice yearly; Hoogland 1996) and is different between age and sex groups. The first to undergo the molt are the non-breeding juveniles, second are the non-breeding adults, third are the breeding males, and last are the breeding females (Hoogland 1995). It is thought that this sequence of molting is related to the overall body condition, with the most "fit" individuals molting first (Hoogland 1995). Juveniles undergo a "post-juvenile" molt starting at the rump and extending anteriorly (Smith 1967). Contrastingly, adults will molt posteriorly from the head every October. Males and females will also exhibit a differential molt, with the genitalia and secondary sexual characters molting soon after the head (Smith 1967). The color pattern on individual hairs differs during the respective molt period (Hoogland 1996).

All five species of prairie dogs (see Taxonomy) are similar in morphology and appearance, but since the species' ranges do not overlap, locality is diagnostic (see below; Hoogland 1995).

Taxonomy and Distribution

Taxonomy

The complete taxonomic classification for the black-tailed prairie dog is as follows (Hoogland 1996): Order: *Rodentia,* Suborder: *Sciurognathi,* Family: *Sciuridae,* Subfamily: *Sciurinae,* Tribe: *Cynomyini,* Subtribe: *Spermophilina,* Genus: *Cynomys,* Subgenus: *Cynomys,* Species: *ludovicianus.* Two subspecies of black-tailed prairie dogs are recognized: *C. l. arizonensis* located in the southern portion of the black-tailed prairie dog range and *C. l. ludovicianus* located in the northern part of the black-tailed prairie dog range (Hall 1981; Hoogland 1996). Black-tailed prairie dogs are one of five species in the genus *Cynomys*, in the family *Sciuridae*. Mexican prairie dogs (*C. mexicanus*) are the closest relative to black-tailed prairie dogs but do not overlap in range. White tailed prairie dogs (*C. leucurus*) and Gunnison's prairie dogs (*C. gunnisoni*) are found in intermountain basins of the rocky mountain west (Clark 1987). Utah prairie dogs (*C. parvidens*) are found in short-grass prairies of southwestern Utah and are more closely related to white tailed prairie dogs (Hoogland 1996).

Interestingly, the prairie dog was originally named the "Louisiana marmot" (*Arctomys ludovicianus*) by Ord in 1815 due to its outward resemblance to a marmot, but the name was changed to the current genus *Cynomys* in 1817 by Rafinesque (Smith 1967).

Distribution

Black-tails are the most widely distributed species of prairie dog (Figure 3), thought to once occur from southern Canada to northern Mexico, covering a continuous 400-mile wide band from the foothills of the Rockies to the central lowlands of the Great Plains (Koford 1958, Hall 1981). Currently, this species still occurs over its entire range (except Arizona) in small, fragmented colonies (VanPutten and Miller 1999). Generally, *C. ludovicianus* occur east of the other four prairie dogs in North America, occupying more mesic habitats.

In Wyoming, the distribution of prairie dogs is restricted to the eastern third of the state, where short and mixed grass prairies dominate the landscape (Figure 4). The western extent of this range is not well defined, and there may be a zone of sympatry between *C. ludovicianus* and *C. leucurus*, which occupy the sage-grassland basins in central and western Wyoming. There is only one documented occurrence of a stable black-tailed prairie dog colony west of this area, in the Bighorn Basin. Since this colony is so far from the main range of black-tails and is located along a main highway, it likely represents an artificial, anthropogenic introduction rather than a legitimate range expansion (D. Keinath, personal communication).

Recently the Wyoming Game and Fish Department (WGFD) in cooperation with the Wyoming Bureau of Land Management (BLM) have completed a digital map of *C. ludovicianus* towns in Wyoming using 2002 aerial photographs. The portion of this map that represents active towns is unknown, since no estimate of activity has been assessed for the digitized towns. In addition, the map is incomplete since 1/3 of the photographs were unable to be digitized. In fall 2005, the map should be available on the Wyoming Natural Diversity Database (WYNDD) website (http://uwadmnweb.uwyo.edu/wyndd) after it has been evaluated and the quality of the map can be reported (D. Keinath, personal communication).

Habitat Requirements

General

Black-tailed prairie dogs are thought to have once covered the entirety of the Great Plains grasslands (Hall 1981, Miller et al. 1994) (Figure 5). Short- and mixed-grass prairies are easily colonized by prairie dogs especially when the range is overgrazed or in poor condition (Koford 1958). Tall-grass prairie appears to be difficult for prairie dogs to inhabit (Allan and Osborn 1954), possibly because the high levels of vegetative production interfere with clipping, a behavior used by prairie dogs to lower overall vegetative height, facilitating predator detection. Fine, non-sandy soils seem to be important for burrow construction (Clippinger 1989, Reading and Matchett 1997) and may influence the distribution of prairie dogs. Shrubby areas are less favorable for colony establishment, but may not inhibit expansion of existing colonies (Weltzin et al. 1997a). Gently sloping areas (0-10 degrees) are preferred and slopes over 20 degrees are rarely used in the establishment of new colonies (Clippinger 1989, Reading and Matchett 1997). *Cynomys ludovicianus* is rarely found above 2,377m and usually found below 1,829m (May 2004). Black-tailed prairie dogs do not require open water (Clippinger 1989) because of a specialized kidney physiology (Harlow and Menkens 1986) that allows them to more efficiently use water obtained from plants. There is no seasonal variation in habitat requirements due to the colonial nature of this species; therefore, the breeding, foraging, and over-wintering habitats are similar (Hoogland 1995).

A habitat suitability index (H.S.I.) model was completed in 1989 for black-tailed prairie dogs by the USFWS (Clippinger 1989). Models, such as the one developed by Clippinger (1989), have identified important habitat attributes for the species of interest. The habitat attributes considered by Clippinger (1989) were availability of food, water, cover, and soil type. His conclusions about food was that suitable habitat must contain sufficient grasses for spring and summer consumption, a forb flora which will be utilized in fall, and adequate prickly pear available for water needs during winter. According to Clippinger (1989), the food component of the H.S.I. model needs to be a minimum of 15% herbaceous cover for continuous habitation by prairie dogs. For the cover component, vegetative height levels of 5cm to 20cm are considered optimal with a slope of less than 10 degrees for burrow establishment. The cover values are considered to be the most critical component of the model by Clippinger (1989). Soil type is also considered, and has a broad spectrum of acceptable soil types for burrow establishment. Clippinger's (1989) H.S.I. equation is the following:

$$(V_1 \times V_2 \times V_3 \times V_4)^{1/4} = H.S.I.$$

Where: V_1= % herbaceous cover, V_2= slope, V_3= vegetative height, and V_4= soil type

In Wyoming, short-grass prairies in the southeast along with mixed-grass prairies through the northeast compose the majority of habitat for *C. ludovicianus* (Figure 4). The productive, gently rolling hills of the eastern third of the state provide the necessary habitat for colony establishment. The climate in Wyoming is favorable for year round activity, and provides a plant species composition and productivity comparable to that of the nationwide range.

Area Requirements

Coteries, the smallest family unit of a colony or town, are on average 0.3 ha in size, but can range from 0.05 ha to 1.0 ha in size (Hoogland 1995). In theory, the smallest possible unit of area prairie dogs could colonize would be the area of land needed for one breeding pair or family unit which would be ~ 0.05 ha. In Colorado, studies indicated that *C. ludovicianus* colony sizes ranged from one acre to 4,129 acres, with an average size of 75acres; however, most colonies were 1 – 20 acres in size (see May 2004).

Landscape Pattern

The general landscape pattern needed for continous habitation of black tailed prairie dogs is typified by the gently rolling topography and abundant forage of the Great Plains. Shrub dominanted landscapes can also be colonized, but are less preferred to open habitats of grasses and forbs (Clippinger 1989).

Movement and Activity Patterns

Dispersal

The most common movement of this species is of minimal distance due to its colonial nature. However, long distance dispersal does occur, but is very difficult to track (Hoogland 1995) and seems to be rarely successful due to predation risk away from the colony. A study conducted on intercolonial dispersal by Garrett and Franklin (1988) found that dispersal distances can be as much as 5 km. They also found that prairie dogs rarely disperse to start a new colony, rather they move to another established colony. The most common time for dispersal to occur is about a month or so after the juveniles have emerged for the year (Hoogland 1995).

The ultimate cause of dispersal from the natal breeding sites is to prevent inbreeding (Felhamer et al. 2004). Within *C. ludovicianus* populations, young males leave the family group before breeding, whereas females remain. In addition, adult males usually leave groups before their daughters mature (Hoogland 1982). Immigration and emigration by yearling males can be important for gene flow (outbreeding) in large complexes of black-tailed prairie dogs if dispersal is across mostly colonized area (Hoogland 1995).

Impediments to dispersal are largely centered on predation risk. Black-tailed prairie dogs heavily rely on the alarm calling actions of nearby vigilant conspecifics (Hoogland 1981), and a low degree of visual obstruction to detect danger. When venturing into uncolonized, unclipped territory, the danger of predation increases (Hoogland 1995). As a result, most adult and some juvenile male dispersal is within his home colony, although not near his home coterie. Long distance dispersal, when it occurs, is most commonly associated with juvenile rather than adult males, and is usually solitary rather than group movements. Male dispersal peaks during a postweaning period (June – August; Roach et al. 2001). Dispersal of juvenile females is very uncommon because they usually stay and breed on the home coterie for life. If dispersal does occur with a female prairie dog, it is almost always long distance dispersal to another established colony (Hoogland 1995). Other barriers to movement are few, but include large bodies of water such as wide rivers and large lakes.

Activity Patterns

Prairie dogs are diurnal, usually appearing above ground at dawn during the warmer months and midmorning during the winter months. The heaviest above ground activity occurs between 7am and 11am and 5pm and 8 pm (Tileston and Lechleitner 1966, Biggins et al. 1993). *Cynomys ludovicianus* may spend as much as 95% of their time above ground during the daylight hours, and retreat into burrow for only 15-20 minutes to momentarily escape the heat (Hoogland 1995).

Black-tailed prairie dogs are not “obligate hibernators”; instead, they exhibit a state of facultative torpor due to food shortage (in captivity) during the winter months (Harlow and Menkens 1986) and/or weather (i.e., ambient temperature for free-ranging *C. ludovicianus*; Lehmer et al. 2001, 2003). Free-ranging females demonstrated facultative aestivation in summer months during periods of precipitation (Lehmer et al. 2003). Although *C. ludovicianus* demonstrate facultative torpor, they can be active throughout the year (Hoogland 1995). Facultative torpor is one area of prairie dog physiology and ecology that needs further study.

Reproduction and Survivorship

Breeding Behavior

Black-tailed prairie dogs exhibit a harem-polygynous mating system (Hoogland et al. 1987). Usually, one breeding male, two to three adult females, and one or two yearlings of each sex make up a territorial family group, or coterie, although as many as 26 prairie dogs may occupy the largest of coteries (Hoogland 1995). Fierce protection of coteries by males can lead to combat between males, but rarely leads to serious injury or death. Coterie size may vary from 0.05 to 1.1

ha and will contain a variable number of burrows depending on the number of animals, especially breeding females, on that coterie. Since prairie dog females usually stay on the natal coterie, this species avoids inbreeding by four mechanisms: 1) male biased natal dispersal, 2) older males disperse from coteries when daughters become sexually mature, 3) yearling females are unlikely to come into estrus when their father is on the colony, and 4) behavioral avoidance of mating with kin. These mechanisms are further explained in Hoogland (1995).

Breeding Phenology

The breeding season of black-tailed prairie dogs occurs between late January and early April (Clark and Stromberg 1987) and lasts for 2-3 weeks (Smith 1967). Timing of copulation is probably dependant on food availability and the severity of the preceding winter (Koford 1958, Smith 1967). Black-tailed prairie dogs are generally synchronized breeders (Hoogland 1981), breeding the same day in a coterie, and perhaps over 5 days throughout the colony (Hoogland 1995). Gestation is between 28 to 32 days (Smith 1967, Clark and Stromberg 1987). Altricial young are usually born in the early spring and emerge from burrows at about 6 weeks of age. Pups are fully grown in about 90 days (Clark and Stromberg 1987). Latitudinal differences in time of breeding are also evident; for example, *C. ludovicianus* in Texas and Oklahoma breed in January, in Colorado during February, and in Montana during March (Hoogland 1995, 1996).

Fecundity and Survivorship

Sexual maturity does not occur until 2 years of age (Smith 1967) differing from white tail prairie dogs which mature and breed at 1 year of age. Garrett et al. (1982) found that the age of first reproduction and pregnancy rate were both affected by the availability of food, and Knowles (1987) found that litter size is directly connected to precipitation level of the preceding year. Additionally, (Koford 1958) stated that breeding success is not necessarily depressed in small groups as it is in other social organisms like colonial nesting birds. An average litter size is 4 (Anthony and Foreman 1951) to 5 pups (Clark and Stromberg 1987) with the range occurring between 2 and 8 (Hoogland et al. 1987).

Survivorship of male prairie dogs can be 3 or 4 years old and females usually live to be 5 or 6 years old (see Figure 6; Hoogland et al. 1987). Natal survivorship is unknown, but infanticide has been documented and is considered the major cause of juvenile mortality within colonies (Hoogland 1995, 1996). Juvenile survivorship does not appear to be as sex-biased as adult survivorship with about 50% of each sex surviving their first year (Hoogland 1995).

Population Demographics

Metapopulation Dynamics

Although immigration and emigration to and from neighboring colonies is not important in maintaining genetic diversity (see below), maintaining corridors between distinct colonies is important for the long-term persistence of a metapopulation. A metapopulation can persist as long as rate of recolonization (i.e., after events such as plague eliminates a colony) exceeds rate of extinction. Increased isolation and disconnectivity of colonies will decrease successful dispersal between colonies, increase genetic diversity between colonies, and may decrease genetic diversity within isolated colonies through possible inbreeding and overall loss of alleles. Movement between existing or unoccupied colonies is affected by physical aspects of the surrounding landscape, such as tall grasses or urban and agricultural development. Maintaining corridors such as drainages, roads, or trails could facilitate recolonization of unoccupied colonies and continual dispersal among colonies (Roach et al. 2001).

Genetic Concerns

Dobson et al. (2004) demonstrated that the polygynous mating system (coteries within colonies) and female philopatry (see Dispersal below) of *C. ludovicianus* results in a strong genetic differentiation of coteries within a colony. This genetic substructure within a colony has a conserving influence on genetic diversity because different alleles predominate in different coteries, and decrease the loss of genetic diversity of the entire colony. In fact, the genetic diversity within a colony was influenced more from coteries within the colony than immigrants (males) from neighboring colonies. Translocation of females (essentially increasing the female dispersal rate) could actually increase the rate of inbreeding and loss of genetic variation by bringing related males and females into spatial proximity (Sugg et al. 1996, Dobson et al. 2004). This information should be considered when reintroducing or relocating *C. ludovicianus* to different colonies.

Food Habits

Cynomys ludovicianus is herbivorous, consuming the stems, leaves, seeds, and roots of various grasses, forbs, shrubs, and cacti. However, despite this breadth of food sources, black-tailed prairie dogs are not considered opportunists (Uresk 1984), apparently selecting for specific species of these growth forms. In fact, prairie dogs have been shown by Wydeven and Dahlgren (1982) and Fagerstone et al. (1981) to choose plants that are not abundant on the range colonized. Unlike other ground squirrels, and even other species of *Cynomys*, the black-tailed prairie dog does not store food in its burrow (Koford 1958) or hibernate during the winter.

The first known food habit study (Kelso 1939) found that western wheat grass (*Agropyron smithii*) and six-weeks fescue (*Festuca octoflora*) were most important followed by Russian thistle (*Salsola australus*), prickly pear cactus (*Opuntia* spp.) and saltbush (*Atriplex* spp.). Uresk (1984) found that only four plant species composed 65% of the diet of black-tails in South Dakota, of which grasses accounted for 87% of the diet and forbs composed 12%. Summers and Linder (1978), as well as Fagerstone et al. (1981) and Wydeven and Dahlgren (1982) also found that grasses are the most important component of prairie dog spring and summer diets, sometimes composing up to 90% of the food eaten.

Much controversy has arisen on the food habits of prairie dogs due to the potential for competition with domestic cattle (Uresk and Bjugstad 1983). However, steer weight gain on pastures with and without prairie dog grazing were not statistically significant (O'Melia et al. 1982, Uresk and Bjugstad 1983). Further, preferred plant species overlap between cattle and prairie dogs is not significant (Knowles 1986). Studies of the grazing relationship between bison (*Bison bison*) (Coppock et al. 1983b, Krueger 1986), pronghorn (Krueger 1986), and cattle (Knowles 1986) suggest that prairie dogs increase nutritional value of forage and change grazing habits by increasing shoot nitrogen and reducing standing dead biomass (Detling and Whicker 1987).

Seasonal change in diet is very common and is thought to occur in response to the decreased crude protein and increased fiber of mature plants (Fagerstone et al. 1981). Koford (1958) and Fagerstone et al. (1981) found that during winter, basal parts of buffalograss (*Buchloe dactyloides*), prickly pear cactus, fourwing saltbush (*A.canescens*), and rabbitbrush (*Chrysothamnus* spp.) were important. Shallow digging for roots may also be an important source of protein during winter (Tileston and Lechleitner 1966). During spring, the newly greening vegetation is preferred and the dominant species consumed are Russian thistle, scarlet globemallow (*S. coccinea*) and summercypress (*K. scoparia*). Shifts from C_3 to C_4 plants throughout the summer may occur in response to the subsequent greening of these species. During fall, the green bases of grasses such as buffalograss and blue grama (*Bouteloua gracilis*) are sought (Koford 1958, Fagerstone et al. 1981). Winter food items include mostly roots and prickly pear cactus (Summers and Linder 1978, Wydeven and Dahlgren 1982). Interestingly, prairie dogs have apparently developed the necessary physiology to cope with the oxalic acid occurring in prickly pear, in order to gain its moisture rich benefit in the winter diet (Fagerstone et al. 1981). It has been suggested that prairie dogs choose the most succulent form of vegetation available on a seasonal basis due to water stress (Fagerstone et al. 1981). Grass may compose as much as 85% of its wet weight as water (Hansson 1971), thus providing prairie dogs with the water needed for efficient assimilation (Becksted 1977).

Community Ecology

The potentially disproportionate influence of black-tailed prairie dogs in prairie ecosystems has led their being called keystone species, but this designation has been contentious (Stapp 1998; Miller et al. 2000). Prairie dogs (*Cynomys* spp.) are important members of grassland communities. They affect rangeland habitats by influencing plant species diversity and composition, creating habitat preferred by other wildlife species (May 2004). An estimated 170 vertebrate species have been alleged to rely on prairie dogs for some life needs (Clark et al. 1982; Reading and Matchett 1997; Lomolino and Smith 2003b). Well known obligates of prairie dog colonies include black-footed ferrets (*Mustela nigripes*) (Biggins et al. 1985, Reading 1993) and burrowing owls (*Athene cunicularia*) (Tyler 1968, Sharps and Uresk 1990), both of which depend on prairie dogs for burrow structures and/or food.

Prairie dogs are thought to affect many ecosystem processes (Detling and Whicker 1987) and habitat characteristics (Weltzin et al. 1997b), thereby having direct and indirect influences on the flora and fauna around them. For example, the black-tail's practice of "clipping" tall vegetation from burrow entrances to increase predator detection is similar to grazing and burning rangeland practices that encourage new plant growth, which is more nutritional and palatable to other wildlife species and domestic livestock (Knight 1994; May 2004). Removal of this species from prairie ecosystems could have effects on plant and animal species diversity and abundance over time. Lomolino and Smith (2003b) determined that *C. ludovicianus* towns harbored more rare and imperiled species (i.e., swift fox, black-footed ferrets, and burrowing owls), and therefore a decrease in prairie dogs could be detrimental to these species.

Conservation

Conservation Status

Federal Endangered Species Act

In 1998, two petitions were received by the U.S. Fish and Wildlife Service (USFWS) to list *C. ludovicianus* as threatened under the Endangered Species Act of 1973 (ESA). One petition was filed on July 30, 1998 by the National Wildlife Federation (NWF), and the second petition was received on August 26, 1998 from the Biodiversity Legal Foundation, the Predator Project, and Jon C. Sharps (see USFWS 2004b). These petitions listed several factors that could be major threats to the viability and conservation of *C. ludovicianus*, including habitat loss, habitat fragmentation, disease, unregulated shooting and poisoning, and the synergistic effects of these threats and others. The 90-day finding for the petitions was published in the Federal Register (FR) on March 25, 1999 (USFWS 1999) which stated that the petition action may be warranted. The 12-month finding by the USFWS on February 4, 2000 announced that listing *C. ludovicianus* was warranted but precluded (USFWS 2000), and therefore considered a candidate for listing.

Four of the five necessary conditions for listing were demonstrated (all were met except #2) (VanPutten and Miller 1999). These conditions were:

1. Present of threatened destruction, modification, or curtailment of habitat.
   This condition for listing was met by demonstrating the limiting of habitat, and reduction of populations, that has occurred largely due to agricultural interests.
2. Over-utilization for commercial, recreational, scientific, or educational purposes.
   This condition was not met. However, recreational shooting of prairie dogs may be reinvestigated in the future, depending on regulation of this activity by agencies.
3. Disease or predation
   This condition was met due to the high mortality (99.9%+) of prairie dogs faced with sylvatic plague. Unfortunate epizootics could easily eliminate the population.
4. Inadequacy of existing regulatory mechanisms
   This condition was met due to the classification of prairie dogs as pests in the states in which they occur. Adequate management actions to curtail recreational shooting and poisoning do not exist for many states.
5. Other natural or man-made factors affecting its continued existence.
   This condition was met due to reasons in #4.

Candidate listing required reassessments and resubmitted petitions to be listed annually in the FR (see USFWS 2001, USFWS 2002, USFWS 2004a). From these assessments and available scientific and commercial information it was determined that the petitioned action to list *C. ludovicianus* under the provisions of the Endangered Species Act (ESA) was not warranted on August 18, 2004. As a result, *C. ludovicianus* is no longer considered a candidate for listing (USFWS 2004b). The action to remove *C. ludovicianus* from the ESA candidate list was based on the following determinations: 1) destruction of habitat from agricultural conversion and other factors was no longer a threat, 2) modification of habitat due to the presence of plague was a moderate, imminent threat, 3) the present limitation of habitat due to chemical control was no longer a threat, 4) effects due to scientific or education purposes and commercial use of the species via the pet trade were not threats, 5) recreational shooting could be a low, imminent threat in some circumstances, 6) predation was not a threat, 7) disease was a moderate imminent threat, 8) the inadequacy of existing regulatory mechanisms was a moderate, imminent threat, and 9) chemical control and synergistic effects were moderate imminent threats (USFWS 2004b).

Bureau of Land Management

The State Offices of the Bureau of Land Management (BLM) in Montana, New Mexico, North Dakota, South Dakota, and Wyoming list *C. ludovicianus* on their sensitive species lists. According to the BLM Manual 6840, this designation is meant to provide protection of *C. ludovicianus* and the habitat on which they depend. Therefore the BLM is responsible for reviewing programs and activities on BLM land to determine their potential effect on *C. ludovicianus* (USDOI BLM Wyoming 2001; Keinath et al. 2003).

Forest Service

The range of *C. ludovicianus* encompasses portions of four forest service regions: the central part of the Northern Region (R1), the eastern half of the Rocky Mountain Region (R2), the eastern portion of the Southwestern Region (R3), and the western portion of the Southern Region (R8). Currently *C. ludovicianus* is listed as a sensitive species in Region 2 (http://www.fs.fed.us/r2/projects/scp/) and the subspecies, *C. l. arizonensis* is listed in Region 3 (New Mexico and Arizona; BISON 2004a).

State Wildlife Agencies

The Wyoming Game and Fish Department (WGFD) has developed a matrix of habitat and population variables to determine the conservation priority of all species in the state. Seven classes of Native Species Status (NSS) are recognized, with NSS1 representing critically imperiled species and NSS7 representing stable or increasing species. Classes 1, 2, 3, and 4 are considered to be high priorities for conservation attention. The WGFD assigns *C. ludovicianus* a special concern rank of NSS3. The NSS3 rank is based on WGFD estimates that *C. ludovicianus* populations in Wyoming are declining or restricted in numbers and/or distribution and habitat is restricted and/or vulnerable to human disturbance (Oakleaf et al. 2002; Keinath et al. 2003). Oklahoma also recognizes *C. ludovicianus* as a special management concern. See Table 2 for a complete list of state designations for *C. ludovicianus* across its range.

<u>Heritage Ranks and WYNDD's Wyoming Significance Rank</u>

The Natural Heritage Network assigns range-wide and state-level ranks to species based on established evaluation criteria (e.g., Keinath and Beauvais 2003, Keinath et al. 2003). *Cynomys ludovicianus* merits a global rank of G3 (averaged), which means that when the range-wide population is considered, it is deemed by Heritage scientists as rare or local throughout its range or found locally in a restricted range. This is based on evidence that the extent of occupied habitat and abundance has been reduced from its historic range (NatureServe 2004).

Twelve western states and provinces have assigned a State Rank to *C. ludovicianus*, none of which rank it as demonstrably secure (Figure 7). In general, state ranks are assigned based on the assessed risk of extinction within a state, where S1 species are deemed critically imperiled and S5 species are deemed demonstrably secure. These assessments are based on the biological information on population status, natural history, and threats at the state level. *Cynomys ludovicianus* is ranked as imperiled (S2) in New Mexico, Wyoming, and Saskatchewan; vulnerable (S3) in Kansas, Montana, Oklahoma and Texas; and apparently secure (S4) in Colorado, Nebraska and South Dakota. They are presumed extirpated (SX) in Arizona and their status is under review in North Dakota (SU) (NatureServe Explorer 2004; Keinath et al. 2003, Keinath and Beauvais 2003). The black tailed prairie dog was ranked as imperiled in Wyoming due to the following factors pertaining mainly to large towns (Keinath et al. 2003):

- Their range encompasses a moderate proportion (between 10% and 50%) of the state. Their historic range in Wyoming likely covered about 40% of Wyoming (Clark and Stromberg 1987). However, given fragmentation of habitat suggesting 0.01% of this historic range being occupied (Table 1), prairie dogs may actually cover less than 240,000 acres, or 0.004% of the state (e.g., Luce 2001). Wyoming likely contains about 17% of the historic black-tailed prairie dog range.
- They exhibit low range occupation (<20% of delineated range) and a patchy range-wide distribution. Historic distribution touches several states, including Montana, Wyoming, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas, New Mexico, Arizona, and Colorado, but is quite patchy within this range.
- Their abundance within Wyoming is uncertain but probably declining (due to the intrinsic vulnerabilities and external threats noted below). At the turn of the century, black-tailed prairie dogs occupied more than 40 million acres, but estimates suggest less than 1% of that area is currently occupied (Merriam 1902 as cited in Van Putten 1999; Van Putten and Miller 1999). The area of occurrence is now very patchy (Mulhern and Knowles 1995). In Wyoming about 0.01% of historically occupied land contains currently active colonies (Luce 2001), which correlates to about 600,000 acres. However, estimates of active towns are al low as 130,000 acres (Mulhern and Knowles 1995).
- They have high intrinsic vulnerability due to habitat specificity and susceptibility to disease. Black-tailed prairie dogs are habitat specialists that occur mainly in flat, short and mixed-grass prairies with fine, non-sandy soils (e.g., Hall 1981;Miller et al. 1994; Clippinger 1989). Further, they are very susceptible to plague (*Yersinia pestis*), and Wyoming seems to be experiencing a statewide epizootic as of summer 2001 (personal communications with state land managers).
- They face high extrinsic threats, including active eradication programs, land conversion, and habitat fragmentation. Poisoning, shooting, land conversion can each be a substantial threat to black-tailed prairie dogs, but when combined they can devastate entire populations beyond the point of recovery (e.g. Luce 2001; Gilpin 1999).

The black-tailed prairie dog's Wyoming Contribution Rank is "high," because it is a native resident with a moderate proportion of its otherwise restricted continental range in Wyoming. Further, it has a restricted and patchy continental distribution and is arguably more secure in Wyoming relative to other states (Keinath et al. 2003, Keinath and Beauvais 2003).

Biological Conservation Issues

Abundance and Abundance Trends

No good estimate of *C. ludovicianus* abundance across its range is available, although it is estimated to be in the millions. Abundance of *C. ludovicianus* is generally expressed in terms of surface area (hectares/acres) occupied by their colonies (Miller and Cully 2001), as it is more cost-effective than surveying populations and calculating density. The USFWS believe that estimates of occupied habitat provide the best available and most reasonable means of gauging populations and status of the species across its range (USFWS 2004b). Ground-truthing exercises are currently being carried out in New Mexico, Oklahoma, Texas, and Wyoming; therefore, a better understanding of the accuracy obtained from using surface area occupied (obtained from aerial surveys) to estimate abundance will be gained (Luce 2003; USFWS 2004b). Using recent estimates of active *C. ludovicianus* acreage obtained from aerial and remote sensing surveys, estimates of *C. ludovicianus* abundance was calculated by multiplying each acre by the typical density of individuals per acre in colonies across its range (2 to 18 individuals per acre). From these calculations the most current estimated abundance of *C. ludovicianus* is between 3,684,000 and 33,156,000 (average 18,420,000; USFWS 2004b). At the beginning of the 19th century, *C. ludovicianus* numbered near five billion (see BISON 2004b). Thus the abundance of black-tailed prairie dogs has drastically decreased in the past century. It is estimated that *C. ludovicianus* has been reduced across its western range by about 98 – 99% of its former abundance (Wuerthner 1997).

In Wyoming, Mulhern and Knowles (1995) estimated that between 53,000 and 82,590 hectares were occupied by black-tailed prairie dogs. Estimates from 2003 indicate that *C. ludovicianus* occupy approximately 51,000 hectares, which conforms to the projected decline suggested by Wyoming Game and Fish Department as a result of plague-infested colonies (USFWS 2004b). In Wyoming, habitat loss or modification does not seem to be a large threat to *C. ludovicianus* populations, since very little habitat has been lost within the past 30 years (i.e., only 25,000 acres of rangeland converted to crops) and possible future land conversion is rather unlikely, since Wyoming's climate is not conducive to productive and economic crop growth (WBPDWG 2001). Please refer to Table 1 for a state-by-state account of occupied acreage and Table 2 for population trends throughout *C. ludovicianus* range.

Prior to 2003, most rangeland estimates of *C. ludovicianus* abundance were inconsistent and based on imprecise and cursory information, such as limited aerial surveys, review of available aerial photographs, and estimates from weed and pest control staff (Sidle et al. 2001; USFWS 2004b). These various methods provided incomplete and ad hoc data in order to determine abundance trends. For more valid estimates, methodologies across *C. ludovicianus* range need to be standardized. In addition, colonies need to be surveyed more regularly. Taking these actions will not only provide a more accurate estimate of abundance, but will also help document changes in populations as a result of plague, drought, and habitat alterations (see Inventory and Monitoring below).

<u>Distribution and Connectivity Trends</u>

At the turn of the 1900's black-tailed prairie dogs occupied more than 40 million nearly continuous hectares (Merriam 1902 as cited in Van Pelt 1999), and their range included portions of eleven States, Canada, and Mexico. Less than 1% of that area (< 324,000 ha) was occupied as of 1998 (VanPutten and Miller 1999). Despite the loss of habitat, *C. ludovicianus* are still widely distributed over their original range; although, they now occur in small, fragmented, isolated patches (Miller et al. 2000; USFWS 2004b). Arizona is the only state that the black-tailed prairie dog has been totally extirpated from its former range (Mulhern and Knowles 1995). Reduction in connectivity between colonies has probably had minor impacts on genetic diversity (see Roach et al. 2001, Dobson et al. 2004), but major impacts on recolonization success after serious population reductions (i.e., after plague or eradication efforts; see below).

Range contractions have been most evident in Arizona (now extirpated), western New Mexico, and western Texas through conversion of grasslands to desert shrub lands and in the eastern portion of *C. ludovicianus* range in Kansas, Nebraska, Okalahoma, South Dakota, and Texas through cropland development (USFWS 2004b). Most of the range reduction from agricultural development occurred in the early- to mid-1900s, and is a minimal threat today (see Extrinsic Threats).

The Interstate Black-tailed Prairie Dog Management Team plan states that Wyoming has a fraction (~ 0.01%) of the historical range currently occupied by active colonies (Luce 2003). In Wyoming, there is very little land under cultivation (< 5%), so the levels of land conversion observed in other parts of this species range have not impacted the species as severely. Competition with livestock ranching, and the control efforts that result (see Below), remains the main threat to further loss of species range. Landowner incentive programs may promote the use of some lands, currently used intensively for grazing, for prairie dog habitat.

Extrinsic Threats

The cause of *C. ludovicianus* population declines in the past century can be attributed to 1) intensive eradication programs, 2) agricultural conversion of rangelands, 3) sylvatic plague, 4) urbanization, and 5) recreational shooting. (Wuerthner 1997; Van Pelt 1999). The synergy of these threats may reduce populations drastically. The following section will address these issues. oisoning and shooting of prairie dogs by ranchers, and agricultural conversion of habitat are responsible for the majority of *C. ludovicianus* population decline (Miller et al. 1990, 1994)

Control Programs

Poisoning programs were initiated in the early 1900's when prairie dogs were first deemed an agricultural threat by Merriam (1902 as cited in Van Pelt 1999), with accusations that prairie dogs compete with domestic livestock for forage (Hoogland 1996). Both small-scale (i.e., trapping and drowning) and large-scale (i.e., poisoning and fumigation) eradication programs were used (Barko 1997). Since federal eradication programs were initiated in 1915, many federal land and wildlife management agencies, as well as state agencies, have been responsible for the extirpation of prairie dogs from millions of hectares (Anderson et al. 1986, Mulhern and Knowles 1995). In fact, it is thought that such poison eradication programs were responsible for the extirpation of *C. ludovicianus* in Arizona (see AGFD 1988). Despite modern evidence about grazing relationships (Coppock et al. 1983b, Uresk and Bjugstad 1983, Uresk 1984), and demonstration of the economic inefficacy of poisoning (Miller et al. 1996), this practice has continued into the 1990's with state and federal mandates. Though federal and state agencies have slowed poisoning in 1999 (WYGF 2001), private land owners are still permitted to exterminate prairie dogs from their lands. However, many states, including Wyoming, are developing incentive programs for private landowners to keep prairie dogs on their lands (WYGF 2001). Shooting also occurs for population control across the range of all 5 species in the U.S. (Mulhern and Knowles 1995). The USFWS (2004b) no longer consider control programs a threat to the persistence of *C. ludovicianus* populations across its range; chemical control programs and synergistic effects were considered a moderate imminent threat.

Recreational Shooting

Little is known about recreational shooting affects on *C. ludovicianus* populations; however, it is suggested that recreational shooting would only limit, not extirpate populations (Vosburgh and Irby 1998). Fox and Knowles (1995 in Mulhern and Knowles 1995) state that it would require one recreational day of shooting for every 6ha of prairie dogs to adversely affect populations. In addition, the USFWS (2004b) have found recreational shooting only a low, imminent threat, since it has been recognized that populations are capable of recovering from such adverse impacts. However, in some states, interest in recreational shooting has increased. Some States with large amounts of public land are experiencing increased shooting pressures on prairie dogs (USFWS 2004b). For example, in Wyoming, an increase in requests from the public as to where to shoot prairie dogs has been noted by Wyoming Game and Fish Department, Wyoming Department of Agriculture, and local Chambers of Commerce. This increased interest in prairie dog shooting, both locally and out-of-state has raised some concern that recreational shooting may become a significant contributor to *C. ludovicianus* population declines in Wyoming (WBTPDWG 2001). States concerned with increased recreational shooting are beginning to implement regulations to better monitor and control this activity (USFWS 2004b). Recently, Thunder Basin National Grassland has implemented a no shooting policy on 45,000 acres of prairie dog habitat in northeastern Wyoming (USDA 2004). This ban is one of the first of its kind on public lands. Other States, such as Arizona, Colorado, Montana, and South Dakota have also begun to restrict hunting on *C. ludovicianus* by limiting seasons and/or closing public lands. Still other States have begun to require hunting permits for public lands (Luce 2003). Shooting restrictions extended by some states on black-tails are a positive step; however, some researchers are concerned that it will cause a shift of shooting to the other species of *Cynomys* (VanPutten and Miller 1999).

Habitat Alterations

Reductions in *C. ludovicianus* habitat have occurred across its historical range, as a result of urban development and conversion of rangelands for agricultural purposes. Historically, it was conversion of short- and mixed-grass prairie for agriculture that was the major cause of populations decline, specifically in the eastern range of *C. ludovicianus* (Graul 1980, Dinsmore 1983). However, conversion of habitat from agricultural development is no longer deemed a threat to the persistence of *C. ludovicianus* (USFWS 2004b), since most of the arable land has already been converted (Mulhern and Knowles 1995). This reduced threat is in part a result of research by Sidle et al. (2001) that noted that vast areas of suitable habitat for colonization and expansion of this species still remain, as well as reports that estimate hundreds of millions of acres of potential habitat still remain intact (see USFWS 2004b and Table 1). Along the Front Range in Colorado, urbanization is considered one of the greatest threats to habitat loss (CBOS 1996; CDOW 2003). The USFWS (2004b) recognize that this may be a factor in habitat loss along the Front Range, but does not feel urbanization would present a substantial threat to *C. ludovicianus* across its entire range. In Wyoming, the population of Crook, Cambell, Johnson, Sheridan, and Laramie Counties has increased >10%, Weston, Converse, Platte, and Goshen Counties has increased by <10%, and the only county within *C. ludovicianus* range that has decreased, is Niobrara County (Miller 2001). The associated urban development with the population growth may become more of a threat to *C. ludovicianus* populations than has been present in the past.

Losses in extent and connectivity of native short- and mixed-grassland ecosystems of the Great Plains of North America have been drastic. Historically, *C. ludovicianus* range was continuous and covered >40 million hectares; however, over the past century, this habitat has been fragmented and reduced to less than 600,000ha (Miller and Cully 2001). Fragmentation of grasslands has occurred from such activities as agriculture, urban development (and its associated roads), and oil and gas development (Van Pelt 1999). As a result of this fragmented landscape, colonies have been isolated from one another, disrupting gene flow and successful distribution of dispersing males from their natal colony (Roach et al. 2001). Although habitat has been fragmented and some colonies isolated, it does not appear that this creates a great loss in genetic diversity (see Dobson et al. 2004). On the other hand, if populations are isolated from potential emigrating individuals, and the population within that colony is eliminated, it could become locally extinct. The USFWS (2004a) suggest that isolation of colonies may present a defense against the spread of plague, leaving some remnant populations unaffected and therefore do not deem habitat fragmentation an imminent threat to *C. ludovicianus* populations. In Wyoming, oil and gas development and population increase may become an issue, since suitable *C. ludovicianus* habitat is being developed (see Figure 8).

Although habitat loss appears to be a large threat to *C. ludovicianus* populations, it does appear that this species can adapt to various changes in their habitat. For example, Sidle et al. (2001) documented active *C. ludovicianus* colonies on small patches of grassland surrounded by agricultural development and near housing developments in Nebraska, and in the vicinity of roads and other developments in Wyoming.

Disease

Sylvatic plague (*Yersinia pestis*; known as Bubonic plague in humans) is an exotic bacterial disease that first entered the United States just before the turn of the century (Culley 1989). It was first discovered in the 1940's in Texas (Cully et al. 1997). This disease has profound impacts on populations of prairie dogs (mortality ≥ 99%), which have little to no immunity. The plague can be especially devastating for isolated populations (see Wuerthner 1997). However, isolation of populations as a result of habitat fragmentation may be beneficial in preventing the spread of plague throughout entire metapopulations (see Habitat Alteration above). Plague not only has serious immediate effects, but long term population and demographic effects as well when coupled with shooting and poisoning. In fact the demographic changes imposed by such activities may place the species in an "extinction vortex" that the species may not recover from (Gilpin 1999). Populations west of the Dakotas commonly experience epizootics every 5-7 years (Culley, pers. comm.) and these outbreaks may hold the population level at about 40% of what it was before the epizootic (Knowles 1987).

Plague continues to be a threat to *C. ludovicianus* populations in Wyoming. Nearly all Wyoming populations of white and black-tailed prairie dogs have witnessed declines due to plague outbreaks since the 1930's (WBTPDWG 2001). It is suspected that the plague is responsible for population declines in Wyoming (see Abundance Trends). Important locations of extensive black-tailed colonies, such as Thunder Basin National Grassland, have experienced losses of up to 70% of the total active acreage due to plague epizootics (T. Byer, personal communication).

The movement and maintenance of plague is not well understood (Anderson and Williams 1997) and needs further research. However, it has not yet expanded to cover the species national range. The occurrence of *Y. pestis* is generally west of the Dakotas; however, new reports indicate steady eastward movement in the southern part of the range, into Kansas (Cully et al. 2000). It is thought that the disjunctive and patchy distribution of *C. ludovicianus* populations throughout its range has prevented the devastating affects of plague on populations (WBTPDWG 2001).

Although the USFWS (2004b) considers plague the most important factor influencing black-tailed prairie dogs, they still only view plague as a moderate, imminent threat. They base their findings on the following information: 1) high exposure doses of plague bacilli may be necessary for disease contraction in some individuals, 2) limited immune response has been observed in some individuals, 3) a population dynamic may have developed in low-density isolated populations that contributes to the persistence of these populations, 4) the apparent ability of some sites to recover pre-plague levels after a plague epizootic, and 5) approximately one-third of the species' historic range has not been affected by plague.

Other

Predation of prairie dogs by coyotes (*Canis latrans*), badgers (*Taxidea taxus*), black footed ferrets (*Mustela nigripes*), bobcats (*Lynx rufus*), rattlesnakes (*Crotalis* spp), bullsnakes (*Piuophis melanoleucus*), golden eagles (*Aquila chrysaetos*), prairie falcons (*Falco mexicanus*), and accipiter and buteo hawks (*Accipiter* sp. and *Buteo* sp.) has occurred for as long as these species have inhabited the Great Plains. It is unlikely that these predators present a significant population threat to the species on their own (Hoogland 1981, 1996; WBTPDWG 2001). In addition, coloniality and antipredator calls offer a great predator detection system to minimize predation loss (Linner 2001). However, human predation in the form of recreational shooting may be an important adverse factor (see Recreational Shooting above), since recreational hunting can remove many individuals each day and change the demographic structure of metapopulations (Knowles 1987).

Invasive plant and animal species (other than plague, discussed below) do not appear to be a problem affecting prairie dog abundance or distribution.

Intrinsic Vulnerability

Habitat Specificity and Fidelity

Black-tailed prairie dogs occupy short- and mixed-grass prairie ecosystems, which can vary with respect to plant species composition, soil type, and topography (see Habitat). However, due to the colonial nature of *C. ludovicianus*, high fidelity for their habitat, once selected, is demonstrated. A loss of utilized habitat may cause populations to decrease.

Territoriality and Area Requirements

Within colonies, family groups (coteries) are extremely territorial defending their territory from other coteries (Hoogland 1995). Coterie's territories usually occupy about one-third of a hectare (Hoogland 1996); however, coteries occupying areas as large 1.01 hectares have been documented (Hoogland 1995). Since individuals of a coterie obtain 99% of their food and other resources within their territory, size and habitat quality is important (Hoogland 1995). Hof et al. (2004) estimated that one hectare could successfully maintain 18.4 individual prairie dogs. However, this number may be high for Wyoming. For example, when compared with other states within *C. ludovicianus* range, it appears that populations within Wyoming require larger tracts of land per colony, averaging 13 – 764 hectares per colony (see Clark et al. 1982). Fragmentation that reduces habitat availability may be detrimental to the populations.

Susceptibility to Disease

Although coloniality is thought to benefit communities of *C. ludovicianus* (i.e., predator detection), coloniality also promotes the spread of disease, which could significantly suppress local populations (Linner 2001). For example, sylvatic plague (*Yersinia pestis*), an exotic bacterial disease that first entered the United States just before the turn of the century (Culley 1989), has profound impacts on populations of *C. ludovicianus* (mortality ≥ 99%), which have no immunity. Plague can spread across whole *C. ludovicianus* complexes in just a few years (e.g., Anderson and Williams 1997, Cully and Williams 2001). Plague not only has serious immediate effects (mortality), but long term population and demographic effects, such as local extirpation of colonies, reduced colony size, increased variance in local population sizes, and increased distances between colonies. The latter can reduce the effectiveness of dispersal among colonies to recolonize after local extinction and increase the probability of extinction for entire complexes (Culley and Williams 2001). The effects of plague on populations are even more devastating when coupled with shooting and poisoning. In fact the demographic changes imposed by such activities may place the species in an "extinction vortex" that *C. ludovicianus* may not recover from (Gilpin 1999). Populations west of the Dakotas commonly experience epizootics every 5-7 years (Culley, pers. comm.) and these outbreaks may hold the population level at about 40% of what it was before the epizootic (Knowles 1987).

In Wyoming plague continues to be a threat to black-tail populations. The disease has not yet expanded to cover the species national range, but nearly all Wyoming populations of white and black-tailed prairie dogs have witnessed declines due to plague outbreaks. Important locations of extensive black tailed colonies, such as Thunder Basin National Grassland, have experienced losses of up to 70% of the total active acreage due to plague epizootics (T. Byer, personal communication). The movement and maintenance of plague is not well understood (Anderson and Williams 1997) and needs further research. The occurrence of *Y. pestis* is generally west of the Dakotas. However, new reports indicate steady eastward movement in the southern part of the range, into Kansas (Cully et al. 2000).

Dispersal Capability

Cynomys ludovicianus are capable of dispersing from natal colonies as far as 5km; however, *C. ludovicianus* will rarely disperse beyond the natal colony due to predatory risk without the warning "predator" calls of conspecifics (see Dispersal). In fact, it is estimated that survival rate decreases by 40% for each 5km dispersal distance (Hof et al. 2002). Roach et al. (2001) showed that prairie dogs within a $264km^2$ area of the Central Plains Experimental Range and Pawnee National Grasslands in northern Colorado had a dispersal rate among established colonies of about 39%. It is largely unknown how often *C. ludovicianus* disperse to previously unoccupied sites, but is thought to be rare. Garret and Franklin (1988) demonstrated that dispersal rates increased as available food resources decreased. In highly fragmented colonies (i.e., urban and agricultural development), dispersal capability may be limited. The inability to disperse may create areas of high population density, increased competition for resources, and result in decreased habitat quality, which may lead to population decline and increased inbreeding (see Johnson and Collinge 2004). Other factors that could affect the dispersal of *C. ludovicianus* is the availability of high-visibility corridors or attractants such as chirping of other prairie dogs (Hof et al. 2002).

Reproductive Capacity

Hoogland (2001) demonstrated that *C. ludovicianus* have lower intrinsic rates of increase and are consequently more vulnerable to colony extinction than most other rodents. Five factors are responsible for this slow reproduction: 1) survivorship is <60% in the first year, 2) only one litter/year is produced, even under optimal conditions, 3) only 6% of males copulate as yearlings, 4) the probability of weaning a litter each year is only 43%, and 5) mean litter size at first juvenile emergence is usually 3.08. In addition, females may breed in their first year, but generally do not breed until their second year. On top of that, free-ranging species may only live three – to four years (Hoogland 1995). As a result, *C. ludovicianus* are slow to recover from population crashes such as a plague epizootic and must rely on recolonization from other colonies to recover or reestablish (see Metapopulation Dyamics). Cincotta et al. (1987) suggest that dispersing prairie dogs do not reproduce during their first year in a new colony. This may also play a factor in reproductive capacity. In spite of these facts, some researchers have suggested that *C. ludovicianus* are capable of rapid population increases subsequent to substantial reductions (see USFWS 2004b).

Protected Areas

In some areas of the species range, prairie dogs are protected from anthropogenically induced effects on national monuments, wildlife refuges and specially protected areas of federally managed lands. One such area is a shooting restricted zone in Thunder Basin National Grassland, Wyoming which provides approximately 20,000 acres. However, in contrast to the species range as a whole, the amount of protected area present is a very small percentage. The lack of large tracts of protected prairie dog range has caused some concern among managers due to the inter-colony dispersal that must occur to ensure long term survival of colony complexes that necessarily span large areas of land. As conservation plans are formulated and adopted by various management agencies, the amount of protected area is expected to increase. However, the extent of protections afforded and the extent of land thus impacted is currently uncertain.

Population Viability Analyses (PVAs)

For purposes of intensive management a suitable PVA has not been developed (Luce 2001). However, an interactive, web-based PVA model has been completed by Michael Gilpin at San Diego State University (SDSU) and contracted with the USFWS is available to view and use at http://gemini.msu.montana.edu/ ~mgilpin.prairie_dog.html. This PVA gives an excellent overview of many aspects of prairie dog management including an introduction to the metapopulation structure of black-tails. The interactive "applets" allow the user to manipulate varying conditions that effect population size and persistence such as plague and shooting.

Conservation Action

Existing Conservation Plans

The eleven states within the range of *C. ludovicianus* began a multi-state conservation effort in 1998 to promote conservation and avoid the federal listing of *C. ludovicianus*. The Black-Tailed Conservation Assessment and Strategy (CA&S) was developed in 1999. The purpose of the CA&S is to manage, maintain, and enhance habitat and populations of *C. ludovicianus* across its historic range and reduce the number of threats impacting their viability through the cooperation of private, tribal, federal, and state landowners. It provides actions, opportunities, and incentives for interested parties to become involved with conservation efforts of *C. ludovicianus*, as well as management suggestions such as eliminating mandatory control, regulating seasons or possession limits, maintaining and conserving required habitat and ecosystems, and establishing core populations on public lands to provide animals for dispersal to uninhabited areas or individuals for recolonization (Van Pelt 1999). In 2003 a Multi-State Conservation Plan (MSCP) was completed as an addendum to the CA&S to provide guidelines under which adaptive management plans will be developed by individual states and their respective working groups representing all stakeholders viewpoints (see Luce 2003). Currently ten of the eleven states in the range of *C. ludovicianus* have developed or drafted state prairie dog management plans: Interagency Management Plan for Black-Tailed Prairie Dogs in Arizona (Van Pelt et al. 2001), Conservation Plan for Grassland Species in Colorado (CDOW 2003), Kansas Black-Tailed Prairie Dog Management Plan (Kansas Department of Wildlife and Parks 2002), A Species Conservation Plan for the Black- and White-Tailed Prairie Dogs in Montana (Knowles 1999), New Mexico, North Dakota, Oklahoma (see Luce 2003), South Dakota Black-tailed Prairie Dog Management Plan (Cooper and Gabriel 2005), Texas Black-Tailed Prairie Dog Conservation and Management Plan (TBTPDWG 2004), Draft Wyoming Black-Tailed Prairie Dog Management Plan (Kruckenberg et al. 2001; WBPDWG 2001). Together, the CA&S, the MSCP, and the eleven state management plans hope to remove enough threats to *C. ludovicianus* in order to curtail needs for listing under the ESA while allowing for more flexible management practices. The following target objectives were created in the MSCP to help achieve this goal:

1. Maintain at least the currently occupied acreage of black-tailed prairie dogs in the U.S. (see Table 1).
2. Increase to at least 1,693,695 acres of occupied black-tailed prairie dog acreage in the U.S. by 2011.

3. Maintain at least the current black-tailed prairie dog occupied acreage in the two complexes greater than 5,000 acres that now occur on the adjacent to Conata Basin-Buffalo Gap National Grassland, South Dakota, and Thunder Basin National Grassland, Wyoming.
4. Develop and maintain a minimum of 9 additional complexes greater than 5,000 acres (with each state managing or contributing to at least one complex greater than 5,000 acres) by 2011.
5. Maintain at least 10% of total occupied acreage in colonies or complexes greater than 1000 acres by 2011.
6. Maintain distribution over at least 75% of the counties in the historic range or at least 75% of the historic geographic distribution.

The issue of recreational shooting is slowly being addressed over much of the range of black-tailed prairie dogs. Licenses that were previously un-necessary to shoot *C. ludovicianus* are now required in all states except Montana and Wyoming. However new management ideas have been presented by the Wyoming citizen's working group. These ideas include: temporary closing of shooting if population numbers decline to 15% above objective (200,000 acres) from current levels, develop management units/licensing protocols, and work with the public to develop management strategies (WYGF 2001). In Wyoming, shooting restrictions were enacted on focal populations in Thunder Basin National Grassland during the spring of 2001 to allow populations to expand in anticipation of black-footed ferret reintroduction. Future yearlong closures are proposed by the Wyoming Game and Fish Department (WYGF) for areas considered as important focal regions for conservation of the species (WYGF 2001). Wyoming G&F has begun to develop a memorandum of understanding (MOU) between agricultural, weed and pest, and wildlife commissions to limit poison distribution and to develop land owner incentives for keeping prairie dogs on their lands (WYGF 2001).

The National Forest Service (NFS) has also adopted management strategies to conserve *C. ludovicianus* on NFS lands (i.e., Thunder Basin National Grassland, Dakota Prairie Grasslands, and Nebraska National Forest Land) which are occupied (>70%) by *C. ludovicianus* populations (USDA 2004). These strategies include guidance and directions for the use of rodenticides, landownership adjustment, vegetation management, livestock grazing, prairie dog shooting/hunting, and other management options to either expand or limit growth of prairie dog populations and colonies on NFS lands (see USFWS 2004c).

Conservation Elements

Although *C. ludovicianus* has not been listed as threatened or endangered by the Endangered Species Act, the long-term decline in abundance and distribution across its historic range suggests that there is a need to undertake conservation actions to mitigate such a decline while viable populations still exist. This need is compounded by the fact that the *C. ludovicianus* provides habitat and a food source for a variety of wildlife species, including the endangered black-footed ferret (see Community Ecology). In Wyoming, conservation efforts should be attentive, since far less habitat has been lost in Wyoming than in most other states within the species' distribution (WBTPDWG 2001) and only 79% of suitable habitat is currently occupied by *C. ludovicianus* in Wyoming (see Table 1). Five main conservation elements should be addressed for *C. ludovicianus* conservation management in Wyoming. For more rangewide suggestions, please review Van Pelt (1999). Specific approaches that have been proposed to address these conservation elements are provided in the following section.

1. **Habitat Conservation**: Reduce conversion of land to uses not compatible with local persistence of *C. ludovicianus* and minimize impacts of semi-compatible uses, including livestock grazing and resource extraction.
2. **Disease Control**: The spread of disease (specifically sylvatic plague) among *C. ludovicianus* should be investigated and management should seek to minimize its impacts on prairie dog complexes.

3. **Shooting and Extermination Control**: Unless strictly controlled, recreational shooting and pest control efforts aimed at killing *C. ludovicianus* are not compatible with healthy populations.
4. **Inventory and Monitor Populations**: Current monitoring efforts are insufficient to generate reliable and comparable trend information and are therefore inadequate to track the future of *C. ludovicianus* populations. A thorough and consistent methodology must be applied in Wyoming and across its range, as discussed in the Inventory and Monitoring section below.
5. **Public Education**: In order to apply the above mentioned conservation elements to successful management programs in Wyoming, public attitudes toward prairie dogs need to change. Literature citing the importance of *C. ludovicianus* to rangeland habitat and its associated species need to be easily acquired and come in a variety of materials (i.e., brochures, videos, information boards, etc.).

Acting on Conservation Elements

There are many state citizens' working groups that have developed or are currently drafting conservation plans for *C. ludovicianus* and provide suggestions for management practices for *C. ludovicianus*. In addition, research published that focused specifically on *C. ludovicianus* has also provided management suggestions that may provide the best opportunity to conserve preferred habitat and viable populations of *C. ludovicianus*.

1. **Habitat Conservation**: It appears that conservation efforts to protect lands currently occupied (and adjacent) by *C. ludovicianus* is beneficial for maintaining or increasing abundance (see Table 2). Identifying tracts of lands occupied by *C. ludovicianus* (especially those >5,000 acres; see Van Pelt 1999) should be conducted through coordinated efforts of all federal agencies to maximize the conservation potential and preserve, if not increase, occupied habitat. In Wyoming, this objective is no less than 200,000 acres (WBTPDWG 2001). Maintaining large tracts of land will provide enough acreage and *C. ludovicianus* population to support reintroduced and recovering black-footed ferret populations, as well as other associated species (Luce 2003). Lomolino et al. (2003) suggest a mixed strategy for preserving habitat: maintain or develop widely

distributed large and small complexes (connected for dispersal purposes; Roach et al. 2001), and retain small and large isolated colonies throughout the range to help create barriers to prevent spread of the plague and potential eradication of metapopulations. Create buffers (~75 feet) around protected areas to provide area for expansion. In cases where adjacent land is not compatible with prairie dog colonies (i.e., hay or crop fields), create barriers beyond the buffers (i.e., tall grasses) to prevent establishment and/or foraging in these sites (CBOS 1996). Provide incentives for private landowners to voluntarily maintain prairie dog colonies on portions of their lands, since conserving *C. ludovicianus* habitat is not fully possible without the assistance of private landowners. In Wyoming, this is important, since private land constitutes a large percentage of total prairie dog habitat (WBTPDWG 2001). The multi-state conservation plan outlines a possible incentive program that could be pursued by individual states under such authorities as the Conservation Title of the Farm bill, Conservation Reserve Program, or Grasslands Reserve Program in Appendix E (Luce 2003). In addition, impacts that could adversely affect established or potential *C. ludovicianus* through urban, oil, and/or gas development should be minimized or eliminated. The following are suggestions to mitigate habitat alteration:

- Identify suitable habitat and current colonies before proposed oil and gas exploration and urban development sites are initiated.
- Determine local population densities, quality of habitat, spatial distribution of colonies and habitats (for connectivity and dispersal purposes), and how activities (i.e., drilling) may impact these factors.
- Locate roads outside areas of current, recent, or potential prairie dog habitats identified.
- Place restrictions on vehicle traffic (for mining operations) during the breeding season and dispersal (March through August) to help minimize stress and possible increased infanticide.

2. **Disease Control**: Currently there are no known vaccines to immunize *C. ludovicianus* against threat of the plague. However, steps can be taken to mitigate plague impacts. The multi-state conservation plan (Appendix D; Luce 2003) provides a plague protocol for all eleven states to initiate. It includes a plague monitoring protocol, procedures for visual evaluation of prairie dog colonies for plague, field procedures for collecting and handling

carcasses as diagnostic specimens, and procedures for swabbing rodent burrows. It is important to identify colonies in which the plague affected populations, and try to isolate these colonies from other complexes to stop the spread of the disease. In this case, colonies should be greater than 3km from their nearest neighbor colonies (Cully and Williams 2001). In addition, implementing the suggested mixed-strategy complex design (connected complexes with isolated colonies) will help reduce disease transmission, while maintaining some vital corridors to facilitate repopulation of eradicated populations (see Lomolino et al. 2003).

3. **Shooting and Extermination Control**: Unless strictly controlled, recreational shooting may not be compatible with healthy populations of prairie dogs, altering behavior and reproductive success, especially if this activity increases (Reeve, personal communication; Vosburgh and Irby 1998; USFWS 2004b). Further, unlike some threats (e.g., disease) it is well under the control of land managers. Optimally, shooting should be eliminated, particularly on otherwise impacted towns (i.e., large plague epidemics). During the past few years, several states have established better regulations (i.e., closures and season restrictions) that allow for management of recreation shooting; as well, they have changed the status of species from pest to a designation that recognizes the need for management. However, inn Kansas, North Dakota, and Wyoming, *C. ludovicianus* is still considered a pest and controlled as such (Luce 2003). The following are some restrictions that could help regulate recreational shooting of *C. ludovicianus* to assist in the conservation and protection of the species (Luce 2003):

   - Seasonal closures to all shooting during whelping and dependent young period (March 1 to June 30).
   - Require permits specific to designated areas and limit take.
   - Collect data on harvest (i.e., age and sex of animals harvested), hunter days per county, and hunter days/harvested animal through annual field checks and mail surveys, allowing State Wildlife Agencies to accurately quantify annual harvest.

   In Wyoming, *C. ludovicianus* is considered a pest and management is overseen by the Wyoming Weed and Pest Council, Board of Agriculture, and Wyoming Game and Fish Commission. Currently a memorandum of understanding is being drafted in which these agencies agree to limit the distribution of poisons and their participation in poisoning efforts when survey results indicate conservation plan objectives (i.e., acreage) is in jeopardy. Temporary restrictions on agency poisoning or cooperation with landowners using poison or other control methods should be implemented at local levels when necessary (i.e., poisoning compounding impacts by other threats to populations; WBTPDWG 2001).

4. **Inventory and Monitor Populations**: Conducting a baseline, state wide inventory of the number of acres contained within is crucial for long term population monitoring of this species. This information will allow management agencies to develop population targets, identify important population centers throughout the state, and give a measurable level of increase or decrease in population size under new management regimes. Sidle et al. (2001) present new estimates of prairie dog abundance in four states that are critically important to conservation of *C. ludovicianus*, and present a new aerial survey technique for abundance estimation that is replicable, includes estimates of precision, and does not require trespass permission from private landowners (Miller and Culley 2001; Sidle et al. 2001). It is important that methods range-wide are compatible with each other for comparison. The following strategies were outlined in the Wyoming conservation plan (WBTPDWG 2001):
    - Develop a cooperative effort to fund and conduct research and regularly scheduled inventories.
    - Continue to develop remote census techniques (i.e., Sidle et al. 2001).
    - Evaluate aerial transect techniques to identify the approach and sampling design best suited for Wyoming (see Appendix IX).
    - Conduct selected techniques in areas where ground surveys are being conducted (e.g., Thunder Basin National Grasslands) and evaluate accuracy and precision of techniques.
    - Coordinate with adjacent states to assure that results will be comparable.
        - Select a reliable method, and initiate inventories to document occupied habitat (initiated July 2002).
        - Conduct monitoring survey at three-year intervals from 2002.
5. **Public Education**: Lamb et al. (2001) conducted an eleven state survey within short-grass prairie systems regarding the public's attitude and knowledge of black-tailed prairie dogs.

Overall, the public did not highly regard *C. ludovicianus* and did not consider conservation of *C. ludovicianus* of great importance when compared with larger environmental issues, such as global warming. People will only value grasslands and prairie dogs to the degree that they understand them. Therefore, education of prairie dog may increase the desire to manage prairie dogs, especially since the anti-prairie dog attitude is still pervasive in federal, state, and public views (Knowles 1999; Lamb et al. 2001). Education and outreach materials should cover many topics including but not limited to prairie dog management, prairie dog ecology, plague, and effects of prairie dogs on rangelands and agricultural land. It is important that outreach materials and education programs are factual and represent interests of all stakeholder groups (TBTPDWG 2004). Examples of educational techniques could be: in-school presentation, nature hikes, slide presentations, brochures, and interpretative displays (CBOS 1996).

Habitat Preservation and Restoration

Habitat fragmentation and transformation of the Great Plains grasslands biome has been the most extensive of any in North America. This habitat alteration has impacted the continuity of large, historic habitat needed to establish extensive networks of prairie dog colonies and maintain inter-colony genetic diversity. Clearly, this is an important component of future conservation efforts. Programs that create, protect, and restore suitable habitat and connectivity offer some promise to provide habitat for successful prairie dog colonies/populations.

Roe and Roe (2003) offer guidelines to be used when selecting habitat for *C. ludovicianus* relocation efforts, which could be used for habitat restoration/preservation efforts (see Table 3). The guidelines present environmental parameters specific to soils, vegetation height, cover, and palatable species, slope, and optimal proximity to other established prairie dog colonies. In addition, Lomolino and Smith (2003b) and Lomolino et al. (2003) recommend conserving a network of native prairie reserves strategically located across the historic range of *C. ludovicianus*. They suggest that the network be comprised of “clusters” of large (presumably >10 ha, but size is not directly specified by the authors) towns, as well as large, isolated towns. The latter will be less likely to be infected or serve as a source for spread of the plague. Large towns will also be more likely support populations of *C. ludovicianus* and other associated vertebrates into the future (Lomolino and Smith 2001), buffering adverse effects from various extrinsic extinction forces (i.e., land conversion, expansion of roads, habitat reduction and fragmentation, and plague).

When restoring habitat for reintroduction of *C. ludovicianus*, whether to provide a food-base for black-footed ferrets, or to reestablish *C. ludovicianus* in their historic range, long-term planning is needed, as well as sufficient 1) area of land and habitat, 2) pre-introduction ecological studies and site preparation, 3) breeding individuals to make a reproducing population, 4) protection, and 5) monitoring and follow up studies (AGFD 2004).

Information Needs

Identifying specific information needs will help management agencies to formulate appropriate conservation strategies by targeting key areas needed for effective conservation of the species. The following list briefly notes some of the key information needed to develop sound *C. ludovicianus* conservation strategies.

1. **Inventory/Monitoring**: The development of long term monitoring and inventory of black-tailed prairie dog populations is needed. Without a way to reliably and quantitatively determine trends in abundance and distribution, managers have no way to assess the status of *C. ludovicianus* populations or the effect of management actions on these populations. Inventories should determine locations and sizes of colonies, land ownership, and presence of plague. Monitoring of known *C. ludovicianus* populations will help managers assess the affects of impacts, such as oil and gas projects, on population trends. Remote sensing and aerial and ground techniques need to be developed and standardized among agencies to ensure validity, smooth information flow, and communication (see Sidle et al. 2001).

2. **Disease**: Plague continues as one of the most detrimental threats to this species longevity and healthy population growth. Although some research has investigated the dynamics of plague in prairie dog colonies, there are still huge questions regarding its prevalence, cycle of occurrence, and distribution in the natural environment. Managers need to know how plague spreads between colonies and how it is maintained within colonies. Strategies allowing managers to predict and mitigate epizootics is very important given the catastrophic impact this disease has had on prairie dogs; for instance, field trials of vaccinations or parasite management strategies and/or real-time, large-scale, high-resolution mapping of epidemics. It is unknown if prairie dogs may one day develop immunity to the disease or if virulence will stay high.
3. **Shooting and Poisoning**: Recreational shooting effects have been studied preliminarily (Knowles 1987, K. Gordon, pers. comm.), but further research is needed to fully understand the impact of this activity on demographic structure and population dynamics. Depending on the outcome of ongoing studies, shooting may continue in some areas, but regulation and monitoring of this activity are keys to controlling its effects as evidenced by many years of hunting regulation for game species.
4. **Ecological Ramifications**: More research is needed on the long-term effects of *C. ludovicianus* on floral, faunal, and soil communities to determine if they are indeed a keystone species, and important for the persistence of a variety of species (see Community Ecology above).

Tables and Figures

Table 1: Baily Eco-Region habitat model distributions for each state (Native American tribes in Montana, South Dakota, and North Dakota set acreage objectives independent of states.)

State	Historic Habitat*	Current Habitat	Gross Habitat**	Suitable Habitat***	Minimum 10-Yr Objective
AZ	7,047,137	0	7,047	4,594	4,594
CO	27,352,880	631,102	273,529	255,773	255,773
KS	35,835,079	130,521	150,714	148,596	148,596
MT	60,442,757	90,000	297,286	240,367[1]	240,367[1]
NE	36,035,433	80,000	146,741	137,254	137,254
ND	11,045,269	20,500	110,453	100,551[2]	100,551[2]
NM	39,021,449	60,000	96,661	87,132[3]	87,132[3]
OK	21,606,120	22,000	70,868	68,657	68,657
SD	29,262,553	160,000	218,121	199,472[4]	199,472[4]
TX	78,592,452	167,625	310,945	293,129	293,129
WY	22,067,599	125,000	179,072	158,170[5]	158,170[5]
Total:	368,308,727	1,486,748	1,861,436	1,693,695	1,693,695

* Refers to total potential habitat encompassed within the range (Hall 1981), not occupied habitat

** Gross habitat = total acreage of primary range x 1% + total acres of peripheral range x .1% (Table 2 and Figure 3)

*** Suitable habitat = gross habitat minus habitat with >10% slope, or other unsuitability factors (Agricultural lands were included in suitable habitat if they fit the slope and suitability factors)

1 The acreage objective in the State of Montana's 2001 Management Plan is 90,000-104,000 acres for non-tribal lands. The state's acreage objective will be subject to modification in response to a financial incentives program for landowners if an incentives program is funded. Separate objectives will be set by individual Native American tribes.

2 The current acreage objective listed in the North Dakota Management Plan is 33,000 acres, including non-tribal and tribal lands. The state of North Dakota and the Standing Rock Indian Reservation will determine the target acreage for each jurisdiction. The state is willing to consider an objective of 100,551 acres on non-tribal lands if a financial incentives program for private landowners is funded. Tribal lands will have separate acreage objectives.

3 The New Mexico acreage objective is based on a percent increase per year, which would take approximately 10 years to achieve the current acreage objective. If future statewide survey efforts indicate a different acreage than the estimated minimum current acreage listed, the rate for achievement of the 10-year objective will be adjusted accordingly.

4 The acreage objective for South Dakota includes 169,551 acres of non-tribal lands and 29,921 acres of tribal lands (pending final approval of management plan).

5 Wyoming's draft management plan contains an objective to maintain the current acreage, or 200,000 acres, which ever is greater.

Table 2: Overview of *C. ludovicianus* status throughout its range.

Country	State/Province	State Status (May 2004)	Heritage Rank	BLM Species of Concern	Population Trend (USFWS 2004b)
United States					
	Montana	Nongame Wildlife; Pest	S3	yes	Decreasing[3] Increasing/Stable[4,5]
	North Dakota	Nongame Wildlife	SU	yes	Stable?/Decreasing?
	South Dakota	Game Wildlife; Varmint	S4	yes	Increasing/Stable[4]
	Wyoming	Species of Special Concern	S2	yes	Decreasing[3] Stable[4]
	Nebraska	Nongame Wildlife	S4	nr	Absent[6] Increasing[4]
	Kansas	Wildlife	S3	nr	Absent[6] Increasing[4]
	Colorado	Small Game Species	S4	nr	Decreasing[1,3] Increasing[4,5]
	New Mexico	No Legal Listing	S2	no	Absent[6] Stable?
	Arizona	Extirpated; Nongame mammals	SX	no	Extirpated[1,2]
	Oklahoma	Species of Special Concern	S3	nr	Absent[6] Stable?
	Texas	Nongame Wildlife	S3	nr	?
Canada					
	Saskatchewan	Special Concern	S2	n/a	Stable[4]
Mexico					
	Amenazada	Threatened	n/a	n/a	Absent[1,2,6] Stable[4]

Heritage Rank: SU = unknown, SX = extirpated, S2 = imperiled, S3 = vulnerable, S4 = apparently secure

BLM Species of Concern:
- yes = the State's BLM office recognizes *C. ludovicianus* as a Species of Concern
- no = the State's BLM office does not recognize *C. ludovicianus* as a Species of Concern
- nr = not reported

Population Trend: 1 = habitat conversion, 2 = control efforts, 3 = plague, 4 = habitat preservation, 5 = recovered, 6 = absent from historic range, ? = not enough information

Table 3: Guidelines for *C. ludovicianus* habitat restoration and preservation. Adapted from Roe and Roe (2003).

Parameters		Description
Vegetation	species	western wheatgrass (*Pascopyrum smithii*), blue grama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), sand dropseed (*Sporobolus cryptandrus*), cheatgrass (*Broums tectorum*), sixweeks fescue (*Vulpia octoflora*), ring myhly (*Muhlenbergia torreyi*), sedges (*Carex* spp.), scarlet globemallow (*Sphaeralcea coccinea*), and plains prickly pear (*Opuntia polyacantha*).
	cover	<40% bare ground; shortgrass prairie grasslands 58-70%; …
	height	<30cm
Soil	depth	≥2.0m
	type	loamy with little to no gravel; low in clay (<30%); meduim in sand (~50%); medium to high in silt (>70%) with good drainage.
Slope		< 20%; preferably ≤10%
Proximity to established colonies		≥46m and up to 185-277m

Figure 1: Photograph of adult and juvenile black-tailed prairie dog, Devils Tower National Monument, WY, © Steven W. Buskirk

Figure 2: Drawing of skull morphology of *C. ludovicianus*, adapted from Hoogland (1981).

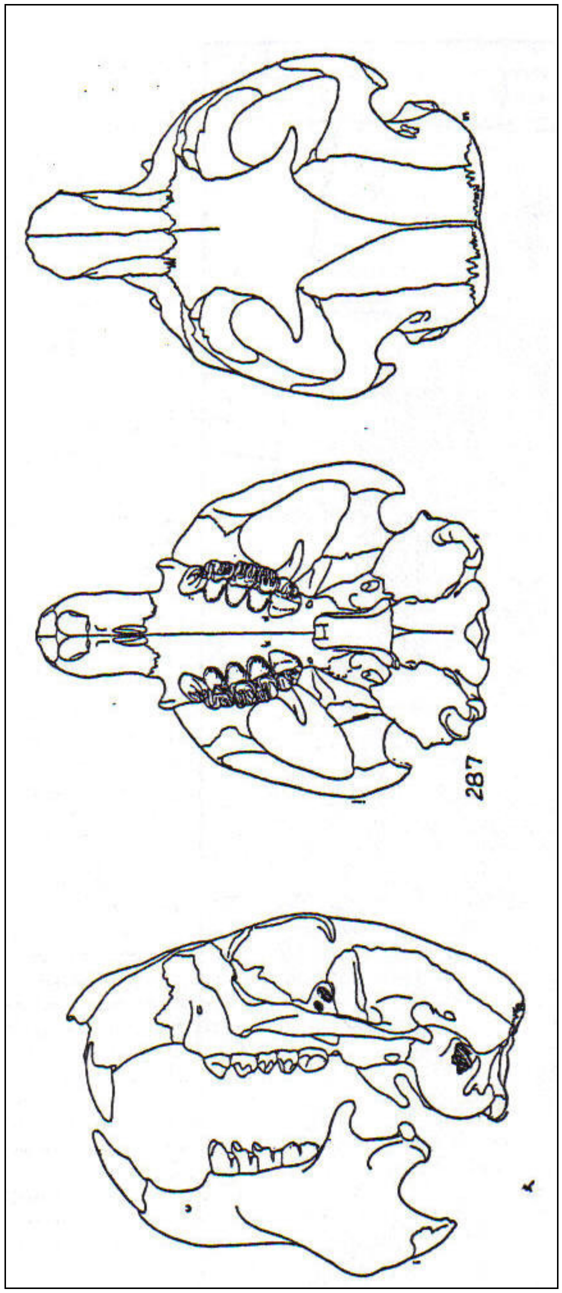
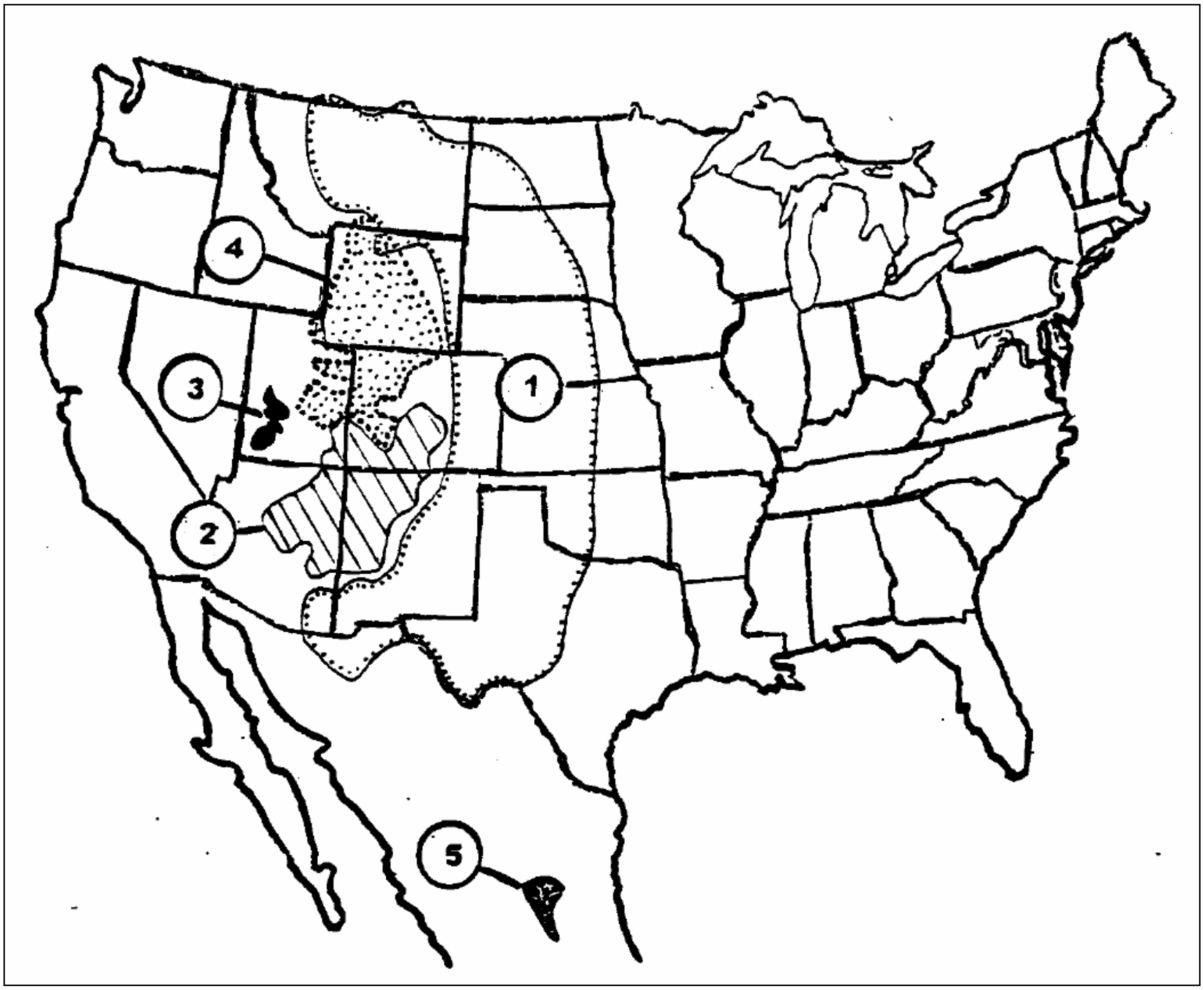


Figure 3: North American range of all prairie dog species from Hall (1981).



1. Black-tailed prairie dog
2. Gunnison's prairie dog
3. Utah prairie dog
4. White-tailed prairie dog
5. Mexican prairie dog

Figure 4: Possible distribution of *C. ludovicianus* based on mixed-grass and short-grass prairie distribution in eastern Wyoming (map acquired from WYGISC website: www.wygisc.uwyo.edu).

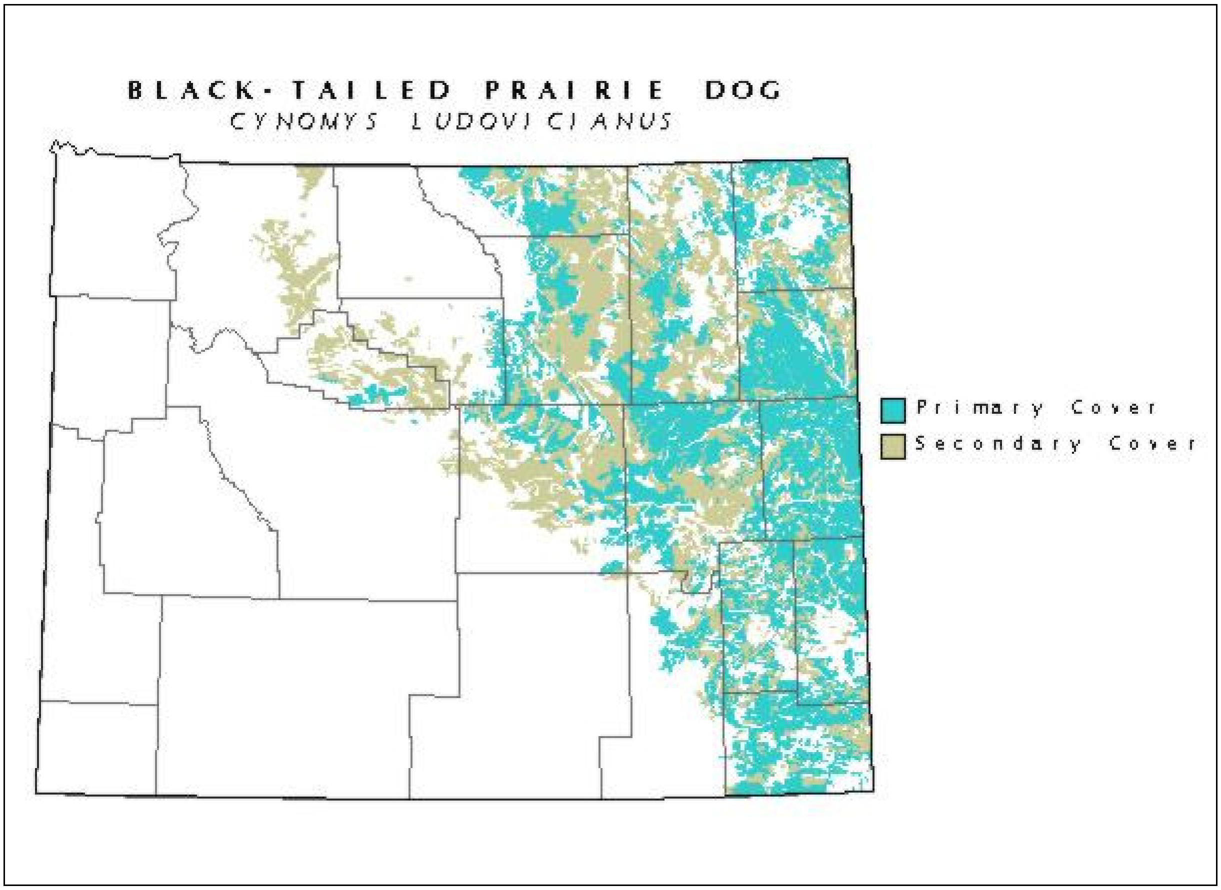


Figure 5: Rangewide distribution of the black-tailed prairie dog. Outline is the historic distribution from Hall (1981) and the shaded portion of the range map is from State surveys. This map does not include current distribution of populations in Canada and Mexico (acquired from Luce 2003).

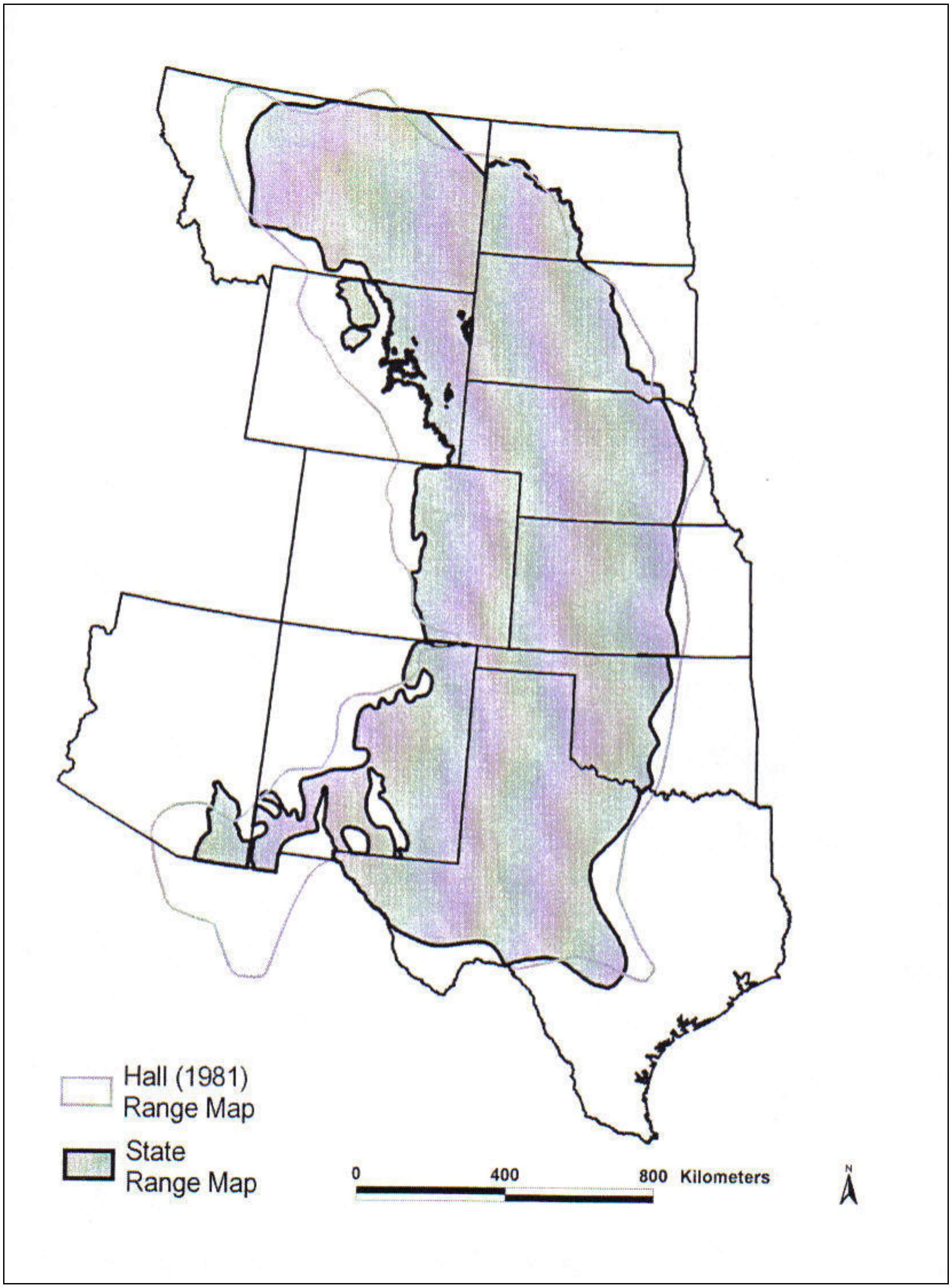


Figure 6. Loop diagram depicting a) life cycle and b) related matrix model elasticities for female black-tailed prairie dogs (*Cynomys ludovicianus*) (courtesy J. Pauli, University of Wyoming). Pi denotes the probability of surviving to the next age class and Fi denotes the fertility of that age class. eij denotes the elasticity from age class j to age class i. Although female black-tailed prairie dogs can reach an age of 9, age classes >6 were excluded in elasticity analyses because older age classes fail to reproduce. The basic loop diagram was constructed from J. Hoogland's 14 year study (1975-1988) of black-tailed prairie dogs in Wind Cave National Park (Hoogland 1995).

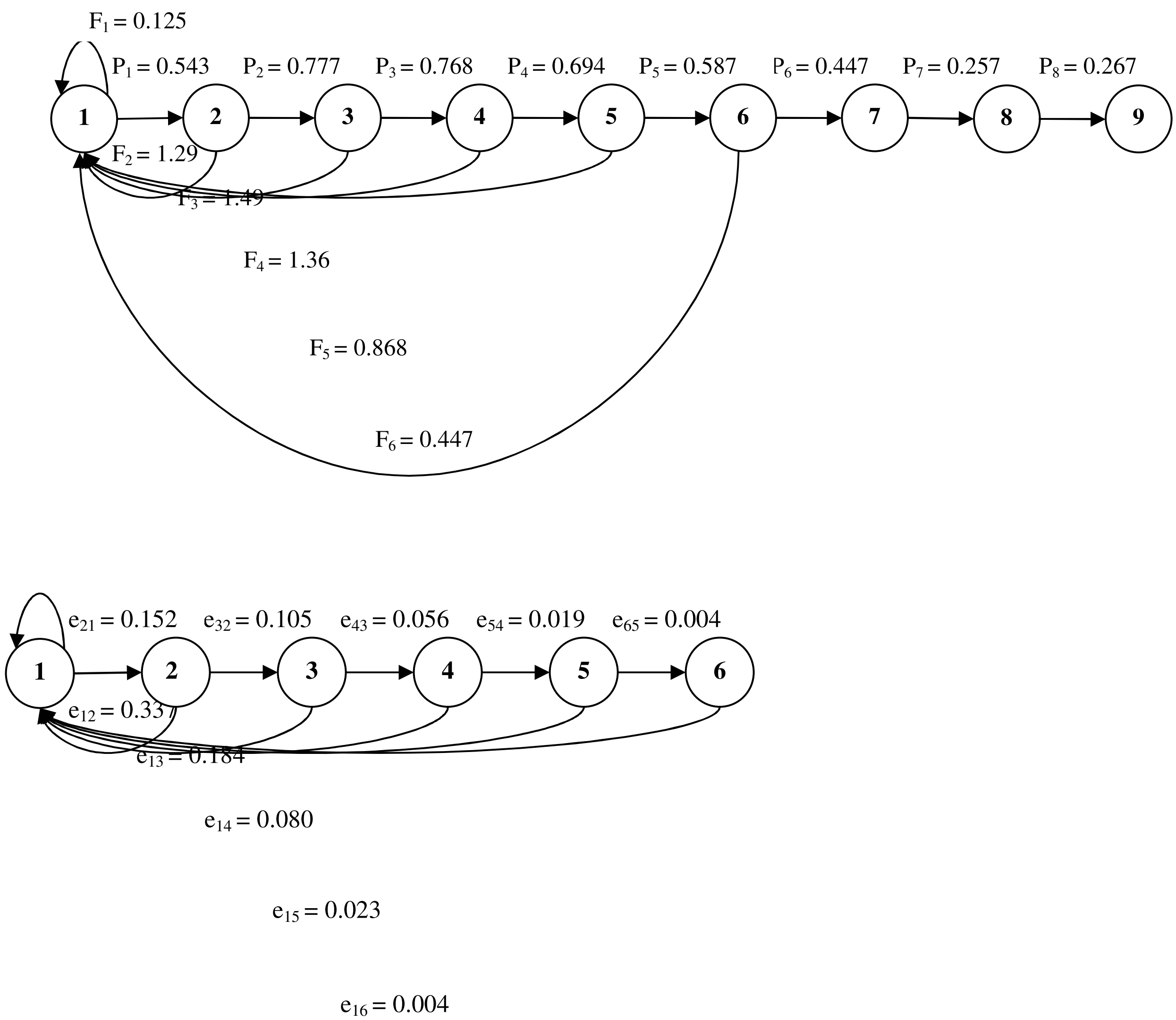


Figure 7: Map of Natural Heritage Ranks for the black-tailed prairie dog (NatureServe 2004).

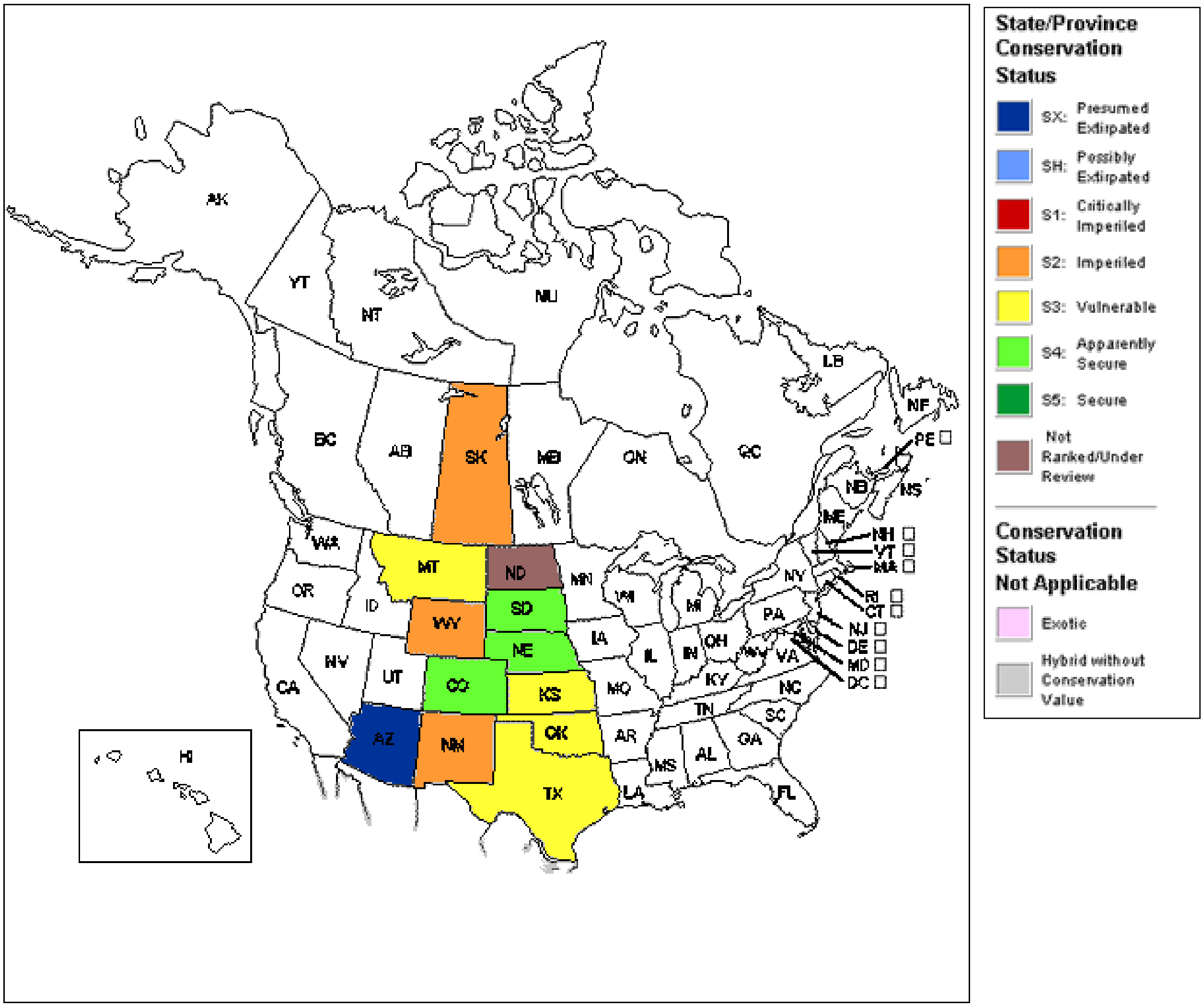
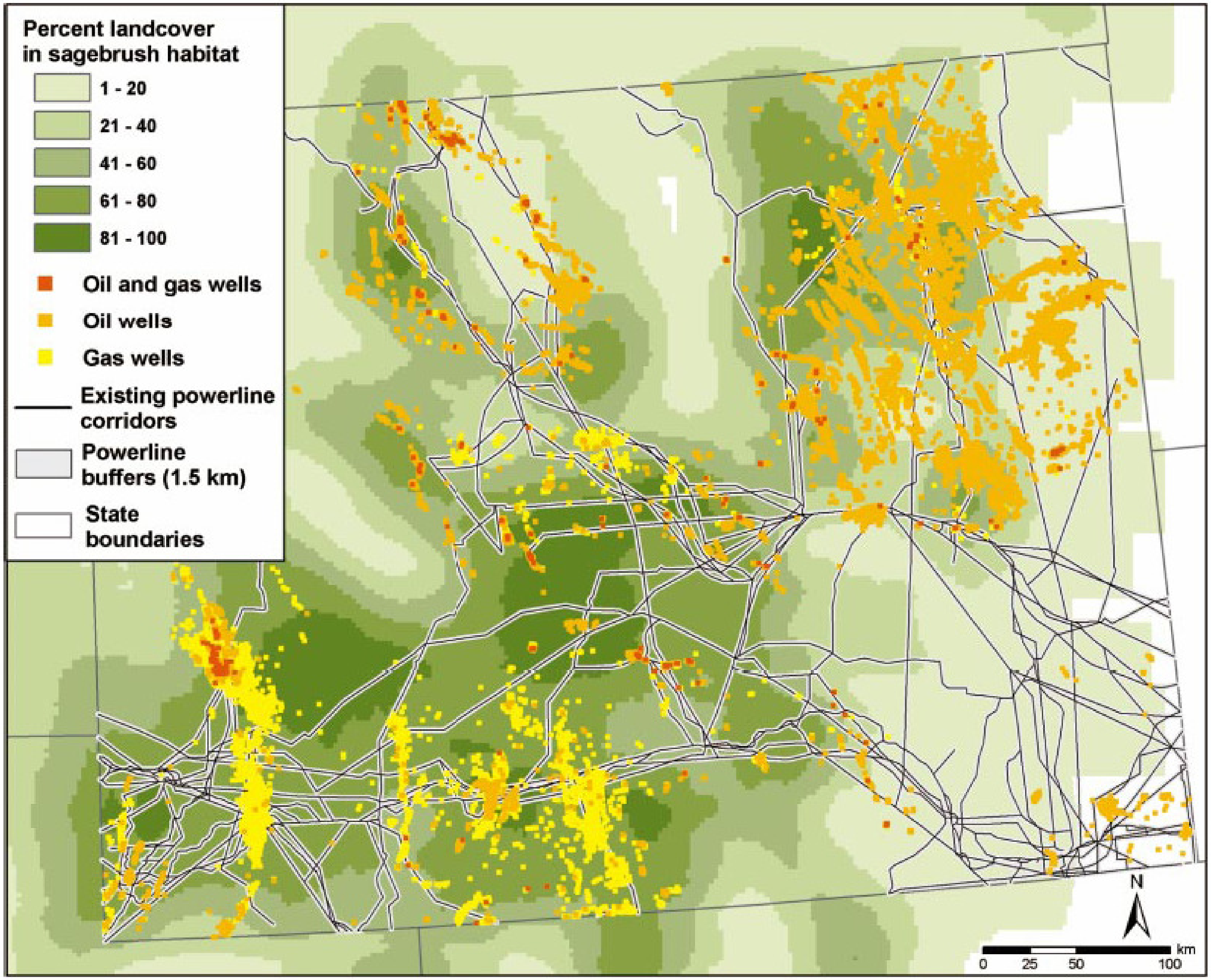


Figure 8: Existing oil and gas developments in Wyoming (Knick et al. 2003, p. 619). Note the amount of development in the northeast section of Wyoming, where the largest populations (acreage) of C. ludovicianus have been reported.



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File Code: 2670-3 **Date:** May 8, 2007
Route To:

Subject: Participation of National Grasslands in Recovery of the Black-footed Ferret

To: Forest Supervisor, Medicine Bow and Routt National Forests, Forest Supervisor, Nebraska National Forest, Forest Supervisor, Arapaho and Roosevelt National Forest, Forest Supervisor, Pike and San Isabel National Forests

Recently I held a coordination meeting with the U.S. Fish and Wildlife Service, Mountain-Prairie Region (FWS). One of the topics we discussed was progress in recovering the black-footed ferret. In follow-up to that meeting, FWS prepared a letter discussing the importance of the national grasslands to the recovery program, and some adjustments they are making in their approach to reintroductions. I am forwarding their letter for your information and consideration.

As you know, the black-footed ferret remains one of the world's most endangered mammals. The species was driven to near extinction by extensive reductions of prairie dogs, its only habitat, and by sylvatic plague, an introduced disease. By 1987, the few remaining ferrets were removed from the wild and a captive breeding program was undertaken. Fortunately, captive breeding and reintroduction techniques have been successful, and today there are about 250 breeding adults at several locations in the wild.

To date, the most successful black-footed ferret reintroduction site is in Conata Basin on the Buffalo Gap National Grassland in South Dakota. A population of about 100 breeding adults has been established, and wild born kits from that site have even been available to supplement other recovery sites. As part of the Northern Great Plains Land Management Plan revision process, the Forest Service designated future black-footed ferret reintroduction sites at another area on Buffalo Gap, and on portions of the Little Missouri and Thunder Basin National Grasslands. These areas are envisioned to contain large acreages of black-tailed prairie dog colonies to support ferret populations.

Additional reintroduction sites are needed to make better progress toward recovery objectives. Finding or even establishing large complexes of black-tailed prairie dog colonies is often problematic. Most black-tailed prairie dog colonies are small and scattered across the landscape. FWS is indicating that smaller complexes of black-tailed prairie dog colonies (1,500 to 3,000 acres) can play an increasingly important role in national recovery by supporting small nursery populations of black-footed ferrets. The enclosed letter from FWS provides the rationale for such nursery populations.

FWS is also working on developing some innovative administrative procedures that may help to expedite reintroduction actions. Recognizing that funding for monitoring may be limited; FWS is also reducing expectations for post-release monitoring.

John Sidle, Great Plains TES species coordinator, has proposed the following two steps in response to the FWS. First, this topic will be discussed at the upcoming National Grasslands Managers' Meeting at Midewin National Tallgrass Prairie (May 14-17, 2007). Second, John will convene a meeting among national grassland units from the three relevant Regions and FWS to discuss these new approaches. An outcome of that meeting would be to recommend courses of actions and timelines for further ferret reintroductions, and to assess opportunities to provide smaller complexes to support some "nursery" populations of ferrets. John will be contacting grassland managers and staff to determine their availability for such a meeting.

Despite our important contributions to the national recovery program to this point, recovery of the black-footed ferret still remains tenuous at best. Opportunities likely remain for the Forest Service to continue to be a leader in the national recovery effort. Please join in the conversations and meetings as you can to better understand and discuss these opportunities in Region 2.

I am sending a copy to the Regional Foresters in Regions 1 and 3, and encourage all units within the historical range of the black-footed ferret to consider opportunities to participate in recovery efforts as appropriate.

/s/ Steve Sherwood (for)
RICK D. CABLES
Regional Forester

cc: Jay Slack
Mike Stempel
Mike Lockhart
Robert L Vaught
Tom Tidwell
Harv Forsgren
Anne Zimmermann
John Sidle

The importance of prairie dogs to nesting ferruginous hawks in grassland ecosystems

Rosamonde R. Cook, Jean-Luc E. Cartron, and Paul J. Polechla, Jr.

Abstract The influence of prairie dogs (*Cynomys* spp.) on the population status and ecology of nesting ferruginous hawks (*Buteo regalis*) has been poorly documented. Based on aerial and ground surveys and GIS mapping, we examined spatial relationships between nesting ferruginous hawks and colonies of Gunnison's prairie dogs (*Cynomys gunnisoni*) in 2 grassland ecosystems of New Mexico: the Estancia Valley in 1999 and 2000, and the Plains of San Agustin in 2000. The numbers of occupied nests and prairie dog towns were greater in the Estancia Valley than the Plains of San Agustin, while median distance to nearest prairie dog town from nests was greater in the Plains of San Agustin. There was a positive spatial association between nests and prairie dog towns in the Estancia Valley in both years, and mean productivity was higher for nests <2 km from the nearest prairie dog town. Furthermore, there was a linear relationship between relative abundance of prairie dog prey remains (relative to other prey taxa) collected from nests and proximity to nearest prairie dog town and between nest productivity and relative abundance of prairie dog prey remains. Nests in the Plains of San Agustin exhibited a negative spatial association with prairie dog towns. We attribute differences between the study areas to abundance of prairie dogs and availability of nest sites in the vicinity of prairie dog towns. Results suggest that prairie dogs can have a significant effect on nest-site selection, abundance of nesting pairs, and productivity of ferruginous hawks in arid grasslands of the American Southwest. Efforts to conserve breeding populations of this top predator where they occur on private or public rangelands in this region should include management of healthy prairie dog populations and the preservation of suitable nesting substrate within the vicinity of prairie dog towns.

Key words *Buteo regalis, Cynomys gunnisoni,* ferruginous hawk, grasslands, grazing, New Mexico, prairie dog, Southwest, spatial association

Prairie dogs (*Cynomys* spp.) play an important, possibly keystone, role in grassland ecosystems (e.g., Miller et al. 1994, Ceballos et al. 1999, Kotliar et al. 1999, Miller et al. 1999). Prairie dogs affect vegetation structure, productivity, nutrient cycling, and ecosystem processes (e.g.,Whicker and Detling 1988). They are important prey items for many terrestrial predators and raptors, and their burrows

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often serve as shelters for other rodents and lagomorphs (Kotliar et al. 1999). Whether the presence of extant colonies ultimately enhances biotic diversity remains a subject of debate (O'Meilia et al. 1982, Olson 1985, but see Ceballos et al. 1999; Miller et al. 1999). However, several mammalian or avian species—namely the black-footed ferret (*Mustela nigripes*), burrowing owl (*Speotyto cunicularia*), and mountain plover (*Charadrius montanus*)—are known to depend on prairie dogs or characteristics associated with prairie dog colonies (Knowles et al. 1982, Clark 1989, Desmond et al. 1995).

Additional species, including the ferruginous hawk (*Beteo regalis*), may also depend on prairie dogs. Ferruginous hawks wintering in Colorado feed primarily on prairie dogs and concentrate in areas with the highest densities of these rodents (Plumpton and Andersen 1997, Seery and Matiatos 2000). Numbers of migrating and wintering ferruginous hawks have been shown to decline following local disappearances of prairie dogs in Colorado and New Mexico (Cully 1991, Seery and Matiatos 2000). By comparison, the importance of prairie dogs to nesting ferruginous hawks is unclear. Most published studies have emphasized the importance of jack rabbits (*Lepus* spp.) in shrubland or ground squirrels (*Spermophilus* spp.) in grasslands to the success of nesting ferruginous hawks (Lokemoen and Duebbert 1976, Schmutz et al. 1980, Smith et al. 1981, Restani 1991). It also has been suggested that nesting ferruginous hawks are affected by the loss of prairie dog towns only at local scales and when no alternative prey is available (Kotliar et al. 1999).

Ferruginous hawk nestling.

In New Mexico, where breeding populations of ferruginous hawks occur at the southern edge of their range (Olendorff 1993), Gunnison's prairie dogs were historically common in grasslands in the northern and western parts of the state (Bailey 1931, Findley et al. 1975). The black-tailed prairie dog (*Cynomys ludovicianus*) was similarly abundant in eastern and southern New Mexico (Findley et al. 1975). However, control measures, implemented as early as the 1880s, largely contributed to a loss in the total area covered by prairie dog towns in the state, from about 486,000 ha in 1919 to less than 202,000 ha by 1981 (Hubbard and Schmitt 1984). The black-tailed prairie dog was the most severely affected, being extirpated from its southwestern range and parts of its eastern range between 1955 and 1972 (Findley et al. 1975). Gunnison's prairie dogs survive throughout much of their historic range but in much-reduced numbers (Knowles 2002).

The present study was part of a larger effort to assess the influence of prairie dog availability on the population status, diet, and conservation of ferruginous hawks nesting in New Mexico. In this paper, we examine spatial relationships between ferruginous hawk nest sites and colonies of Gunnison's prairie dogs and the productivity of nesting ferruginous hawks as a function of those relationships. Together with data on diet (Cartron et al. 2003), this study provides some of the strongest evidence to date that the presence of prairie dogs is an important component of ferruginous hawk nesting habitat.

Study area

We conducted our study in 2 large shortgrass prairie ecosystems in western and central New Mexico (Figure 1). One of these was the Estancia Valley (EV), a topographically closed basin of approximately 512,000 ha bounded by the Peder-

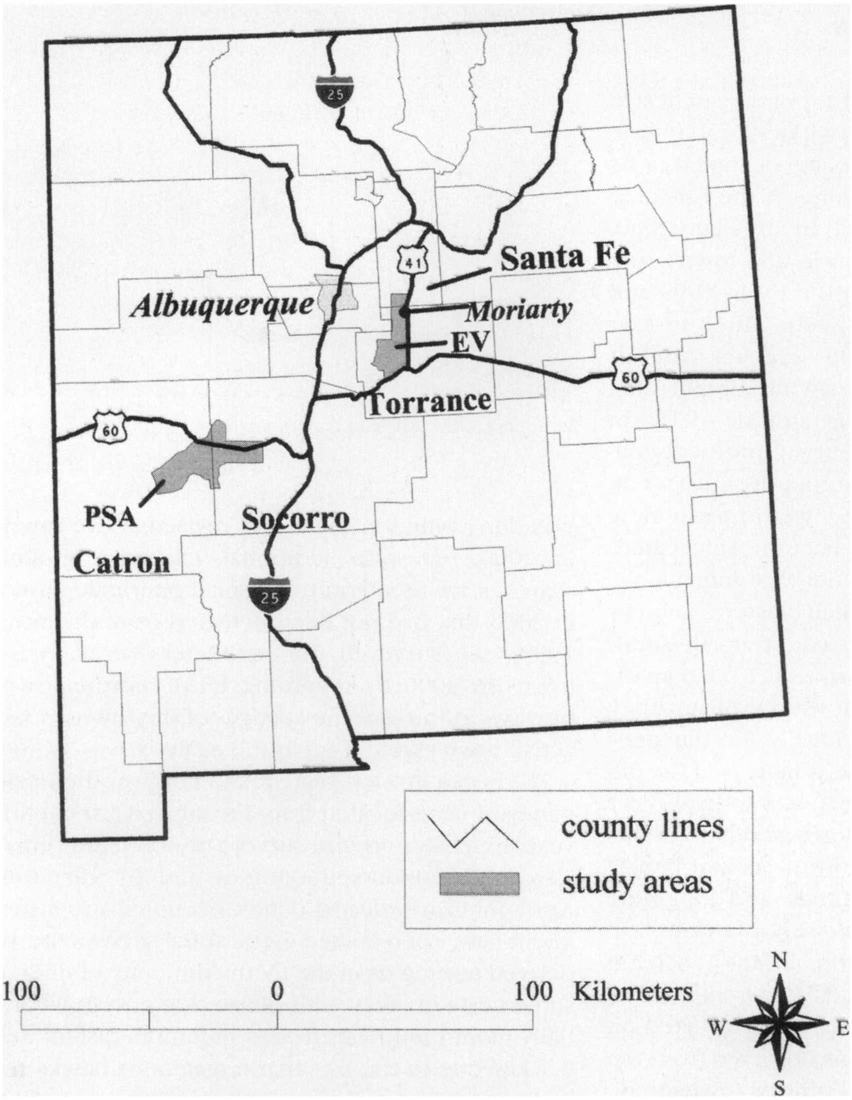

Figure 1. Map of New Mexico showing 2 grassland ecosystems in which ferruginous hawk nesting ecology and the distribution of prairie dog colonies were studied in 1999 and 2000. EV: Estancia Valley. PSA: Plains of San Agustin.

across the grassland. Most of the land was privately owned, with a few sections owned by the state. Land use consisted primarily of cattle grazing and agriculture (mostly corn and alfalfa). Most rangelands were <400 ha. Much of the original prairie has been fragmented by fences and roads, and urban development has occurred recently around the town of Moriarty and southward along NM Highway 41.

The second study area covered approximately 216,600 ha in the Plains of San Agustin (PSA), a topographically closed basin of approximately 257,000 ha located west of Magdalena in Socorro and Catron counties. The PSA was bounded by the San Mateo Mountains to the east, Gallinas Mountains to the northeast, Datil and Mangas Mountains to the northwest, Tularosa Mountains to the west, and the Luera, Pelona, and O-Bar-O mountains to the south. As in the EV, grasslands were dominated by blue grama. Vegetation on the lower slopes of surrounding mountains consisted mostly of pinyon-juniper woodland with scattered ponderosa pine (*P. ponderosa*). Juniper was the only tree found in the grasslands, where it occurred only sparsely, alone or in small clusters along low ridgetops. Unlike the EV, only about half the land was privately owned. Much of the rest was rangeland managed by the United States Bureau of Land Management (BLM) and leased to a comparatively small number of private landholders. The predominant land use was cattle grazing, and ranches were much larger by comparison with the EV. There also were fewer roads in this area and an absence of agriculture and urban development.

nal Hills to the east, the Manzano and Sandia mountains to the west, Chupadera Mesa to the south, and a small escarpment to the north (Barrie 1987). Our study area consisted of approximately 111,200 ha in the western half of the EV in Torrance and Santa Fe counties. Lower slopes in this area were covered by pinyon (*Pinus edulis*)-juniper (*Juniperus monosperma*) woodland. Grasslands were dominated by blue grama (*Bouteloua gracilis*), often mixed with large numbers of juniper clustered along small ridges or arroyos. Nonnative trees such as Chinese elm (*Ulmus parvifolia*) and Russian olive (*Elaeagnus angustifolia*) were scattered

Methods

Surveys

We used aerial surveys and ground searches to locate occupied ferruginous hawk nests and prairie dog towns. Aerial surveys to locate occupied nests were conducted at the beginning of the breeding season (late March to late April) in 1999 and 2000. We conducted surveys for prairie dog towns concurrently with nest surveys in the EV in 1999 and separately in the PSA in July 2000. Three to four observers in a Cessna® 205 (Cessna Aircraft Company, Wichita, Kans.) fixed-wing aircraft conducted all surveys at an average altitude of 150 m and a speed of 120 km/hr. Survey protocols differed between study areas due to a dissimilarity in the density of trees. In the PSA we primarily flew over the grassland-woodland ecotone since there were few trees in the grassland. We individually inspected isolated trees and small clusters. Surveys for prairie dog towns consisted of north-south transects above the grassland, spaced 1.6 km apart. The greater density of trees in the EV meant they could not be inspected individually for the presence of nests. At the same time, it increased the difficulty of locating prairie dog towns from the air. For this reason, we spaced north-south transects only 400 m apart to survey both nests and prairie dog towns. We recorded latitude and longitude coordinates of nests and towns with a Garmin® 92 (Garmin International, Olathe, Kans.) Global Positioning System unit designed for aircraft.

From late spring through summer, we visited on the ground all prairie dog towns observed from the air in both study sites. We determined towns to be active if we observed prairie dogs or if signs of recent burrowing were present. Status of EV towns was determined in 1999. We revised active towns in 2000. Despite additional, extensive ground searches, we found only one small prairie dog town in 2000 that had not been detected from the air in 1999. We surveyed the perimeters of all active towns in 2000 by recording UTM coordinates of burrows at the outermost edges of the towns. Only active towns were used in the analysis.

Ferruginous hawk nest tree.

Gunnison's prairie dog.

We began ground searches to confirm the occupancy of nests located from the air in April of each year. Extensive ground surveys of both study areas also were conducted on foot and by car from April-June in order to detect occupied nests that might have been missed in the aerial surveys due to delayed nesting or, in the EV, the difficulty of finding some nests in areas with dense tree cover. We initially monitored nests from a minimum distance of 0.4 km, due to the fact that ferruginous hawks are highly sensitive to human-caused disturbance during the early part of the nesting season (Lokemoen and Duebbert 1976, White and Thurow 1985, Bechard et al. 1990). We conducted visits to nests during the latter part of the season, followed by a period of observation to verify the return of adults. We defined productivity as the number of fledglings (birds 38-50 days old that had reached the age of flight) per nest. We determined nests to be successful if they produced at least one fledgling.

We collected regurgitated pellets and unconsumed prey remains present in nests and in a 10-m radius on the ground around nests near the end of the nesting season in 2000. We made collections from all successful nests, with the exception of 2 (one in each study area) that were inaccessible. We searched 3 of the 5 nests that failed in 2000 (4 in the EV, one in the PSA). None of these held prey remains, probably because failures were not discovered immediately, which gave scavengers time to remove them. Two nests in particular failed early in the season (before mid-May), so occupancy time was relatively brief. We suspect that failures likely were due to disturbance; all of these nests were clearly visible from nearby roads. Further, nests that failed prior to mid-May likely did so during the incubation period (Bechard and Schmutz 1995), when adults are most sensitive to disturbance (White and Thurow 1985).

Only recent prey remains (bones with attached flesh) and regurgitated pellets were considered for analysis, to avoid the potential inclusion of data from previous years. We identified vertebrate specimens by reference to synoptic collections at the Museum of Southwestern Biology at the University of New Mexico. We determined the minimum number of individuals of all prey species at each nest from skeletal material only, using methods described by Mollhagen et al. (1972). From these counts, we calculated the ratio of prairie dogs to all other vertebrate prey items per nest. We calculated ratios only for successful nests because of a lack of data for unsuccessful nests. Although the EV represents a convergence zone between Gunnison's and black-tailed prairie dogs (Findley et al. 1975), we determined all prairie dog specimens to be Gunnison's.

The calculation of accurate prey ratios from remains at the nest can be biased by differences in prey species detectability, rates of decay, removal by adult birds and scavengers, and other factors (e.g., Thomsen 1971, Quinn 1991, Mersmann et al. 1992). Although we collected prey remains only during the latter part of the nesting season, the disproportionate disappearance of certain types of remains, if any, would have introduced random error rather than a directional bias in our data: prairie dog remains likely disappear at the same rate regardless of distance to the nearest prairie dog town.

Analyses

We used ArcView® (Environmental Systems Research Institute, Redlands, Calif.) Version 3.2 software to map locations of occupied ferruginous hawk nests and boundaries of prairie dog towns. We examined differences in size of prairie dog towns between study areas for 2000 only, as towns in the PSA were not surveyed in 1999. We measured distance between occupied nests and nearest prairie dog town as the shortest (straight-line) distance to the center point of the town. We tested the null hypothesis that the distribution of ferruginous hawk nests was spatially independent of prairie dog towns using a 2-species test of association (Reich and Davis 2000). An equal-area grid was laid over the map of each study area, and counts were made of quadrats containing both species, each species but not the other, and neither species. We then compared the observed number of co-occurrences with the expected under the null hypothesis using a formula for chi-square described by Reich and Davis (2000). In order to detect the scale of any potential association, we conducted tests with quadrats of 0.5 km on a side (or 0.25 km^2) and from 1 to 5 km in 1-km intervals (i.e., from 1 to 25 km^2).

Ferruginous hawk and Gunnison's prairie dog habitat.

We used linear regression (Zar 1999) to examine relationships between 1) productivity per successful nest and distance to nearest prairie dog town, 2) relative abundance of prairie dog remains per successful nest and distance to nearest prairie dog town, and 3) productivity and relative abundance of prairie dog remains per successful nest. We used the ratio of prairie dogs to all prey instead of whole numbers because number of prey remains was a significant predictor of presence or absence of prairie dog remains for nests from both areas combined (binary logistic regression [$W_1 = 4.7$, $P = 0.03$]).

Results

We located 43 active prairie dog towns in the EV in 1999. Of these, 27 were active in 2000. Reasons for the decline were undetermined. One new active town discovered in 2000 brought the total to 28 for that year. We mapped the boundaries of 25 of the 28 towns. By contrast, we found only 6 active towns in the PSA, all of which were mapped. Mean area of towns in 2000 was 33±31 ha in the EV and 36±31 ha in the PSA. We detected no difference in town size between study areas ($P=0.839$). However, the total area covered by towns mapped in the EV was 919 ha, or 0.83% of the study area, a conservative estimate because 3 of the towns were not surveyed, but more than 4 times greater than that of towns in the PSA (214 ha, about 0.10% of the survey area). Results of ferruginous hawk surveys and reproductive outcome were reported by Cartron et al. (2002). In sum, we detected 20 occupied nests in the EV in 1999 (13 successful, 4 unsuccessful, and 3 undetermined) and 18 in 2000 (14 successful, 4 unsuccessful). By contrast, there were only 11 occupied nests in the PSA in both years (8 successful, one unsuccessful, and 2 undetermined in 2000).

The median distance between occupied nests and the nearest prairie dog town was greater in 2000 in the PSA (13.69 km) than it was in the EV the same year (2.55 km) ($U=248, P<0.001$) as well as 1999 (2.40 km) ($U=271, P<0.001$). Although there were more occupied nests and prairie dog towns in the EV in 1999 than 2000, we detected no difference in median distance from nests and nearest town between those years ($P=0.629$).

The 2-species test of association for the EV suggested that a greater number of occupied nests and prairie dog towns co-occurred within quadrats of 0.25 km^2 in 1999 ($\chi^2_1=19.73, P<0.0001$) and 2000 ($\chi^2_1=12.01, P=0.0005$) than expected under the null hypothesis of no association. We observed similar relationships at 1 km^2 in 1999 ($\chi^2_1=6.403, P<0.01$) and 2000 ($\chi^2_1=7.11, P<0.01$), and at 4 km^2 in 1999 ($\chi^2_1=4.19, P<0.05$) and 2000 ($\chi^2_1=10.34, P<0.005$). These results suggest a positive spatial association between nest sites and prairie dog towns at approximately 0.7 km to 2.8 km, as these distances were the lengths of the diagonals (the greatest distance that a pair of points can be separated from each other in a square area) of the 0.25-km^2 and 4-km^2 quadrats, respectively.

Linear regression revealed a nearly significant relationship between productivity of successful nests and proximity to nearest prairie dog town in the EV in 1999 ($F_{1,12}=3.60, P=0.08$) but not in 2000 ($F_{1,13}=0.04, P=0.84$). However, observed mean productivity was higher for nests located within 2 km of a prairie dog town versus greater distances in 2000 (2.5 vs. 2.0 fledglings per nest).

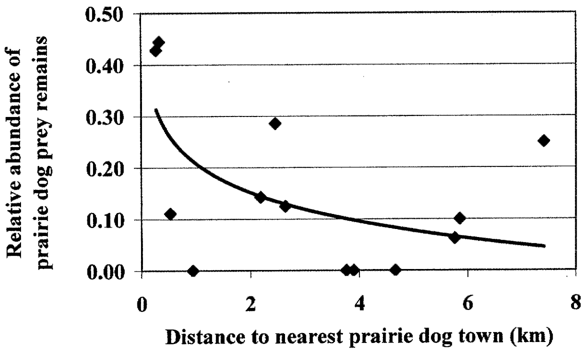

Figure 2. The relative abundance of prairie dog prey remains (as a proportion of all vertebrate prey remains) vs. $\log_{10}$ distance to nearest prairie dog town of successful ferruginous hawk nests in the Estancia Valley of New Mexico in 2000. The line represents the least squares fit to the data.

Furthermore, there was a negative logarithmic ($\log_{10}$) relationship between relative abundance of prairie dog remains collected from nests and distance to nearest prairie dog town ($F_{1,12}=5.64, P=0.037$) (Figure 2), and a positive relationship between abundance of prairie dog remains and productivity ($F_{1,12}=8.97, P=0.012$) (Figure 3).

The 2-species test of association failed to detect a positive spatial association between occupied nests and prairie dog towns in the PSA. To the contrary, there were fewer co-occurrences than expected under the null hypothesis of no association for quadrats of 0.25 km^2 ($\chi^2_1=23.37, P<0.001$) and 1 km^2 ($\chi^2_1=6.82, P<0.01$). Unfortunately, reproductive outcome was undetermined for the only nest occurring in the near vicinity of a prairie dog town (1.7 km). For this reason, and because the number of successful nests was small ($n=8$), results of any further analysis between ferruginous hawks and prairie dogs in the PSA are likely to be unreliable.

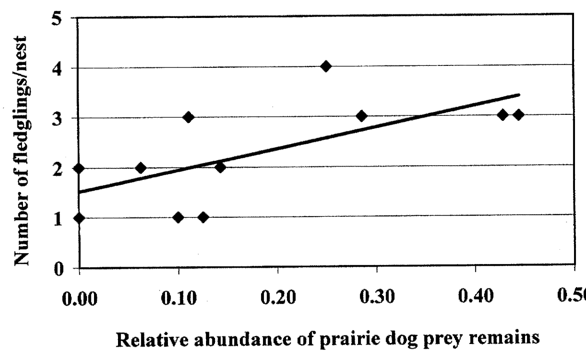

Figure 3. The number of fledglings produced per nest vs. relative abundance of prairie dog remains (as a proportion of all vertebrate prey remains) for successful ferruginous hawk nests in the Estancia Valley of New Mexico in 2000. The line represents the least squares fit to the data.

Discussion

Our results suggest that Gunnison's prairie dogs can play an important role in the nesting ecology and productivity of ferruginous hawks. In a related study, we found that prairie dogs likely comprised the greatest proportion of diet by weight in the EV (Cartron et al. 2003). The situation was different in the PSA, where Botta's pocket gopher (*Thomomys bottae*) was by far the most abundant prey item found in ferruginous hawk nests. We found prairie dog remains in very small numbers, and they amounted to a small proportion of the diet in terms of biomass.

Relationships between distribution and productivity

Significant patterns of spatial association observed in the EV suggest that ferruginous hawks preferred to nest within 0.7–2.8 km of a prairie dog town, with the strength of association increasing at lesser distances. The negative associations observed in the PSA likely were not due to any interaction between predators and prey but due rather to a lack of suitable nest sites in the vicinity of prairie dog towns. In the PSA most potential nest sites were located at the ecotone between grassland and pinyon-juniper woodland, along the lower slopes of the valley. More than half of the nests we observed were in these areas. This contrasted with a greater density of potential nest sites in EV grasslands, where all observed nests occurred.

The preference for nesting in the vicinity of important food resources is consistent with optimal foraging theory (e.g., Pyke et al. 1977), as reduced foraging distances can maximize net energy intake. McAnnis (1990) reported that the majority of foraging attempts by ferruginous hawks occurred within 1 km of the nest site. A link between productivity of ferruginous hawks and vicinity of a primary prey source (ground squirrels) also has been reported (Zelenak and Rotella 1997). Rates of foraging on prairie dogs and productivity were highest among successful pairs nesting within 2 km of a prairie dog town in the EV, suggesting that the energetic costs associated with travel and handling of prairie dog prey may outweigh the benefits to be gained beyond this distance. The spatial associations we observed at distances within 2.8 km suggest that these factors influenced choice of nest sites among ferruginous hawks in localities where nesting in the proximity of prairie dog towns was possible.

The apparent relationship between productivity and consumption of prairie dogs could occur if productivity is directly enhanced by availability of prairie dog prey or if pairs that happened to have larger broods prey more frequently on prairie dogs. Logical extensions of optimal foraging theory predict increased provisioning effort associated with larger broods to be accompanied by changes in load size, foraging distances from the nest, and possible changes in the type and size of prey delivered (Wright et al. 1998). Such behavior has been demonstrated with experimental manipulation of brood size of European starlings (*Sturnus vulgaris*) (Wright et al. 1998). We were not able to test the first hypothesis directly. To test the second, we performed a partial correlation analysis on successful nests. If this hypothesis alone were true, we would expect to observe no relationship between relative abundance of prairie dog remains and proximity to nearest prairie dog town, independent of brood size. Results ($r_1 = 0.474$, $P = 0.197$) suggest this might be the case; however, these are not strong and it remains possible that both processes occur. Abundance of prey is known to influence clutch size in ferruginous hawks (Smith et al. 1981), and we must assume that nesting in the proximity of a prairie dog town facilitates access to this important source of prey.

We did not find a significant linear relationship between productivity and proximity to the nearest prairie dog town for the EV in 2000 due to the large influence of a single nest in the northernmost part of the EV. This nest was located more than 7 km from the nearest known prairie dog town but produced the largest number of fledglings (4) observed during this study. Prey analysis suggested this pair foraged heavily on prairie dogs (a quarter of all prey items collected from the nest). With the omission of this data point, the relationship between productivity and $\log_{10}$ (distance) to the nearest prairie dog town was significant ($F_{1, 12} = 4.90$, $P = 0.049$). It is possible that a prairie dog town existed near this nest, either inside or outside of the study area, but went undetected during the surveys. However, it is possible that brood size influenced the foraging behavior of this pair as well.

Patterns of reproduction

Mean levels of productivity were similar in both study areas during 1999 and 2000 (Cartron et al.

2002). However, because a larger number of ferruginous hawk pairs nested in the EV in those years, total productivity was substantially higher in the EV versus the PSA (136% in 1999 and 71% in 2000). Abundance of main prey has been shown to affect all components of reproduction in ferruginous hawks (Smith et al. 1981); prey abundance influenced first the number of nesting pairs, followed in order by failure to achieve maximum clutch size, total number of young fledged, and total number of young hatched. The first 2 components were important limiting factors on reproduction, and acted, at least in part, to regulate the size of ferruginous hawk populations. Thus, the relatively low abundance of prairie dogs in the PSA and the lack of suitable nest sites near prairie dog towns could explain the relatively small numbers of pairs that nest in that area.

The fact that Botta's pocket gophers comprised the principal prey item of nesting ferruginous hawks in the PSA suggests that most foraging for food also occurred along the grassland-woodland ecotone. This is because few forbs or shrubs (food for pocket gophers) occurred in the grasslands. This also may explain why more than half of the occupied ferruginous hawk nests occurred at the edge of the grasslands. However, the relatively high density of trees in the ecotone is likely to pose a challenge in terms of foraging and prey capture. Ferruginous hawks are known to avoid areas of dense vegetation that reduce their ability to see prey (Schmutz 1987). The abundance of pocket gophers in the diet of the PSA population therefore suggests that preferred prey may have been scarce in the grasslands. The similar numbers of young fledged per nest in both areas suggest that differences in abundance of all prey items were not large enough to affect per-nest rates of production, but might have affected numbers of nesting adults.

Prey abundance is not the only factor influencing reproductive success. In an experimental study involving 62 nesting pairs, White and Thurow (1985) found that a third of nests disturbed by human activity associated with land development on western rangelands were deserted by adults. Although the period of disturbance was brief, the remainder of nests fledged fewer young than a control group not exposed to disturbance. Disturbance levels are likely to be higher in the EV, where lots are smaller and there is a higher density of roads and human habitations (we observed one recently fledged ferruginous hawk that had been killed by a vehicle during this study). The percent of nests that failed was twice as high in the EV (22%) as in the PSA (11%) in 2000.

Historic changes in distribution of nesting abundance

Surveys conducted in 1999 and 2000 established that a larger number of pairs nested in the EV than the PSA in those years (Cartron et al. 2002). Results of prior annual surveys from 1996 suggested the same (Hawks Aloft Inc., unpublished data). These findings contrast with the narratives of early naturalists. The PSA and surrounding area were described during the early twentieth century as supporting the highest densities of nesting ferruginous hawks in New Mexico (Bailey 1928). The same general area (i.e., the "high Continental Divide country") was contrasted at that time to other parts of New Mexico, as it still supported colonies of Gunnison's prairie dogs that served as an important source of food for nesting ferruginous hawks (Ligon 1961). Regrettably, neither Bailey nor Ligon mention the status and ecology of the ferruginous hawk in the EV, but proximity to Albuquerque suggests the area was known to these naturalists.

The PSA and EV exhibit notable differences in vegetation and human disturbance, with potential repercussions on the local status of the ferruginous hawk. A striking difference between these valleys, as described above, is the greater abundance of native and exotic trees suitable for nest sites in the EV. In 2000, 6 nests (a third of the EV total) occurred in the crowns of the Chinese elm, an exotic species planted for ornamental purposes but which often seeds itself in the more moist soils of native grassland. It is possible therefore that the incursion of this species has increased the number of potential nest sites in recent years.

To the contrary, the distribution of nest sites probably has changed little in the PSA since the early twentieth century; however, the size and number of prairie dog towns have changed drastically. Reports by biologists in the 1920s and 30s refer to Gunnison's prairie dogs as "always present in varying numbers" over the PSA, "abundant" over the Quemado Valley (west of the PSA), and "plentiful" on bordering hillsides (Bailey 1931:128). Thus, colonies would have existed in closer proximity to the grassland-woodland ecotone at that time and would have been available to foraging hawks without the need to travel large distances.

Massive control efforts began as early as the

1880s. The total amount of land subject to eradication efforts from 1931-1957 was equal to 61,000 hectares in Catron County alone, which contrasts with 22,000 hectares in Torrance County in the EV during the same period (Hubbard and Schmitt 1984). It is not clear that the difference reflects actual differences in control effort or historical distribution of prairie dogs. Nonetheless, the EV today supports a larger, more widely distributed population of prairie dogs than the PSA. Since both productivity and the status of nesting populations of ferruginous hawks are known to be negatively affected by declines in abundance of main prey species (Smith et al. 1981, Cully 1991, Seery and Matiatos 2000), there is good reason to suspect that the apparent drastic reduction in abundance of prairie dogs has reduced the nesting population of ferruginous hawks in the PSA from historic levels.

Interviews with ranchers and realtors during this study indicated that prairie dog control is still practiced in both the EV and the PSA. Prairie dog control efforts usually have been focused most intensively on grazing lands. In the PSA, where ranching is the predominant use of land and prairie dog control may be more common, the negative spatial association between nests and towns may reflect not only the scarcity of trees in the valley proper but also the tendency for the extant prairie dog towns we observed to be distant from the main roads. In contrast, land use in the EV includes a mixture of agriculture and grazing, and efforts at control may be less intense. Further, the patchwork of small parcels of land owned and managed by many people likely would make the extirpation of prairie dogs more difficult in the EV as this would require greater coordinated effort.

Results of this study provide further support for the notion that prairie dogs are an important component of prairie ecosystems and substantiate coincidental declines of prairie dog numbers and nesting populations of ferruginous hawks in other parts of the American Southwest (Glinski 1998). We conclude that the population status of nesting ferruginous hawks is likely to benefit from the protection and enhancement of prairie dog populations as well as the preservation of suitable nest sites near prairie dog colonies. Continued attempts to eradicate prairie dogs would be ill-advised. The disappearance of an important food source for ferruginous hawks in locations where they nest ultimately could harm agricultural practices by reducing predation on other rodents. It would also likely have negative impacts on the many other species that benefit in either an obligate or a facultative way from association with prairie dog colonies.

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Plague, Prairie Dogs, and Black-footed Ferrets

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Abstract. The historic range of black-footed ferrets (*Mustela nigripes*) roughly corresponds with the range of black-tailed (*Cynomys ludovicianus*), white-tailed (*C. leucurus*), and Gunnison's prairie dogs (*C. gunnisoni*) in western North America. Prairie dog numbers declined drastically between 1900 and 1970, largely from governmental pest control and probably from plague epizootics that have swept through prairie dog colonies over extensive areas since the late 1930's.

Concomitant with the reduction in area of prairie dog colonies, the black-footed ferret, which depends on prairie dogs for prey, also disappeared from most of its range. Because of the black-footed ferret's dependence on prairie dogs for food and prairie dog burrows for shelter, plague epizootics in prairie dog colonies are one of the most serious problems in the management and recovery of the black-footed ferret.

This paper presents a review of the literature on plague in prairie dogs. Known differences in responses to plague between prairie dog species and several plague related management problems are described. The most important questions that plague in prairie dogs pose for the management of black-footed ferrets are (1) How is plague maintained in the prairie dog ecosystem between epizootics? (2) How are plague epizootics in prairie dog colonies started? and (3) Once plague epizootics begin, how can their effects be minimized? Answers to these questions are instrumental for the selection of sites for reintroductions of ferrets and for the stabilization of prairie dog populations when ferrets are released.

Key words: Prairie dogs, *Cynomys*, plague, *Yersinia pestis*, epizootic, black-footed ferret, recovery.

In the late 1800's, an estimated 283 million ha were occupied by prairie dogs (*Cynomys* spp.) in the western United States. By 1971, that area had declined to 600,000 ha (Cain et al. 1971, in Fagerstone and Biggins 1986). Black-footed ferret (*Mustela nigripes*) populations declined, and the species range became restricted at the same time (Hillman and Clark 1980). Although eradication of prairie dogs by government agencies greatly reduced prairie dog numbers, the simultaneous introduction of plague (*Yersinia pestis*) may have been of equal importance. Plague, a disease of wild rodents, came to the United States in 1899 (Link 1955; Barnes 1982; Gregg 1985). The combined effects of the government's eradication and plague, which often kills more than 99% of prairie dogs in affected colonies, have had a devastating effect on populations of Gunnison's (*C. gunnisoni*), black-

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tailed (*C. ludovicianus*), and white-tailed prairie dogs (*C. leucurus*).

Prairie dog populations have increased in many areas since control was reduced in 1972 (Hanson 1993; Hubbard and Schmitt 1984). However, in the western United States, plague epizootics continue to devastate populations of Gunnison's (Rayor 1985; J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data), black-tailed (Barnes 1982), and white-tailed prairie dogs (Ubico et al. 1988) at intervals as short as 3 years (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data) or more commonly at 5–10 year intervals (Barnes 1982). "Although people disagree on how management should be carried out, most agree that management of the black-footed ferret is dependent upon management of the prairie dog" (Linder 1973:171). An integral part of management of prairie dogs where plague is prevalent will be an understanding of community-wide dynamics of plague to predict the onset of epizootics and retard the spread of plague between prairie dog colonies after epizootics begin.

In this paper, I address (1) the reason plague is an important component of the ecology of black-footed ferrets, (2) the literature on plague that provides insights for management of prairie dogs, (3) plague epizootics in prairie dogs and the roles that other rodent species might play in the long-term maintenance of plague foci, and (4) urgent research into specific aspects of the ecology of plague.

Plague of Wild Rodents in the United States

Plague is found primarily in wild rodents and is transmitted by fleas. The etiologic agent is *Yersinia pestis*, "a gram-negative, bipolar staining coccobacillus of the family Enterobacteriaceae" (Poland and Barnes 1979). Rodents range in their susceptibility to plague from highly resistant species (*Dipodomys*) to highly susceptible species (*Cynomys*). Among the susceptible rodents, the effects of plague vary by the rapidity of death. Among species of *Cynomys*, death occurs so quickly that antibodies and overt signs of pathology do not always develop (Poland and Barnes 1979).

Plague-infected fleas are the primary vectors of plague and are probably responsible for infecting most prairie dogs after an onset of an epizootic. Infected fleas have a long survival in the laboratory where they have survived for more than 1 year at room temperature in dark conditions (Prince and Wayson 1947a, 1947b; Pavlovsky 1966). Infected fleas have been removed from prairie dog burrows more than a year after the beginning of epizootics and at least several months after the disappearance of susceptible prairie dogs (Fitzgerald 1970; J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data). Precise survival times under natural conditions in the field have not been determined because when the last prairie dog in a colony dies or emigrates is difficult to determine and because, as epizootics wane, the immune status of the survivors is unknown.

Plague was probably introduced to the United States from Asia circa 1899 (Link 1955; Barnes 1982; Gregg 1985). The first record of plague in native mammals in North America was near Berkeley, California, in 1908 among California ground squirrels (*Spermophilus beecheyi*; McCoy 1908; Wherry 1908). Since then the disease has spread throughout the western states west of the 100 meridian (Poland and Barnes 1979; Barnes 1993) in 76 species of 5 mammalian orders: Rodentia, Lagomorpha, Insectivora, Artiodactyla, and Primates (Barnes 1982).

The potential for humans to contract plague resulted in considerable research into the ecology of plague during the past 80 years. The disease occurs in foci (or nidi; Pavlovsky 1966) at various locations around the world, including North America, where the disease is recurrent and seems to be persistent. There are also non-focal areas where plague seems to be periodically reintroduced from outside and then disappears between epizootics (Poland and Barnes 1979). Terms in disease ecology that may not be familiar to wildlife ecologists are defined in the Appendix.

Plague epizootics frequently involve diurnal rodents, mostly ground squirrels or prairie dogs of the family Sciuridae. Many sciurids, including prairie dogs, reach high population densities and, because they are easily visible, epizootics in these species are noted and investigated. Epizootics in prairie dogs may spread over hundreds of square kilometers (Barnes 1982). Furthermore, cases of plague in humans occur most frequently during or shortly after epizootics (Weber 1978). Consequently, the epizootic phase of the plague cycle has received a great deal of attention from researchers in public health and is the source of most of the current knowledge about the ecology of plague.

The enzootic or maintenance species are probably "moderately to highly resistant rodent species with little or no overt disease (Baltazard 1953; Kartman et al. 1958; Baltazard et al. 1963)" (Barnes 1982:238). California voles (*Microtus californicus*) in San Mateo County, California, fit these criteria. Although the response varies between individuals, California voles carried plague bacteremia without overt symptoms (Goldenberg et al. 1964; Hudson et al. 1964). Despite many years of research, this California vole population is the only verified example of an enzootic system. Other North American species, which are moderately to highly resistant to plague and which may serve as enzootic hosts, are kangaroo rats (*Dipodomys* spp.), deermice (*Peromyscus maniculatus*; Holdenried and Quan 1956), and northern grasshopper mice (*Onychomys leucogaster*; Thomas et al. 1988). All occur in prairie dog colonies and may serve as reservoirs for plague between the epizootics in prairie dogs.

In other vector-borne diseases, such as La Crosse encephalitis, the pathogen is maintained by the insect vector, and the mammalian hosts are thought to serve primarily to infect new insects (DeFoliart 1983). Given that plague-infected fleas may survive more than a year whereas their rodent hosts die after only a few days, plague, like La Crosse, might be a flea parasite that is amplified by prairie dogs and other rodents.

There is evidence that some mammal species are evolving a reduced susceptibility to plague (Williams et al. 1979; Shepherd et al. 1986; Thomas et al. 1988). For example, during epizootics in some areas of California, California ground squirrels began to have higher rates of survival than early in the century (Meyer et al. 1943; Nelson 1980). Rock squirrels (*Spermophilus variegatus*) also developed resistance where contact with plague has been continuous, but not in areas in Utah where plague has not been identified in this species (Marchette et al. 1962 [in Quan et al. 1985]). Variance in susceptibility to plague in rock squirrels (Quan et al. 1985), California ground squirrels (Williams et al. 1979), and northern grasshopper mice (Thomas et al. 1988) is also great.

The ecology of plague in North America may be changing because of evolutionary changes in resistance in the host mammal community. As resistance develops, species' roles may shift from epizootic to enzootic status. If that happens, populations in areas where plague has been infrequent could become enzootic foci in the future. This change has obvious implications for the management of prairie dogs.

Plague in Prairie Dogs

Plague was first observed in Gunnison's prairie dogs in northwestern Arizona in 1932, in eastern Arizona in 1937, and in New Mexico in 1938 (Eskey and Haas 1940). It was first recorded in Utah prairie dogs (*C. parvidens*) in Utah and in white-tailed prairie dogs in Wyoming in 1936 (Eskey and Haas 1940). Ten years later, plague had reached black-tailed prairie dogs in Texas (Miles et al. 1952). In Colorado, the first report of plague in prairie dogs was between 1945–49 when an epizootic occurred in Gunnison's prairie dogs at South Park (Ecke and Johnson 1952). Today plague has spread throughout the range of Gunnison's prairie dogs in Arizona, Utah, New Mexico, and Colorado (Barnes 1982). It also persists in white-tailed prairie dogs in Wyoming (Clark 1977; Clark et al. 1985; Ubico et al. 1988), in Utah prairie dogs in Utah, and in black-tailed prairie dogs in Colorado, New Mexico, Texas, and Oklahoma (Barnes 1982).

The rate of spread of epizootics may be a function of host population density (Barnes 1982; J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data), flea species, flea density, and host susceptibility. With the exception of host density, there are no experimental data on the effects of any of these factors on the rate of epizootics in prairie dogs. White-tailed prairie dogs, which occur in much lower-density colonies than black-tailed or Gunnison's prairie dogs (Eskey and Haas 1940; Clark et al. 1985; Menkens and Anderson 1989, 1991), seem to experience slower rates of spread and less consistent population declines.

The mean density of prairie dogs at four white-tailed prairie dog colonies at Meeteetse, Wyoming was 3.8 / ha (Clark et al. 1985), which compares well with 3.4 / ha in southern Wyoming (Clark 1977) and 3.6 / ha in Colorado (Tileston and Lechleitner 1966). A plague epizootic in white-tailed prairie dogs in 1967 in southeastern Wyoming killed 85% of the prairie dogs in 4 months (Clark 1977). At Meeteetse, Wyoming, a plague epizootic swept through 4 of 37 prairie dog colonies (Menkens and Anderson 1991), but these four colonies included 1,521 ha of the 2,995 ha of active prairie dog colonies in the complex (Clark et al.

1986). Plague-positive fleas continue to be collected from prairie dog burrows at these colonies after 4 years (G. Menkens, U.S. Fish and Wildlife Service, personal communication). The prairie dog population there is slowly declining, and the epizootic is gradually spreading to other colonies. At this time, the prairie dog population at Meeteetse is below the necessary minimum for the reintroduction of black-footed ferrets (B. Miller, U.S. Fish and Wildlife Service, personal communication).

At Meeteetse, the plague epizootic in white-tailed prairie dogs waned while many prairie dogs were alive. The density of prairie dogs was low, burrows were widely dispersed (compared with Gunnison's and black-tailed prairie dogs), and more than 100,000 burrows were dusted to stop the epizootic (G. E. Menkens and S. H. Anderson, University of Wyoming, unpublished manuscript). Although plague-positive fleas continued to be found in burrows, dusting may have reduced the flea population below the vector transmission threshold (MacDonald 1957).

A laboratory study demonstrated that white-tailed prairie dogs are highly susceptible to plague, and therefore the epizootic probably did not stall because the prairie dogs were resistant (E. Williams, University of Wyoming, undated report to the U.S. Fish and Wildlife Service). If fleas are maintaining plague and low rates of transmission to prairie dogs are adequate to amplify plague in the fleas, the white-tailed prairie dog complex at Meeteetse may be an enzootic plague system. Researchers of plague at Meeteetse should consider this possibility.

Miles et al. (1952) described epizootics of plague in black-tailed prairie dogs near Lubbock, Texas, during 1945–49, and plague epizootics still occur there today (R. Chesser, Savannah River Ecology Laboratory, personal communication). Plague epizootics in black-tailed prairie dogs have been extensive in eastern Colorado (Barnes 1982), but apparently plague has not occurred in this species north of Colorado. Reports of plague epizootics are not as detailed for black-tailed as for Gunnison's prairie dogs, but mortality rates and rate of spread seem to be similar in the two species (see below). The most detailed long-term studies of the behavior and ecology of black-tailed prairie dogs were at the Wind Cave National Park in South Dakota where plague has never been reported in prairie dogs (King 1955; Koford 1958; Hoogland 1979, 1981a, 1981b; Hoogland and Foltz 1982; Garrett and Franklin 1988; Garrett et al. 1982). The reason plague has not struck northern black-tailed prairie dogs is unknown. Plague has been identified in species other than prairie dogs in eastern Montana and Wyoming in counties where black-tailed prairie dogs occur (Barnes 1982). Epizootics in black-tailed prairie dogs may have occurred but have not been noticed because of the remote locations of the colonies.

The densities of Gunnison's prairie dogs are often as high as densities of black-tailed prairie dogs, and like the colonies of black-tailed prairie dogs, colonies of Gunnison's prairie dogs often cover very large areas (Ecke and Johnson 1952). In South Park, Colorado, colonies of Gunnison's prairie dogs covered more than 370,000 ha in 1941. At that time, the U.S. Fish and Wildlife Service began control of prairie dogs, and workers reported that some disease (probably plague) killed prairie dogs on more than 97,000 ha prior to poisoning. Between 1947 and 1949 in South Park, plague reduced colonies of Gunnison's prairie dogs to less than 5% of their former extent (Ecke and Johnson 1952).

Although the epizootic at South Park was the most drastic reported for prairie dogs, colonies of Gunnison's prairie dogs do not have to be large to become the focus of an epizootic. Lechleitner et al. (1962) watched the extinction of a colony of about 275 Gunnison's prairie dogs in an isolated mountain meadow near South Park between June and September 1959. Likewise, Lechleitner et al. (1968) observed the passage of a plague epizootic through a complex of seven colonies of Gunnison's prairie dogs in Saguache County, Colorado, during 1964–66. Two of the colonies were eliminated during the first summer, and three had become extinct by 1966. A few prairie dogs remained at two colonies when the epizootic ended in 1966. Fitzgerald (1970) studied Gunnison's prairie dogs in 1965 at a small colony that was isolated by 12.8 km from other Gunnison's prairie dogs. The colony covered 4.74 ha and consisted of 68 prairie dogs in summer 1965. After 2 years, mortality from a combination of plague and winter kill resulted in the extinction of the town.

Rayor (1985) observed a plague epizootic in a marked population of Gunnison's prairie dogs at the Curecanti National Recreation Area near Gunnison, Colorado. She reported the annihilation of a colony of 1,000–1,500 prairie dogs during a 2 month epizootic in spring 1981. However, some animals were still present in shrubby habitat surrounding her Blue Mesa study area after the epizootic (A. Barnes, Centers for Disease Control, Fort Collins, Colorado, personal communication), and when I visited the site in July 1986, prairie dogs were again abundant despite attempts by the National Park Service to control them.

An epizootic in Gunnison's prairie dogs swept through the Moreno Valley in north-central New Mexico during 1983–87 (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data). The epizootic probably began near the town of Eagle Nest (Figure) where a human had plague in August 1983. Surveillance by the New Mexico Environmental Improvement Division and the Centers for Disease Control revealed plague-positive fleas of species that associate with Gunnison's prairie dogs, thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) and deermice. In October 1984, few prairie dogs were found near Eagle Nest; however, prairie dogs were abundant in the west and south of the valley. At a study area between Eagle Nest Lake and U.S. Highway 64 (Midlake) where prairie dogs were marked and trapped in October 1984, their density was 30/ha. With the marked population as a guide to density at other areas and from a survey of colonies in the valley, J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin (University of Notre Dame, unpublished data) estimated that the population of Gunnison's prairie dog in the Moreno Valley at that time numbered more than 100,000.

In October 1984, prairie dogs were as abundant north of Six-mile Creek and west of Moreno Creek as at Midlake. In March and April 1985, few prairie dogs emerged from hibernation in the north, and by 1 July 1985, the density was less than 0.1/ha. Subsequent serology tests of survivors indicated that plague had been present (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data).

There were no indications of plague in prairie dogs at Midlake until July 1985. However, a large, but uncounted population of thirteen-lined ground squirrels that had been present in October 1984 was reduced to two animals in April 1985. In July 1985, an adult female prairie dog had a weak serum antibody titer, and in August, plague-positive fleas were collected from prairie dogs and their burrows. By 1 October 1985, the marked prairie dog population, which consisted of 168 animals in July, was reduced to about 25. Only seven prairie dogs emerged from hibernation in March 1986, and all had disappeared by 1 July of that year. On 1 September 1986, a careful search of 200 ha between Eagle Nest Lake and Highway 64 revealed two prairie dogs (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data).

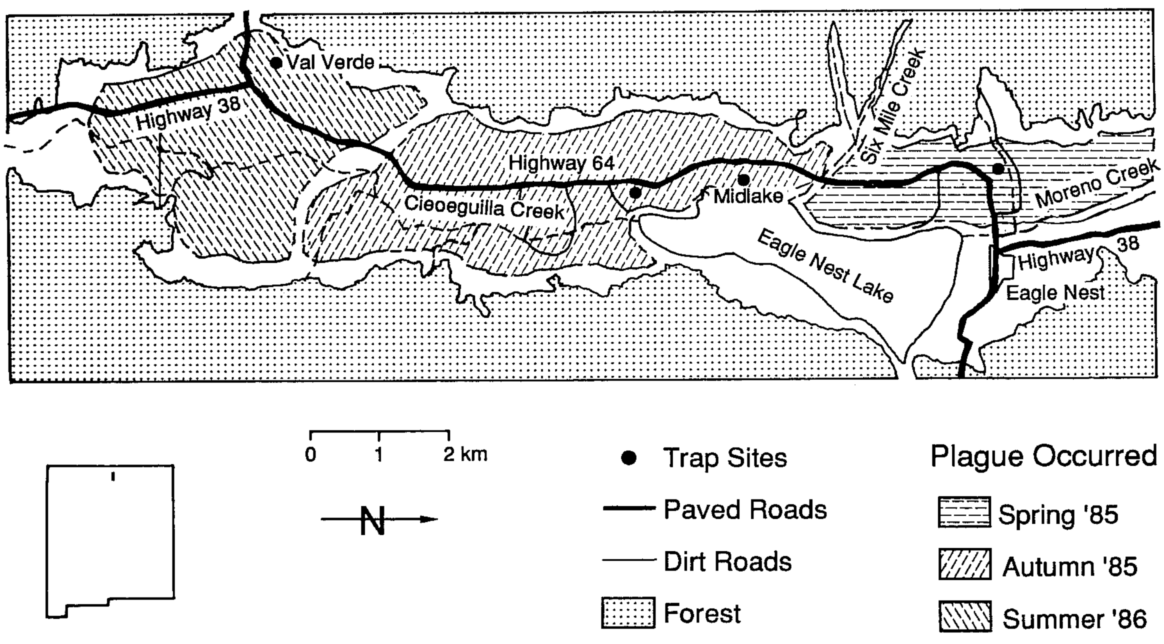

Figure. Moreno Valley in north-central New Mexico.

The pattern at the north and center of the valley was repeated in the south with only minor differences during 1986–87. After the epizootic had spread through the Moreno Valley in June 1987, the entire population of Gunnison's prairie dogs in the valley consisted of 250–500 prairie dogs (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data). This figure includes several colonies in the north that had undergone 2 years of post-plague population growth at that time. Using the conservative estimates of 100,000 prairie dogs in October 1984 and 250–500 in June 1987, plague reduced the population of Gunnison's prairie dogs by 99.5–99.8%.

All of the described studies of plague in Gunnison's prairie dogs were of isolated colonies or colonies that were in isolated complexes. Climatic conditions and prairie dog flea species (*Oropsylla hirsuta, O. labis, O. tuberculata cynomuris*) were similar in every case, and in all cases, the declines of prairie dog populations were between 95 and 100%. At the end of the epizootics, many prairie dog fleas were infectious for plague. In the Moreno Valley, fleas that associate with other rodent species were taken from prairie dog burrows (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data): *O. bacchi*, associated with thirteen-lined ground squirrels; *Rhadinopsylla sectilis* and *Aetheca wagneri*, associated with deermice (Haas et al. 1973).

Gunnison's prairie dogs are clearly not the maintenance species for plague. At most, the species spreads the disease rapidly over large areas and possibly allows plague to infect new, potentially enzootic populations of other species. White-tailed prairie dogs are able to maintain sizeable populations much longer during plague epizootics (G. Menkens, U.S. Fish and Wildlife Service, personal communication), whereas the more social black-tailed and Gunnison's prairie dogs suffer rapid, intense die-offs (Miles et al. 1952; Lechleitner et al. 1962, 1968; Fitzgerald 1970; Barnes 1982; Rayor 1985; J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data). The simplest explanation for this difference is that the higher population densities and higher rates of social contact of Gunnison's and black-tailed prairie dogs enhance the spread of plague-positive fleas. Other explanations are less likely because the flea vector species are the same, and all the prairie dog species seem to be similarly susceptible to plague in laboratory studies.

The current ideas of plague epidemiology assume that enzootic populations are spatially homogeneous. That is, there is no spatial structure in the habitat that can affect the rates of contact between individuals in subpopulations or patches. This assumption is clearly unrealistic in natural rodent communities where contact between individuals inside patches is more likely than contact between individuals from different patches. Cully (1986) developed a hypothetical model for the enzootic maintenance of plague in the Moreno Valley, New Mexico, that does not depend on resistant maintenance populations. In that model deermice or meadow voles are enzootic at that focus. Both species are abundant inside some patch types and rare in others. Social contacts by individuals inside patches are frequent, thus enhancing transmission of plague. If there are time lags between colonization of patches by healthy individuals and the appearance of plague at those patches from immigration of infected individuals, plague might be maintained by highly susceptible species. If the model is correct, detection of enzootic plague could be very difficult even at known foci because it would only be present in a given patch at unpredictable times. Because deermice and voles are not conspicuous, epizootics in these species could go unnoticed.

Black-footed Ferrets

Black-footed ferrets were once in prairie dog colonies from Canada to Mexico through the high plains of the western United States. Black-footed ferrets are nearly obligate predators on prairie dogs and use their burrows for shelter (Sheets et al. 1971; Gates 1973; Hillman and Clark 1980; Hillman and Linder 1973; Stromberg et al. 1983; Clark 1986). Black-footed ferrets may occasionally take other prey, but except for transients, they are always found in association with prairie dogs. During the first half of the twentieth century, the species disappeared from most of its former range (Hillman and Clark 1980) as the range of prairie dogs contracted.

At Meeteetse, Wyoming, the colonies of white-tailed prairie dogs that supported ferrets underwent a plague epizootic that began during the winter of 1984–85. At that time, black-footed ferrets began to disappear, presumably as a result of either starvation because of the disappearance of prairie dogs or of canine distemper that subsequently reached epizootic proportions in the black-footed ferret population (Forrest et al. 1988; Williams et al. 1988). Plague is not thought to be directly responsible for the loss of ferrets because many carnivore species, including domestic ferrets (*Mustela putorius*) and Siberian polecats (*M. eversmani*), seem to be resistant to plague (E. S. Williams, undated. Experiemental infection of white-tailed praire dogs [*Cynomys leucurus*] with plague [*Yersinia pestis*]. Unpublished report to U.S. Fish and Wildlife Service. 11 pages).

Ultimately it makes no difference if plague kills black-footed ferrets directly or by destroying their prey base. If black-footed ferrets are to be successfully restored to their historic range, they must have a prey base that is sufficiently consistent to secure long-term survival. Stable prairie dog populations may exist in areas outside the range of plague or where the transmission of plague is sufficiently slow to allow populations to maintain themselves through an epizootic. Such maintenance might be possible where critical flea vector species are rare or missing and where prairie dogs occur at sufficiently low density that contact with infected conspecifics is unlikely or if prairie dogs can develop resistance to plague.

Management Problems

Some of the management problems created by plague in prairie dogs are: (1) predicting whether a complex of prairie dog colonies with sufficient numbers to support a population of black-footed ferrets persists through time, (2) knowing in advance when an epizootic occurs so that ferrets can be moved or other mitigation can be started, (3) understanding how plague is spread inside and between colonies so that the rate of epizootics and the probability of spread to adjacent colonies inside a complex can be reduced.

The first and most serious gap in knowledge of plague ecology is what happens to the disease between epizootics. Plague has been recorded in non-epizootic rodents, but except for the California vole system described earlier, plague is present in populations for a time and then seemingly disappears (Poland and Barnes 1979; Barnes 1982). The Plague Branch of the Centers for Disease Control in Fort Collins, Colorado, monitored plague antibodies in badgers (*Taxidea taxus*) and other carnivores; but after 8 years of positive records, the disease disappeared. During that time, deermice were thought to be the maintenance hosts (A. Barnes, Centers for Disease Control, Fort Collins, personal communication). Lechleitner et al. (1968) and Fitzgerald (1970) implicated deermice as an enzootic species. Richardson's ground squirrels (*S. richardsoni*; Lechleitner et al. 1962), woodrats (*Neotoma* spp.; Miles et al. 1952; Barnes 1982), and meadow voles (J. F. Cully, Jr., A. M. Barnes, T. J. Quan, and G. O. Maupin, University of Notre Dame, unpublished data) have also been implicated, but no direct evidence that any of these species maintains the disease has been reported.

The most plausible mechanism for the maintenance of plague at foci between sciurid epizootics is the involvement of other mammalian host species. The California vole example cited above is a case in point. At San Bruno Mountain, San Mateo County, California, California voles may become infected like other rodents and attain sufficient numbers of bacteria in their blood to infect fleas, yet show no overt symptoms of the disease (Hudson et al. 1964). Presumably after initial infection, these animals are immune to further infection. Survivors produce young naive voles that provide a susceptible host population. In that system, the rodents can produce several litters of offspring per year, therefore infected fleas can probably maintain plague during short periods when susceptible voles are not available. Such clear enzootic systems have not been identified elsewhere, and the process of maintaining plague in other areas may be different.

The second problem in plague ecology is lack of information on how, when, and why plague is transmitted to prairie dog populations to start epizootics. Knowing the enzootic species is obviously critical to understanding how prairie dogs initially become infected. Transmission to prairie dogs at the beginning of epizootics could be by contact with fleas that were infected when feeding on other bacteremic rodent species; by contact with prairie dog fleas transported from distant prairie dog colonies by dispersing prairie dogs, raptors, wild carnivores (Fitzgerald 1970; Poland and Barnes 1979), or domestic dogs (Rust et al. 1971a, 1971b); by consumption of plague-infected carrion (Rust et al. 1972); or by pneumonic transmission from other species (Rollag et al. 1981). Assuming that plague is maintained by enzootic rodents and transmitted to prairie dogs by fleas, variables that increase the risks of transmission between species have to be known. Data on flea densities prior to epizootics in prairie dogs or other rodent species are few, but variance in flea density could alter the likelihood of interspecific transmission. Data on the population dynamics of potential enzootic mammal species prior to epizootics or on the changes in habitat overlap that occur with changing rodent density are also few. As the density of enzootic or epizootic species increases, habitat overlap with other species may increase and in turn increase the probability of interspecific contact and exchange of fleas.

The third problem is minimization of the effects of plague in prairie dogs after the onset of an epizootic. There are no published data that demonstrate effective control of plague epizootics. Fitzgerald (1970) attempted to control fleas by dusting prairie dog burrows on half of the colony he studied, but the population was small and after 2 years went extinct. At Meeteetse, burrows were dusted to control fleas, and the epizootic seemed to stabilize. Because long-term maintenance of plague in prairie dogs has not been described from other sites, dusting may have been partially effective. It is also possible that the epizootic was not affected by the attempted flea control but instead was slowed by the long distances between prairie dogs and burrows typical of colonies of white-tailed prairie dogs. Additional controlled experiments with replication could elucidate the effectiveness of flea control. Barnes (1993) described a successful effort to end an epizootic in Gunnison's prairie dogs at the Curecanti National Recreation Area in Colorado. Under some circumstances, plague epizootics can seemingly be modified by flea control after onset of the epizootic, but the necessary conditions and techniques have not been well defined.

If flea control is an effective method for controlling epizootics, the effects will be manifest in individual colonies. A separate problem is the spread of plague between colonies in a prairie dog complex. Such spread could occur in several ways but most likely by dispersing prairie dogs or flea-carrying predators moving among colonies.

A variety of flea controls should be tested at selected prairie dog complexes to determine better flea control prior to epizootics and to identify the most cost-efficient methods. Experiments should be conducted to determine whether the reduction of inter-colony dispersal of prairie dogs is possible by controlling prairie dog density, by manipulating spatial distribution of colonies, or by creating dispersal barriers with vegetation between colonies.

The ecology of plague in most areas probably is affected by a complex interplay of the described factors. Focusing on only one aspect of the system probably does not provide useful insight for management. Flea density may be a function of host population density, and interspecific transmission of plague may depend on spatial overlap of the rodent species and density of fleas on enzootic or epizootic rodents.

Finally, I iterate that, because of the broad spectrum of habitats and the extensive geographic range of prairie dogs, details of the ecology of plague may differ between populations or species. Prairie dogs occupy a wide variety of habitats, each with unique rodent species. Because different rodent species have different habitat associations, the degree of overlap varies. Each rodent species carries different species of fleas, and different fleas may affect transmission by being more or less host specific or effective as plague vectors. In some systems, plague might be transmitted directly from enzootic to epizootic species, whereas in other systems, intermediate hosts may be necessary. Thus, broad generalities about the ecology of plague that can be translated into broad management plans may never be possible. Nevertheless, site specific information from monitoring may be useful for determining whether reintroductions of black-footed ferrets will be successful.

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Appendix. Definitions of epidemiological terms as they are used in this paper[a]

Amplifier A host that serves to infect additional vectors or hosts. It amplifies the infected portion of the population.

Disease Pathology caused by microparasites or macroparasites.

Enzootic Refers to a species or animal that maintains a disease system with little temporal change in intensity for a long time.

Epizootic An explosive outbreak of disease with rapid transmission in non-human animals. An epizootic species supports an epizootic. Because susceptible hosts are quickly used up, epizootics are short-lived.

Focus A geographic area where an enzootic disease system is maintained through time.

Immunity A state following infection in which the host has circulating antibodies that eliminate infections.

Infection A state in which an organism, with or without disease, has reproducing parasites in its body.

Microparasite Virus, rickettsia, bacteria, or protozoa that cause disease in susceptible hosts.

Resistance Used here in the context of resistance to disease, the ability to survive infection.

Susceptibility The ability to become infected by disease causing organisms.

Vector An animal, usually an arthropod, that transmits disease, causing the transfer of organisms between hosts. Fleas are vectors of plague because they transmit plague from one mammal to another.

[a] Some can be defined differently in other contexts.

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INTERSPECIFIC COMPARISONS OF SYLVATIC PLAGUE IN PRAIRIE DOGS

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Of the 3 major factors (habitat loss, poisoning, and disease) that limit abundance of prairie dogs today, sylvatic plague caused by *Yersinia pestis* is the 1 factor that is beyond human control. Plague epizootics frequently kill >99% of prairie dogs in infected colonies. Although epizootics of sylvatic plague occur throughout most of the range of prairie dogs in the United States and are well described, long-term maintenance of plague in enzootic rodent species is not well documented or understood. We review dynamics of plague in white-tailed (*Cynomys leucurus*), Gunnison's (*C. gunnisoni*), and black-tailed (*C. ludovicianus*) prairie dogs, and their rodent and flea associates. We use epidemiologic concepts to support an enzootic hypothesis in which the disease is maintained in a dynamic state, which requires transmission of *Y. pestis* to be slower than recruitment of new susceptible mammal hosts. Major effects of plague are to reduce colony size of black-tailed prairie dogs and increase intercolony distances within colony complexes. In the presence of plague, black-tailed prairie dogs will probably survive in complexes of small colonies that are usually >3 km from their nearest neighbor colonies.

Key words: *Cynomys gunnisoni, C. leucurus, C. ludovicianus,* disease, epizootic, landscape, metapopulation, plague, *Yersinia pestis*

Between 1900 and today, the area covered by colonies of black-tailed prairie dogs (*Cynomys ludovicianus*) in the western United States was reduced from about 4×10^7 ha to <600,000 ha, a reduction of >98% (Biggins and Godbey 1995; K. Graber et al., in litt.; Knowles 1998; Nowak 1999). The primary cause of this reduction has been attributed to government and private pest control, habitat loss through conversion of grasslands to crop agriculture, and sylvatic plague (*Yersinia pestis*). After a reduction in control that began in 1973, with an executive order that banned the use of compound 1080, prairie dog species made moderate recoveries. However, continued poisoning since then and sylvatic plague epizootics have resulted in declines of prairie dogs throughout their range during the past 2 decades (United States Department of Interior, Fish and Wildlife Service 2000).

Plague is not endemic to the New World, but entered the United States at several ports around 1900 and became established in commensal rodents in San Francisco in 1900 (Link 1955). The 1st records of plague in wild rodents in the United States occurred in the Berkeley Hills, California, when plague was identified in California ground squirrels (*Spermophilus beecheyi*) in 1908 (McCoy 1908; Wherry 1908). After that, plague spread quickly in a number of species of wild rodents. *Y. pestis* was cultured from fleas of ground squirrels collected in Yellowstone National Park, Wyo-

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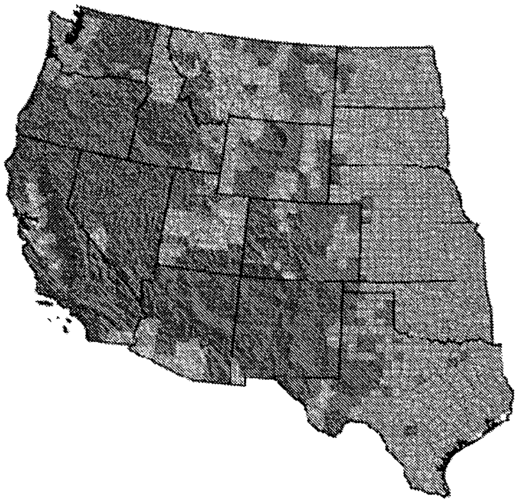

FIG. 1.—Distribution of plague in the United States by county (dark gray) during 1970–2000; unpublished records from Centers for Disease Control, Bacterial Zoonoses Branch. The current distribution was attained by 1950 and has remained relatively stable since that time.

ming, in 1936 (Quan 1982). Plague 1st was identified in Utah prairie dogs (*C. parvidens*) and from fleas on white-tailed prairie dogs (*C. leucurus*) in southwestern Wyoming in 1936 (Eskey and Haas 1940). The 1st records of plague in Gunnison's prairie dogs (*C. gunnisoni*) occurred in New Mexico in 1938 (Eskey and Haas 1940) and in black-tailed prairie dogs in western Kansas in 1945 (Cully et al. 2000) and near Lubbock, Texas, in 1947 (Miles et al. 1952). By around 1950, the current distribution of plague was established near its current limit (Fig. 1). Although minor range extensions have occurred since then, the western boundary of plague has been near its present location since the early 1950s (Barnes 1982, 1993).

The overall impact of plague on prairie dogs during the 1st one-half of the 20th century is not well documented but was probably much greater than is appreciated generally. For example, Ecke and Johnson (1952) reported a die-off of a large population of Gunnison's prairie dogs in South Park, Park County, Colorado, that was later diagnosed as a consequence of a plague epizootic. That die-off resulted in nearly 100% eradication of Gunnison's prairie dogs in 250,000 ha during a 2-year period. At that time, poisoning control was considered effective if 85% of prairie dogs were killed, which resulted in the need for frequent repoisoning. If plague operated on other large colonies of Gunnison's and black-tailed prairie dogs as it did in South Park in 1945–1946, its impact may have been greater than that of poisoning.

Today, plague is an important part of the ecology of the 4 species of prairie dogs in the United States. Some of the important consequences of plague in prairie dogs are local extirpation of colonies, reduced colony size, increased variance in local population sizes, and increased distances between colonies. Black-tailed prairie dog colonies often occur on the grassland landscape in clusters or complexes. The impacts of plague reduce the effectiveness of dispersal in demographic rescue among colonies and increase the probability of extinction of entire complexes.

We review the dynamics of plague in white-tailed, Gunnison's, and black-tailed prairie dogs. We also consider their mammalian associates and fleas. We then identify what differences in plague dynamics among prairie dog species can teach us about the biology of *Y. pestis.* Finally, we use that information to make predictions about the long-term impacts of plague on prairie dogs.

LABORATORY CHALLENGE STUDIES

All 4 species of prairie dogs are highly susceptible to plague infections. The relative susceptibility of rodents to *Y. pestis* typically is determined through laboratory exposure of hosts via subcutaneous inoculation of pure cultures of the bacterium (Holdenried and Quan 1956). Williams (in litt.) challenged white-tailed prairie dogs with titrated doses of *Y. pestis* and found that the mean lethal dose was 46 bacterial cells. In general, laboratory challenges led to signs of illness in 3–4 days, with death following 2–3 days later (E. S. Williams, in litt.). Survival time was related inversely to dose. One animal survived a challenge of 2,300 organisms and developed serum antibodies. On the other hand, 25% of individuals challenged with 2 organisms died.

The number of bacteria inoculated into hosts probably varies by flea species, but may be in the realm of 15,000 organisms for effective vectors (Burroughs 1947), well above the number necessary to cause infections in most rodents. Poland and Barnes (1979) did not cite particular laboratory challenge studies but generalized for species of *Cynomys* that <100 bacteria cause disease with near 100% mortality.

Plague in Fleas

Fleas serve as vectors for *Y. pestis* in a manner somewhat different from other biologically transmitted parasites, in that bacteria grow in the gut of fleas and form a bolus, which obstructs the proventricular valve (stomach valve). When an infected flea takes a blood meal, the blood travels to the stomach, but because the valve is blocked, the blood then is regurgitated with an infective dose of bacteria, which is injected back under the skin of the vertebrate host (Poland and Barnes 1979). This has 2 important effects: it puts a large inoculum into the mammal host, and because the flea is unable to feed successfully, it becomes famished and tries to feed more times than it would if it could successfully retain its meal (Eskey and Haas 1940). This starved condition probably causes host specificity to break down, enhancing multispecific transmission of plague. In laboratory studies, plague infections become established in fleas after about 9–28 days (Eskey and Haas 1940; Poland and Barnes 1979).

More than 20 species of fleas have been collected from prairie dogs or their burrows (Table 1). Five species of fleas (*Opisocrostis labis, Oropsylla hirsutus, O. tuberculatus cynomuris, Neopsylla inopina*, and *Pulex* spp.) that specialize on prairie dog are collected frequently and are implicated in transmission of plague. *Pulex* spp. is collected frequently from black-tailed prairie dogs but is a poor vector (Burroughs 1947). Two ground squirrel fleas, *Thrassis bacchi* and *T. pandori*, are frequently positive for *Y. pestis.* These species most often are found on ground squirrels but frequently are found on prairie dogs and other rodent species (Table 1). Thus, these 2 species may be particularly important as multispecies vectors. *Aetheca wagneri* and *Rhadinopsylla*, fleas of deer mice (*Peromyscus maniculatus*), have been found positive for *Y. pestis* in prairie dog burrows, and *Monopsylla exilis*, a flea of the grasshopper mouse (*Onychomys leucogaster*—Thomas 1988; Thomas et al. 1988) infected with *Y. pestis*, recently was collected from a burrow of a black-tailed prairie dog on Cimarron National Grassland in southwestern Kansas (J. F. Cully, Jr., in litt.). Many of these fleas regularly are positive for *Y. pestis* when collected from prairie dog burrows, implicating their normal mammal hosts in plague epizootics.

Infected prairie dog fleas have been obtained from burrows 3 months (Cully et al. 1997**;** Fitzgerald 1970) to 1 year (Lechleitner et al. 1968) after disappearance of the last prairie dog. Persistence of fleas infected with *Y. pestis*, in addition to the importance of fleas in both intraspecific and interspecific transmission, contributes to the persistence of plague in the rodent community. Diversity of flea species found in prairie dog burrows provides numerous opportunities for interspecific spread of *Y. pestis* from other species of rodents to prairie dogs, and from prairie dogs to other species of rodents.

Epizootic Patterns of Plague

Plague has been well documented in Gunnison's prairie dogs (Cully et al. 1997; Ecke and Johnson 1952; Fitzgerald 1970; Lechleitner et al. 1968; Rayor 1985). In the Moreno Valley of north-central New Mexico, plague in Gunnison's prairie dogs was

TABLE 1.—Fleas associated with 3 species of prairie dogs and their burrows or with deer mice. P indicates that the flea species collected was infected with *Yersinia pestis*; N indicates that plague has not been documented for the species.

Flea species	Mammal species			
	Gunnison's prairie dog	White-tailed prairie dog	Black-tailed prairie dog	Deer mouse
Aetheca wagneri	N[a–c]	N[d,e]		P[a,d]
Catallagia decipiens	N[a]	N[d]		P[a,d]
Cediopsylla inaequalis		N[d]		
Diamanes montanus	N[f]			
Histrichopsylla dippiei		N[e]		
Hoplopsylla anomalus	N[f]			
Monopsylla eumolpi	P[c]			
Monopsylla exilis			P[g]	
Neopsylla inopina		P[d,e]		N[d]
Opisocrostis labis	P[a–c,f]	P[d–f]		P[a]
Oropsylla hirsutus	P[a–c,f]	P[f]	P[f,g]	N[a]
Oropsylla idahoensis	P[b,c,f]	P[d–f]		P[d]
Oropsylla tuberculatus cynomuris	P[a–c,f]	P[d–f]	P[f]	P[d]
Pulex spp.	N[f]	N[d,f]	P[g]	N[f]
Rhadinopsylla sectilis	P[a]	N[e]		
Rhadinopsylla fraterna	N[c]	P[d,e]		N[d]
Thrassis bacchi	P[a]			N[a]
Thrassis fotus			P[g]	
Thrassis pandori		P[d–f]		

[a] Cully et al. 1997.
[b] Lechleitner et al. 1968.
[c] Fitzgerald 1970.
[d] Anderson and Williams 1997.
[e] Ubico et al. 1988.
[f] Eskey and Haas 1940.
[g] Cully et al. 2000.

1st documented in 1949 (Cully et al. 1997). The next record there involved a human case in the town of Eagle Nest, New Mexico, in 1983, which was attributed to *T. bacchi* or *Rhadinopsylla sectila,* fleas from either 13-lined ground squirrels (*Spermophilus tridecemlineatus*) or deer mice at a rock quarry north of the town. In September 1984, prairie dogs were abundant throughout the grassland of the valley. West of Moreno Creek and south of Eagle Nest (Fig. 2), prairie dogs were abundant at that time. Mark–recapture trapping indicated that the population density in the area was about 30 prairie dogs/ha. During winter 1984–1985, most of the prairie dogs in the northern one-third of the valley, north of Six-mile Creek disappeared. By late June 1985, only isolated prairie dogs could be found.

At that time, no indications of plague existed in marked prairie dogs at the study colony, but 13-lined ground squirrels, which had been abundant in the previous autumn, were rare and disappeared by early summer. Fleas (*T. bacchi*) of 13-lined ground squirrels infected with *Y. pestis* were collected subsequently from nearby prairie dog burrows. In August 1985, plague was documented at the study site in fleas from prairie dog burrows, and the marked population was in decline. Only 25% of those present in June 1985 were estimated to have survived to enter hibernation in October. Seven emerged in spring 1986, and no prairie dogs could be found by July 1995. The pattern repeated itself in the southern one-third of the valley between summer 1996 and 1997, except that ground

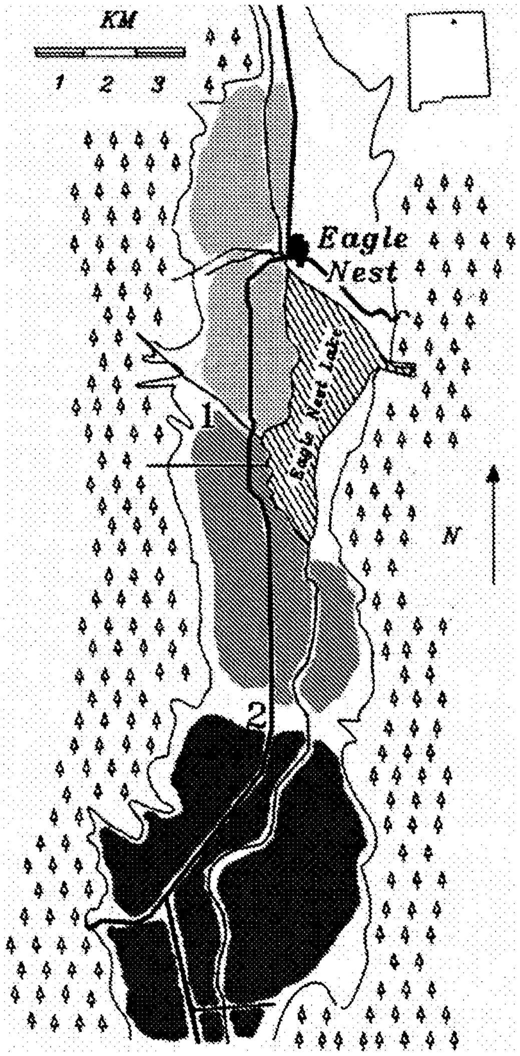

FIG. 2.—Map of the Moreno Valley of New Mexico (modified from Cully et al. 1997) showing the locations of plague epizootics during 1985 (light gray), 1986 (medium gray), and 1987 (dark gray). The 3 regions probably were separated by geographic barriers with 1) deep vegetation at Six-mile Creek and 2) shallow rocky soil at Jackson Hill.

squirrels were not affected. After epizootics, survival of prairie dogs was <1%. In survivors, about 50% had antibody titers, indicating that they had been exposed to plague but had survived. In August 1997, prairie dogs occurred in the Moreno Valley, but colonies were small and scattered, nothing like what had existed there before 1984.

In white-tailed prairie dogs, epizootic patterns are different. Clark (1977) reported a plague epizootic in a small white-tailed prairie dog colony in Wyoming that killed about 85% of the prairie dogs. however, the bacterium quickly disappeared. Years later, plague was diagnosed in a single marked juvenile prairie dog in the same colony (E. S. Williams, in litt.). During that summer no other marked prairie dogs died of plague and no decline was apparent in the population. Conditions likely were not adequate to initiate a plague epizootic in the colony, even though *Y. pestis* was present and prairie dogs were numerous.

Menkens and Anderson (1991) and Anderson and Williams (1997) documented a plague epizootic in white-tailed prairie dogs near Meeteetse, Wyoming, that has continued from 1985 to the present. It was characterized by a slow but continuous decline in the prairie dog population. Plague has been present since 1987 at Shirley Basin, Wyoming. Plague was monitored there in association with black-footed ferret (*Mustela nigripes*). As at Meeteetse, prairie dog populations at Shirley Basin have steadily declined, with local variation in population size (R. Luce and R. Oakleaf, pers. comm.; Menkens and Anderson 1991; Williams et al. 1992, 1997).

The interaction of *Y. pestis* and individual white-tailed prairie dogs is similar to that with Gunnison's prairie dogs. Important vector fleas are also similar (*O. labis* and *O. t. cynomuris*), except that *O. hirsutus* is seldom associated with plague in white-tailed prairie dogs. The population response of white-tailed prairie dogs to plague is considerably less severe than that of Gunnison's prairie dogs. Differences in densities and social interactions probably influence impacts of plague on these rodent species (Gasper and Watson 2001). Colonies of Gunnison's prairie dog that are exposed to plague are very nearly extirpated. Nonetheless, Menkens and Anderson

(1991) reported that variation in populations of uninfected colonies was nearly as great as in infected colonies. Subsequently, Anderson and Williams (1997) revised that opinion; they found that infected colonies declined more precipitously than did uninfected colonies in 1989–1990. However, those declines were less severe than those in Gunnison's prairie dogs, and affected colonies generally rebounded in 1–2 years. Plague has been present continuously in the Meeteetse complex since 1985 and at Shirley Basin since at least 1987. As with Gunnison's prairie dogs, *Y. pestis* has been found in *A. wagneri*, *T. pandori*, *O. labis*, and *O. t. cynomuris* collected from burrows of white-tailed prairie dogs (Ubico et al. 1988).

Reports of plague in black-tailed prairie dogs are not as frequent in the literature as they are for Gunnison's prairie dogs, probably because most research on black-tailed prairie dog was done in South Dakota, outside the current range of plague. The 1st published report of plague in black-tailed prairie dogs (Ecke and Johnson 1952) was for Logan and Weld counties, north of Denver, Colorado, but the associated die-off was not confirmed as induced by plague. The 1st confirmed records of plague in black-tailed prairie dogs were from western Kansas in 1945 (Cully et al. 2000) and from 1946–1947 near Lubbock, Texas (Miles et al. 1952). The current distribution of plague (Fig. 1) was established, with minor variations, by the 1950s. Why plague has not spread east beyond its current distribution is not known. Until the mechanistic basis of the limits are understood better, it is unwise to assume plague will not reach previously unaffected colonies east of the current distribution.

When individual black-tailed prairie dogs are infected with plague, the infection follows a pattern similar to that described above for white-tailed and Gunnison's prairie dogs, with nearly 100% mortality. This high individual susceptibility leads to epizootic die-offs similar to those of Gunnison's prairie dogs; colony populations are extirpated or reduced to <1% of preplague levels. The pattern among colonies has been documented for black-tailed prairie dogs at the Rocky Mountain Arsenal National Wildlife Refuge (United States Department of Interior, Fish and Wildlife Service, in litt.). A plague epizootic began there in 1994. By September 1995, the epizootic ran its course, and the prairie dog population was recovering through May 1999 (Figs. 3 and 4). The pattern of rapid die-off for multiple colonies was similar to the pattern observed on Comanche National Grassland, Colorado, in 1995–1996, where all the large prairie dog towns in the Carizo Unit of the grassland collapsed (J. F. Cully, Jr., in litt.). Regrowth of colonies at Rocky Mountain Arsenal was faster than at the Comanche, in part because of transplantation of prairie dogs to aid recovery at the Rocky Mountain Arsenal (D. Seery, pers. comm.).

Epidemiology

Rate of spread of a disease from individual to individual is the transmission rate. If transmission is fast, the disease spreads more quickly through a population than if transmission is slow. All other things being equal, transmission rate will vary with the degree of sociality in a host. Social species have more frequent intraspecific contact than do less social species. As with sociality, high-density populations are expected to yield higher numbers of contacts, with enhanced rates of transmission. Transmission rates also may vary depending on ability of different species of flea to transmit plague. Other factors that are important to transmission rate include numbers of susceptible individuals, infective individuals, and recovered or immune individuals. In the case of plague in prairie dogs, number of recovered individuals is effectively zero. The population can recruit new susceptible individuals via reproduction or migration. If transmission is fast relative to recruitment and infected animals all die, the population will decline. If the recruitment rate is equal

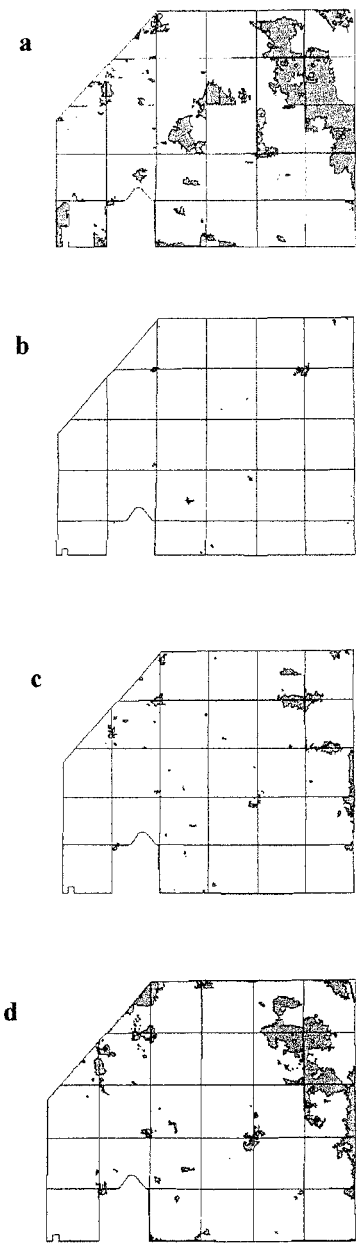

FIG. 3.—Map of black-tailed prairie dog colonies (lines are section lines) at Rocky Mountain Arsenal National Wildlife Refuge near Denver, Colorado (shaded in gray), showing the locations and extent of colonies a) before a plague epizootic in May 1994 (983 ha), b) after a plague epizootic in September 1995 (9 ha), c) after 2 years (140 ha), and d) after 4 years (534 ha) of population growth (United States Department of the Interior, Fish and Wildlife Service, in litt.).

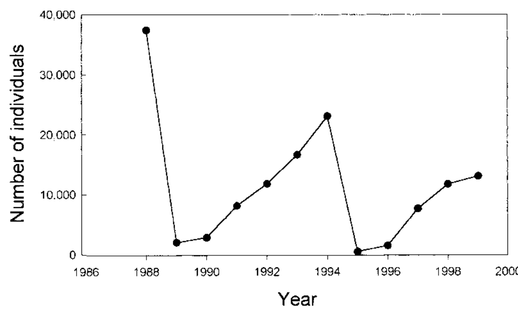

FIG. 4.—Estimated number of black-tailed prairie dogs on Rocky Mountain Arsenal National Wildlife Refuge, Colorado, 1988–1999. Plague epizootics occurred in 1989 and 1995 (modified from United States Department of the Interior, Fish and Wildlife Service, in litt.).

to or faster than the transmission rate, the host population and parasite can persist despite high mortality in infected hosts. Epizootic species are taxa in which disease spreads rapidly and may reduce the size of the susceptible host population either by killing all the hosts or producing a population of immune individuals. In contrast, the disease can persist for a long period with only minor effects on overall population size in enzootic species because loss of individuals from the susceptible population due to death or immunity are compensated by recruitment.

For the past century, scientists have tried to identify enzootic hosts for *Y. pestis* that are characterized by moderate to high resistance to disease, heterogeneity in response to challenge, long and polyestrous breeding season, and short life expectancy (Barnes 1982, 1993; Biggins and Kosoy 2001; Poland and Barnes 1979). Although moderately to highly resistant species have been found with plague from foci around the world (Barnes 1982; Biggins and Kosoy 2001; Poland and Barnes 1979), only rarely has the bacterium been found continuously in a population of rodents (Goldenberg et al. 1964; Hudson et al. 1964).

We believe the expectation for resistant hosts is not necessary for the persistence of *Y. pestis*, a highly virulent disease in which even moderately resistant species may show mortality rates of ≥50% (Holdenried and Quan 1956). White-tailed prairie dogs may provide an example of a new model of an enzootic, or maintenance, host system. White-tailed prairie dogs are as susceptible to plague as are Gunnison's or black-tailed prairie dogs and exhibit epizootics of plague. Individuals infected with moderate doses of *Y. pestis* show essentially 100% mortality. Despite high susceptibility, the low-density colonies of this least social prairie dog species (Nowak 1999) probably contribute to persistence of plague in white-tailed prairie dog colonies because transmission is slow. A relatively rapid rate of recruitment compared with the rate of transmission is an important feature of a species' ability to maintain a highly virulent disease like plague, whether the species is moderately or highly susceptible. Menkens and Anderson (1991) reported that white-tailed prairie dogs were eliminated at a colony with a starting density of 23/ha for 1 year after a plague epizootic. Some animals survived epizootics (Menkens and Anderson 1991) at colonies with lower densities (7–11 prairie dogs/ha). Cully (1989) hypothesized that transmission rates of plague in prairie dogs are density dependent. At low density, transmission of plague is slow enough in white-tailed prairie dogs to allow survivors to reproduce new susceptible individuals at a rate high enough to maintain a host population (i.e., recruitment ≈ mortality).

Adding spatial structure in the form of discrete colonies with intervening unoccupied grassland may enhance persistence by slowing dispersal among colonies where transmission is much slower than it is within colonies. Persistence of virulent organisms in populations of hosts in relatively large geographic areas has been suggested by Yuill (1986) for other arthropod-borne diseases. Migration among colonies can transmit plague from infected to healthy colonies, or provide colonists to restart extirpated colonies. This is the picture that has emerged at Meeteetse and Shirley Basin over the past 15 years.

The Future of Black-Tailed Prairie Dogs

Black-tailed and Gunnison's prairie dogs occur at densities up to 10 times as high as white-tailed prairie dogs and are more social. Thus, they have many more opportunities to exchange fleas or directly transmit the infection. The consequences of the faster spread of plague in these 2 species are profound. Field mortality rates of individuals in infected colonies rise from 85% in white-tailed prairie dogs, which may well be extreme for this species, to nearly 100% in black-tailed and Gunnison's prairie dogs. Infected black-tailed and Gunnison's prairie dog colonies are often extirpated by plague.

Black-tailed prairie dogs on Cimarron National Grassland in Kansas may illustrate a more hopeful pattern, in terms of persistence, at the scale of colony complexes. Despite the fact that plague has been documented from Cimarron National Grassland in 1949, 1997, and 1999 (Cully et al. 2000; J. F. Cully, Jr., in litt.), the area occupied by black-tailed prairie dogs has been fairly stable over the past 10 years. Data for 1989, 1992, 1997, 1998, and 1999 consistently indicate that about 30% of identifiable colony acreage is inactive (United States Forest Service, in litt.). Some of this may be due to shooting, but shooting pressure on Cimarron National Grassland has not been sufficient to eliminate large populations (J. F. Cully, Jr., in litt.). Grassland managers have not allowed any prairie dog poisoning since 1989 (J. Hartman, District Ranger, pers. comm.). Plague is the only disease known to cause extensive die-offs in prairie dogs (Barnes 1993).

Plague may be transmitted intraspecifically into new colonies by prairie dogs dispersing from other, infected colonies, or interspecifically by contact with plague-infected fleas of other rodent species. If transmission among colonies is intraspecific, colonies close together should contract

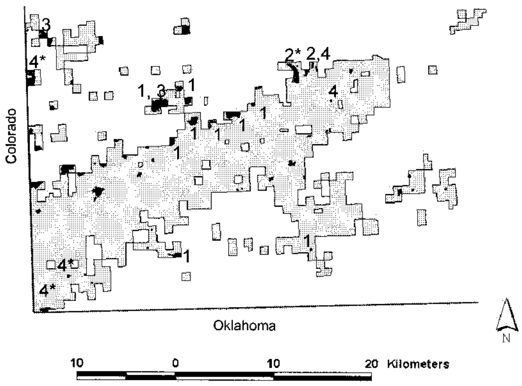

FIG. 5.—Distribution of prairie dog colonies (dark gray) in extreme southwestern Kansas on Cimarron National Grassland (light gray) in 1989–1999. Colonies that were affected by plague are indicated as 1 for 1992, 2 for 1997, 3 for 1998, and 4 for 1999. Asterisks (*) indicate that plague was confirmed at that colony during the given year. Other colonies were assumed to have been reduced by plague because shooting pressure was relatively low, poisoning was not being done, and plague was the only disease known to cause extensive die-offs in prairie dogs.

plague in a wavelike pattern, with close colonies infected before more distant ones. If transmission is interspecific, depending on the dynamics of plague in other host species, plague is expected to occur in prairie dog colonies independent of whether nearby colonies have plague. Staff of the Forest Service at Cimarron National Grassland mapped colonies by hand on 1:126,720 maps in 1989 and 1992, and with global positioning units and geographic information systems in 1997, 1998, and 1999 (Fig. 5). In 1989, 20 colonies were mapped on 303 ha. The 2nd largest town in 1989 covered 92 ha, but <1 ha was active, suggesting a recent die-off. Five additional colonies covering 31 ha also were inactive. In 1992, 30 colonies were mapped. The largest colony from 1989 (102 ha) was 5 ha in 1992. The 1-ha active area in the 92-ha inactive colony mapped in 1989 grew to 63 ha in 1992. A cluster of 7 colonies near the center of the grassland, with intercolony nearest neighbor distances of <3 km, was inactive in 1992 (Fig. 5). Two other colonies (>10 km from the 7 infected colonies) were mostly or totally inactive in 1992. Despite the colonies that became inactive between 1989 and 1992, total active colony area grew 31% to 438 ha during the same period. In 1997, 27 colonies were mapped that covered 504 ha. Two large colonies in the northeastern part of the grassland had plague epizootics, which appeared to extirpate their prairie dog populations in 1997 (Cully et al. 2000). Colony area grew again to 526 ha in 1998 when 30 active colonies were mapped. The large colony in the north-central part of the grassland that was the largest colony in 1989, but 5 ha in 1992, grew to 28 ha in 1997 and again died back in 1998, presumably because of plague, although plague was not confirmed. Another colony in the far northwestern part of the grassland also had a die-off at that time. In 1999, plague was confirmed at 3 colonies, in the northwest, far southwest, and 3 km distant, also in the southwest (Fig. 5).

So what does this say about plague on Cimarron National Grassland? First, the scattered distribution of colonies that were positive for plague in 1997, 1998, and 1999, with intervening unaffected colonies is at odds with the idea that plague is transported by dispersing prairie dogs, although that remains a possibility. Other possibilities are that fleas infected with *Y. pestis* are carried long distances by coyotes or raptors (Barnes 1982, 1993; Cully et al. 2000; Poland and Barnes 1979). Presence of flea species infected with *Y. pestis* and associated with other rodent species in prairie dog burrows supports the hypothesis of interspecific transmission. Second, prairie dog colonies probably are maintained by metapopulation dynamics, in that the rate of colonization of extirpated colonies is about equal to the rate of colony extinction caused by plague. Third, clusters of prairie dog colonies that were extirpated by plague have nearest-neighbor distances <3 km, indicating transmission from recently infected colonies, probably by dispersing prairie dogs.

Work with black-tailed prairie dogs on Cimarron National Grassland (Cully et al. 2000), Gunnison's prairie dog in New Mexico (Cully et al. 1997) and Colorado (Fitzgerald 1970, 1993), and white-tailed prairie dogs in Wyoming (Anderson and Williams 1997; Menkens and Anderson 1991; Ubico et al. 1988) has found fleas of other rodent species, which were positive for *Y. pestis*, in prairie dog burrows. This provides strong support for the hypothesis that epizootics in isolated prairie dog colonies may be caused by contact with fleas of other rodent species such as deer mice, ground squirrels, voles (*Microtus*), or grasshopper mice. This has important ramifications for the delivery of vaccines to curtail epizootics and points to a critical need for research regarding conditions for intraspecific and interspecific plague transmission.

Sylvatic plague is an exotic disease that entered the United States 100 years ago and has become well established in wild rodents in the western one-half of the country. Plague has infected the 4 prairie dog species in the United States for about 60 years with devastating effects. *Y. pestis* is highly virulent to individual prairie dogs of all species, and no evidence suggests that prairie dogs have evolved resistence to plague, although other rodent species have done so in areas of endemic plague (Isaäcson et al. 1983; Quan et al. 1985; Shepherd et al. 1986; Thomas et al. 1988). On Cimarron National Grassland, larger colonies are more likely to become infected with plague compared with smaller colonies. When uninfected colonies occur in close proximity (<3 km) to infected colonies, their likelihood of contracting plague is high. These 2 factors likely result in complexes of small colonies that are mostly >3 km from their nearest neighbors, a situation similar to the distribution on Cimarron National Grassland. Ongoing research must determine if similar patterns of colony distribution within complexes are present at other sites.

The ecology of plague in prairie dogs is highly variable. Prairie dog species differ in density, social behavior, and associated rodents and their ectoparasites. In different parts of the range of black-tailed prairie dogs, rodent associates, their fleas, and climate may be important factors affecting prevalence of plague. It is not possible to predict if plague will cause black-tailed prairie dogs to become dangerously rare, but it is highly likely that they will never attain the dominance on the western plains that was reported at the beginning of the 20th century as long as plague is present.

The current distribution of prairie dogs is modified greatly from the distribution reported 100 years ago. Today, colonies of black-tailed prairie dog are mostly small and widely dispersed, especially in areas where plague is present. Where plague is present, throughout most of the short-grass prairie, it is unlikely that prairie dogs will ever be able to attain their former abundance. To the extent that black-tailed prairie dogs are a keystone species and provide prey or shelter for other wholly or partially dependent species, other components of biodiversity of short-grass prairie also may be threatened by plague. Conservation of black-tailed prairie dogs on mixed-grass prairies, where plague is not present, is essential to maintain the large-scale functional role of prairie dogs on grassland ecosystems so that dependent species can be maintained in viable numbers.

Acknowledgments

We would like to acknowledge the contributions of the long-term monitoring effort for plague in Shirley Basin by R. Luce and R. Oakleaf, Wyoming Game and Fish Department. We are grateful to J. Hartman, J. Cline, D. Svingen, and J. Chynoweigh, who provided data and logistical support on the National Grasslands. K. Gage, Centers for Disease Control, Fort Collins, Colorado, provided the map in Fig. 1 showing the current distribution of plague in the United States, and D. Seery, United States Fish and Wildlife Service, provided maps and data on distribution of black-tailed prairie dog at Rocky

Mountain Arsenal National Wildlife Refuge. We thank D. Biggins, C. Rae, R. Mclean, and an anonymous reviewer for helpful comments on the manuscript. The United States Fish and Wildlife Service and Forest Service, Kansas State University, and United States Geological Survey provided financial support for research on Cimarron National Grassland.

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Special Feature Editor was Michael R. Willig.

- Juvenile prairie dogs are more susceptible to recreational shooting than adults. Among adults, females are more vulnerable than males.
- If landowners regard prairie dogs as an economic resource via recreational shooting, their best strategy is to manage colonies so that the number of individuals shot is always replaced by either births or immigration.
- One common approach to control harvesting of prairie dogs via recreational shooting is to impose a quota on numbers shot. Another approach is to regulate harvesting effort (e.g., by limiting the number of shooters).
- Recreational shooting involves several risks: self-inflicted wounds; accidental shooting of other humans or nontarget species such as burrowing owls; and lead poisoning among scavengers that consume prairie dogs killed by bullets.
- New financial incentives from recreational shooting might make it worthwhile for ranchers and farmers to preserve and manage prairie dog colonies that they otherwise would not tolerate. Consequently, and ironically, today's ranchers and farmers might willingly share responsibility for the long-term survival of prairie dogs.

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CHAPTER 11

Conservation of Prairie Dogs in Areas with Plague

Jack F. Cully, Dean E. Biggins, and David B. Seery

For most of the last 200 years, poisoning and loss of habitat have been primarily responsible for the sharp decline of prairie dog populations (Chapters 8 and 16). More recently, plague has been a key culprit as well, and has claimed millions of victims in the western portion of the prairie dog's geographic range.

Because it completely eliminates so many colonies, and partially eliminates so many others, the relevance of plague to the conservation of prairie dogs is clear. We begin this chapter with a description of plague and its transmission. We then examine whether plague is natural or introduced into North America, and how this might affect the vulnerability of prairie dogs. We investigate possible outcomes regarding the evolutionary battle of prairie dogs versus plague, and the transfer of plague from prairie dogs to humans. We then tackle one of the most vexing questions: what happens to plague between epizootics? We describe the puzzling rarity of this disease in eastern populations, and then explore ways to reduce plague's impact. We conclude by speculating on the long-term prognosis of prairie dogs versus plague.

Plague and Its Transmission

Plague, called sylvatic plague when it affects wild rodents, is a disease caused by a bacterium (*Yersinia pestis*). Because plague commonly infects large numbers of prairie dogs within groups of nearby colonies over a short period of time, biologists and wildlife managers commonly talk about epizootics (or epidemics) of plague. The usual vectors (i.e., organisms that transfer disease-causing microorganisms from one host to another) are fleas, which acquire plague bacteria when they ingest blood of infected mammals (Barnes 1993). Direct transmission of plague among fleas does not occur.

Plague bacteria sometimes cause a blockage at the front of a flea's stomach (Poland and Barnes 1979; Hinnebusch et al. 2002). When a flea with blockage attempts to feed, blood rushes into the gut and hits the block where it picks up plague bacteria; infected blood is then regurgitated back into the host. Because the flea cannot get blood into its stomach, it remains unsatisfied and often bites repeatedly. Blockage and regurgitation promote transmission of plague from fleas to prairie dogs (Gage 1998), but transmission also might occur via contaminated flea mouthparts without blockage (Ken Gage, quoted in Orent 2004).

Yersinia pestis is the same bacterium that killed about 40% of the human population of Europe between 1347 and 1352 (Gage 1998; Orent 2004). For humans and probably for other susceptible mammals as well, plague has three overlapping stages (Orent 2004). When transmitted by fleas it first attacks the lymphatic system, and infected lymph nodes swell into the lumps known as buboes (bubonic plague). Soon thereafter, plague bacteria enter the bloodstream and proliferate there (septicemic plague). Septicemic transmission occurs after contact with infected blood. During the final stages of plague, the infection sometimes enters the victim's lungs and causes pneumonia (pneumonic plague). Pneumonic transmission occurs when the host coughs out bacteria as respiratory droplets that are inhaled by others. Inhaled bacteria rapidly reproduce in the lungs and usually cause a serious infection, which is often fatal.

Prairie dogs sometimes cannibalize carcasses (Hoogland 1995), so direct (septicemic) transmission might occur if individuals cannibalize victims of plague. In the laboratory, pneumonic transmission of plague also can occur (T. E. Rocke, National Wildlife Health Center, Madison, Wisconsin, personal communication, 2002). For prairie dogs living under natural conditions, however, transmission of plague almost always involves fleas (Barnes 1993; Cully and Williams 2001; Hoogland et al. 2004).

Is Plague Natural or Introduced to Western North America?

The origin of plague in North America is uncertain. Perhaps plague arrived via the Bering Land Bridge during the Pleistocene (Biggins and Kosoy 2001b). From historical, biochemical, and genetic data, however, most researchers now believe that plague first arrived in the United States in 1899 or 1900 via com-

mercial ships from China (Link 1955; Achtman et al. 1999; Biggins and Kosoy 2001a, 2001b; Orent 2004). In the vicinity of San Francisco, California, introduced plague flourished among house (black) rats. The first native rodent to be identified with plague was the California ground squirrel in 1908 (McCoy 1908; Wherry 1908). By the early 1920s, plague occurred in southern California to the south and in southern Oregon to the north (Link 1955). By the mid-1930s, plague occurred as far east as Wyoming, Utah, and Arizona, and by 1950 it had spread to its current distribution (Figure 11.1). Among the different species of prairie dogs, the first suggestion of plague was a die-off among Gunnison's prairie dogs in Arizona in 1932, but proof of plague in this species did not come until 1937 (Eskey and Haas 1940). Plague was documented among Utah prairie dogs in 1936 (Eskey and Haas 1940). The first demonstration of plague among black-tailed prairie dogs occurred in Kansas in 1945, in Texas in 1947, and possibly in Colorado in 1945 (Ecke and Johnson 1952; Miles et al.

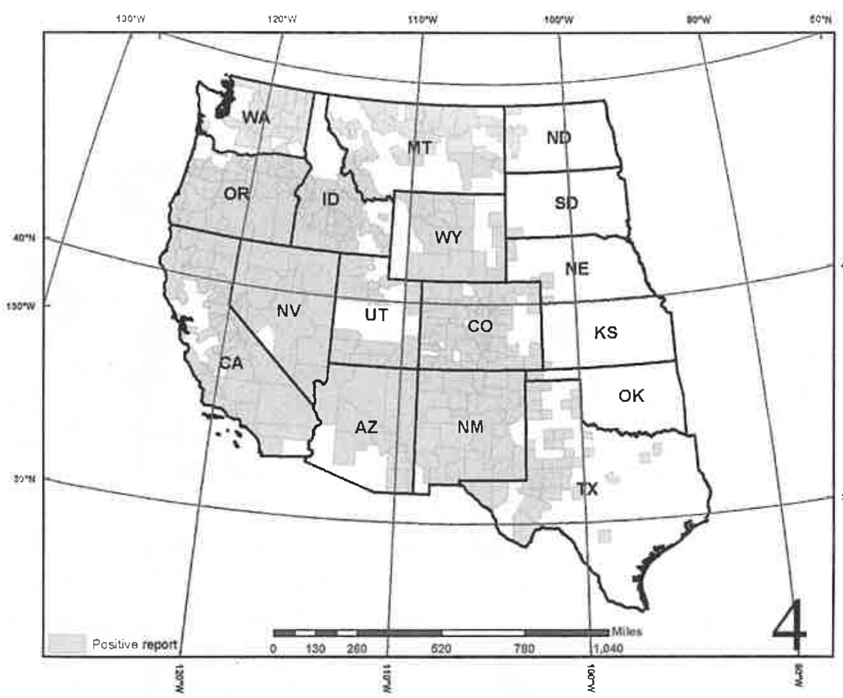

Figure 11.1. Counties with plague among humans, wild mammals, or fleas from 1970 through 2002. Undetected plague also might have occurred in other counties. The 102nd meridian is the approximate eastern boundary of plague. Map courtesy of Center for Disease Control.

1952; Cully et al. 2000). Varela and Vásquez (1954) recorded plague among Mexican prairie dogs in Coahuila, Mexico, but this report is questionable because none of the "infected" individuals died (see also Trevino-Villarreal et al. 1998).

Vulnerability of Prairie Dogs to Plague

When plague infects a prairie dog colony, mortality usually approaches 100% (Miles et al. 1952; Barnes 1993; Cully and Williams 2001). Indeed, we usually first suspect plague among prairie dogs by the sudden disappearance of most or all residents within a colony. Mortality results because plague bacteria release fatal toxins (Barnes 1993; Achtman et al. 1999). Most victims show no aboveground symptoms and perish underground. Occasionally an ailing, disoriented victim dies aboveground (Barnes 1993; see also Rayor 1985; Hoogland et al. 2004) (Figure 11.2). The time between initial exposure to plague and mortality varies for prairie dogs, but usually it is less than 14 days (Marinari and Williams 1998; Chapter 13).

Figure 11.2. Disoriented, wobbly juvenile prairie dog that is probably infected with plague. Plague-infected individuals usually die underground, but sometimes they wander aimlessly and then perish aboveground. Photo by Frederic Nichols.

Two factors, not necessarily mutually exclusive, might help to explain the extreme vulnerability of prairie dogs to plague. The first factor is that plague is an introduced disease to which prairie dogs have been exposed for only about 60 years. In this short time, prairie dogs probably have been unable to evolve a good defense—and consequently remain highly susceptible. The second factor involves the virulence of toxins produced by plague bacteria. After a prairie dog dies from the toxins, infected fleas from the carcass are probably more likely than infected fleas on live hosts to seek new hosts and thereby transmit plague. If so, then natural selection for increased virulence of plague (and consequently increased dispersal of infected fleas away from dead prairie dogs) might be stronger than natural selection for resistance among prairie dogs—so that prairie dogs remain highly susceptible. If plague is so virulent that it kills all the prairie dogs within the home and nearby colonies, however, then finding suitable hosts will be difficult for dispersing fleas.

Plague devastates populations of numerous species of marmots, ground squirrels, and chipmunks, but prairie dogs seem to be especially susceptible when compared to other species of ground-dwelling squirrels (Pollitzer and Meyer 1961; Olsen 1981; Barnes 1982, 1993; Biggins and Kosoy 2001b; Orent 2004). One likely explanation for this difference is that prairie dogs are more densely colonial than other squirrels (Hoogland 1981a; Michener 1983), and thus are more susceptible to costs of coloniality such as increased transmission of diseases (Alexander 1974; Hoogland 1979a, Cully and Williams 2001). On the other hand, their extreme vulnerability to plague relative to other taxonomic relatives might be an artifact that results because highly interactive prairie dogs in large colonies amidst low vegetation are easier to census and track than other, less interactive ground-dwelling squirrels that live in smaller colonies amidst taller vegetation (Miles et al. 1952; Lechleitner et al. 1968).

Plague Threatens the Conservation of Prairie Dogs

In combination with unpredictability regarding the place and timing of epizootics, the catastrophic mortality from plague inhibits efforts to conserve prairie dogs (Wuerthner 1997; Cully and Williams 2001; USFWS 2000a). Consider the recent history of prairie dogs at the Rocky Mountain Arsenal National Wildlife Refuge (RMA) in Colorado, for example. In 1988, prairie dogs at RMA inhabited 1,850 hectares (4,570 acres). Three epizootics ravaged colonies over the next 13 years, and at one point reduced RMA's cumulative area of occupancy to a mere 9 hectares (22 acres) (Figure 11.3). If devastation of this magnitude is typical and widespread, then conservation of prairie dogs will be exceedingly difficult.

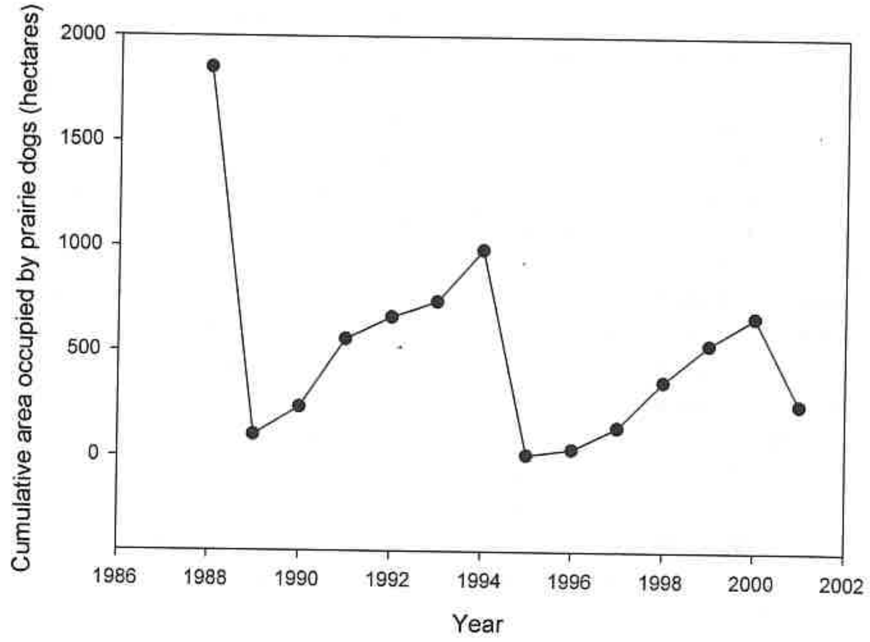

Figure 11.3. Annual variation in cumulative area inhabited by prairie dogs at Rocky Mountain Arsenal National Wildlife Refuge from 1988 through 2001. Epizootics of plague occurred in 1988–1989, 1994–1995, and 2000–2001.

Possible Outcomes Regarding the Evolutionary Battle of Prairie Dogs Versus Plague

In the future, at least three outcomes regarding the evolutionary battle of prairie dogs versus plague are possible, as described below.

- Prairie dogs might continue to go locally extinct wherever plague occurs. Some populations of prairie dogs have permanently disappeared after first exposure to plague, and others have been devastated by exposure to plague every four to five years or so (Barnes 1993; see also Figure 11.3). Consequently, the cumulative population of prairie dogs, as measured by cumulative area of colony-sites, has declined steadily since the introduction in the 1940s of plague into areas with prairie dogs. Other factors such as poisoning, loss of habitat, and recreational shooting also have decimated populations over the last 60 years, however (Chapters 8, 10, and 16), so that quantifying the historic effect of plague alone is impossible.
- Prairie dogs might become more resistant to plague. Some rodents in North America (Quan et al. 1985; Thomas et al. 1988), Asia (Kucheruk 1965; Rall 1965), and Africa (Isaäcson et al. 1983) have developed partial immunity to plague. In theory, prairie dogs also might evolve immunity. In practice, however, evidence for immunity is scarce. Small numbers of surviving Gunnison's, white-tailed, and Utah prairie dogs have developed serum antibodies after exposure to plague (Cully et al. 1997; Biggins 2001a, 2001b), but the colonies with survivors nonetheless have remained highly susceptible to later epizootics. Survival sometimes might result when exposure contains insufficient bacteria to ignite a lethal infection. Perhaps survivors are individuals that, for some unknown reason, require an unusually high number of initial bacteria for serious infection.
- Prairie dogs might develop a mechanism that reduces the impacts of plague. Today's colonies are smaller, rarer, and more isolated than they were before the arrival of plague in the 1940s (Chapters 12 and 16). These characteristics probably render today's prairie dogs less susceptible to plague (Cully and Williams 2001; Chapter 12). Today's population structure is almost certainly not an evolved response to combat plague, however—but rather is the inevitable consequence of poisoning, loss of habitat, and plague itself.

Transfer of Plague from Prairie Dogs to Humans

Human cases of plague resulting from prairie dogs and their fleas are few because humans rarely handle infected prairie dogs, and because prairie dog fleas tend to be highly host-specific and therefore avoid humans (Weber 1978; Polland and Barnes 1979; Barnes 1982; Levy and Gage 1999). Prairie dogs sometimes harbor fleas of the genus *Pulex*, which commonly bite people, but these fleas are poor vectors of plague (Burroughs 1947). Most cases of human plague in the United States result from association with rodents other than prairie dogs, especially ground squirrels. Ground squirrel fleas are less host-specific than prairie dog fleas, and therefore are more likely to bite humans and transmit plague (Weber 1978; Barnes 1982; Cully and Williams 2001).

People worried about plague should never handle prairie dogs. They also should avoid colony-sites where prairie dogs recently have vanished, because, as noted below, plague-positive fleas might persist at such deserted sites for more than one year.

What Happens to Plague between Epizootics?

After an epizootic of plague among prairie dogs, the disease typically vanishes, often for many years. Where does it go? At least four hypotheses might explain the maintenance of plague between epizootics:

- Plague-positive fleas can survive and maintain live bacteria for at least one year, and therefore might serve as an important reservoir for plague bacteria between epizootics (Lechleitner et al. 1968). Infected fleas remain inside burrows after an epizootic or come to burrow-entrances, and thus can infect other rodent species that visit burrows. Fleas also might jump onto large animals such as coyotes and pronghorn that routinely visit prairie dog colony-sites.
- Perhaps plague bacteria persist in the soil at colony-sites between epizootics (WHO 1970; Poland and Barnes 1979; Orent 2004). This mechanism seems unlikely, for two related reasons (Cully 1989). First, plague bacteria do not produce spores or other obvious devices that might aid long-term survival when the bacteria are outside hosts and vectors. Second, the interval between epizootics at the same colony-site is usually more than three years—probably too long for the bacteria to survive outside hosts and vectors.
- Perhaps prairie dogs themselves sometimes maintain the plague bacteria between epizootics (Cully and Williams 2001). White-tailed prairie dogs in the vicinity of Meeteetse, Wyoming, for example, have maintained plague continuously since 1985 (Anderson and Williams 1997), even though individuals are still extremely susceptible (E. S. Williams, personal communication, 2002). Because white-tailed prairie dogs are less social than black-tailed prairie dogs and usually occur in smaller colonies of lower density (Hoogland 1979b, 1995), opportunities for transmission of diseases probably are reduced (Cully and Williams 2001). Consequently, plague might not move within and between colonies of white-tailed prairie dogs so quickly as it usually does within and between colonies of black-tailed prairie dogs—so that 100% mortality of white-tailed prairie dogs within a complex of nearby colonies is less likely. Similar maintenance of plague might occur among black-tailed prairie dogs in areas where colony sizes and colony densities are unusually low for some reason (e.g., poor habitat, frequent poisoning, heavy predation, or plague itself) (see Chapters 3 and 6).
- In our opinion, the most likely hypothesis to explain the maintenance of plague between epizootics involves other rodent species. More than 70 species of mammals in North America contract plague, harbor plague-infected fleas, or have serum antibodies to plague bacteria (Barnes 1993). Some of these 70 species are rodents that commonly live at or near prairie dog colony-sites, such as deer mice, northern grasshopper mice, meadow voles, and certain species of ground squirrels (Kotliar et al. 1999; Chapter 4). These latter associates sometimes might have rates of recruitment that are higher than rates of mortality from plague—and thus might be able to maintain plague for many years at or near colony-sites (Cully and Williams 2001). When the conditions are right, plague infects prairie dogs once again and devastates colonies. Maintenance of plague between epizootics does not necessarily involve just a single rodent species that associates with prairie dogs, but rather might involve—either simultaneously or sequentially—several associated species.

Rarity of Plague in Eastern Populations of Prairie Dogs

Plague is rare among prairie dogs in the eastern part of the geographic range. Specifically, even though plague has been annihilating prairie dogs in the western two-thirds of the geographic range since the 1940s, plague is rare—indeed, almost totally absent—among prairie dogs east of a line that approximates the 102nd meridian (see Figure 11.1). Consequently, plague among prairie dogs is rare throughout most of Kansas, Nebraska, Oklahoma, North Dakota, and South Dakota. Reasons for the absence of plague in the eastern one-third of the range are elusive. Perhaps something about the climate is not conducive to the maintenance or transmission of plague in the mixed-grass prairies east of the 102nd meridian. Or perhaps the community of mammals—or the community of fleas—changes east of the 102nd meridian to a mix of species that cannot maintain plague. On the other hand, perhaps the rarity of plague farther east is merely accidental. If so, then migration to the east—after a stall at the 102nd meridian that has persisted for more than 60 years—might eventually occur.

Studies of mammals and fleas on both sides of the "plague line" are beginning to address the absence of plague among prairie dogs east of the 102nd meridian. At this point we only know that certain mammals that contract plague west of the line are present east of the line as well, as are several species of fleas that transmit plague. Examples of the former include prairie dogs themselves, deer mice, northern grasshopper mice, and thirteen-lined ground squirrels; examples of the latter include *Oropsylla hirsutus*, *Oropsylla tuberculatus cynomuris*, and *Pulex* spp. (Cully and Williams 2001).

Ways to Reduce the Impact of Plague on Prairie Dogs

Efforts to protect prairie dogs from plague have focused on killing fleas by infusing burrows with insecticide-dusts such as Pyraperm and Deltadust (Bayer Environmental Science, Montvale, New Jersey) (Figure 11.4). Pyraperm contains permethrin and reduces flea infestation within colonies of black-tailed prairie dogs for at least three months (Beard et al. 1992). At a 5-hectare (12-acre) colony-site of Utah prairie dogs, Pyraperm killed fleas and immediately halted an outbreak of plague in both 1998 and 2001 (Hoogland et al. 2004).

Figure 11.4. Infusion of burrows with insecticide-dust such as Deltadust, which kills fleas for as long as six months and thereby helps to protect prairie dogs from plague. Photo by Eric Stone.

Deltadust is an insecticide-dust that contains deltamethrin, a chemical similar to permethrin, but the formulation is more resistant to moisture and therefore kills fleas over a longer period of time after infusion of prairie dog burrows (Seery et al. 2003). Deltadust also suppresses fleas among other rodent species that associate with prairie dogs (Biggins 2001a).

Besides permethrin and deltamethrin, other insecticides also control fleas on small mammals (Hinkle et al. 1997). Possible choices for use on prairie dogs include insect growth regulators such as methoprene (Lang and Chamberlain 1986), lufenuron (Davis 1999), pyriproxyfen (Karhu and Anderson 2000), and fluazuron (Slowik et al. 2001). After application to the skin or fur, fipronil deters fleas on pets such as domestic dogs and domestic cats, and it might work for prairie dogs as well if simple, inexpensive methods of application can be developed (Metzger and Rust 2002).

We recognize that insecticide-dusts, in addition to killing fleas that transmit plague, also kill other arthropods within prairie dog burrows (e.g., other insects; arachnids such as mites, ticks, and spiders). Because of these negative side effects, we only recommend the use of insecticide-dusts where the conservation of prairie dogs is especially important (e.g., study-colony of marked individuals, or colony with black-footed ferrets).

In theory, vaccines also might help to protect prairie dogs against plague. In practice, however, the development of vaccines is still in its infancy (Creekmore et al. 2002).

Long-Term Prognosis of Prairie Dogs Versus Plague

Plague has found a home among prairie dogs of the western United States. Evidence that prairie dogs have begun to evolve resistance is minimal, so we should assume that plague will continue to ravage colonies. Because of so many unanswered questions, the best conservation strategy versus plague for now is to maintain numerous colonies of prairie dogs distributed throughout their geographic range, with special emphasis on the plague-free eastern one-third of the range (see also Chapters 12, 16, and 17).

Summary

- Plague, called sylvatic plague when it affects wild rodents, is a disease caused by a bacterium (*Yersinia pestis*). The usual vectors are fleas. Plague probably first arrived in the United States in about 1900 via commercial ships from China.
- Because they have been exposed to plague for only about 60 years, prairie dogs probably have been unable to evolve a good defense—and consequently remain highly susceptible. Mortality within infected colonies usually approaches 100%.
- In combination with unpredictability regarding the place and timing of epizootics, the catastrophic mortality from plague inhibits efforts to conserve prairie dogs.
- Human cases of plague resulting from prairie dogs and their fleas are few because humans rarely handle infected prairie dogs, and because prairie dog fleas tend to be highly host-specific and therefore avoid humans.
- After an epizootic of plague among prairie dogs, the disease typically vanishes, often for many years. Maintenance of plague between epizootics probably involves other rodent species such as deer mice, northern grasshopper mice, and meadow voles that frequently live at or near prairie dog colony-sites.
- For unknown reasons, plague is currently rare among prairie dogs in the eastern one-third of the geographic range.

- Efforts to protect prairie dogs from plague have focused on killing fleas by infusing burrows with insecticide-dusts such as Deltadust.
- Because of so many unanswered questions, the best conservation strategy versus plague for now is to maintain numerous colonies of prairie dogs distributed throughout their geographic range, with special emphasis on the plague-free eastern one-third of the range.

CHAPTER 12

Does the Prairie Dog Merit Protection Via the Endangered Species Act?

Rob Manes

The prairie dog and the Endangered Species Act (ESA) polarize people. Some argue that the prairie dog is an important species threatened with extinction, that it reflects the health of the fragile grassland ecosystem, and that it deserves ESA protection. Others protest that the prairie dog is a pest for farmers and ranchers of western states, and that ESA protection would hinder eradication.

In this chapter I summarize the history and purpose of ESA, and define some of the many associated terms. I then explain how a species comes under consideration for ESA's Federal List of Endangered and Threatened Wildlife and Plants (FLETWP), and clarify the distinction between endangered and threatened species. I examine the United States Fish and Wildlife Service (USFWS) reasons for classifying the prairie dog as a candidate species for addition to FLETWP in 2000, and why USFWS reversed this controversial classification in 2004. Finally, I discuss how politics might affect the addition of species to FLETWP.

History and Purpose of ESA

In 1966, Congress passed the Endangered Species Preservation Act, which authorized acquisition of land to protect imperiled native species. The Endangered Species Conservation Act of 1969 prohibited importation of endangered species from other countries. Next, in 1973, came ESA, which combined and strengthened earlier legislation by defining key terms; authorizing protection for plants as well as animals; establishing tougher standards for federal

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Disease Limits Populations: Plague and Black-Tailed Prairie Dogs

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Abstract

Plague is an exotic vector-borne disease caused by the bacterium *Yersinia pestis* that causes mortality rates approaching 100% in black-tailed prairie dogs (*Cynomys ludovicianus*). We mapped the perimeter of the active portions of black-tailed prairie dog colonies annually between 1999 and 2005 at four prairie dog colony complexes in areas with a history of plague, as well as at two complexes that were located outside the distribution of plague at the time of mapping and had therefore never been affected by the disease. We hypothesized that the presence of plague would significantly reduce overall black-tailed prairie dog colony area, reduce the sizes of colonies on these landscapes, and increase nearest-neighbor distances between colonies. Within the region historically affected by plague, individual colonies were smaller, nearest-neighbor distances were greater, and the proportion of potential habitat occupied by active prairie dog colonies was smaller than at plague-free sites. Populations that endured plague were composed of fewer large colonies (>100 ha) than populations that were historically plague free. We suggest that these differences among sites in colony size and isolation may slow recolonization after extirpation. At the same time, greater intercolony distances may also reduce intercolony transmission of pathogens. Reduced transmission among smaller and more distant colonies may ultimately enhance long-term prairie dog population persistence in areas where plague is present.

Key Words: Connectivity—*Cynomys ludovicianus*—Epizootic—Fragmentation—Population regulation—*Yersinia pestis.*

Introduction

Plague, caused by the bacterium *Yersinia pestis*, has occurred in black-tailed prairie dogs (*Cynomys ludovicianus*) at least since 1945, when plague-positive fleas (*Oropsilla hirsuta*) were first recorded from black-tailed prairie dog burrows in western Kansas (Public Health Service records cited in Cully et al. 2000). Apparent epizootic die-offs of black-tailed prairie dogs were reported from near Denver, Colorado, and in west Texas at around the same time (Ecke and Johnson 1952). *Yersinia pestis* is an exotic pathogen in the prairie dog system, and its impacts on populations of all four U.S. species are well known (Barnes 1982, Miller and Cully 2001, Gage and Kosoy 2005) with population declines at individual colonies ranging between 85% and 100% (Barnes 1982, 1993, Cully et al. 1997, Cully and Williams 2001, Antolin et al. 2002), and overall declines at mesoscale colony complexes (40,000–250,000 ha) from 80% to 95% (Cully and Johnson 2005).

Plague decreases the size and number of colonies, thereby creating larger distances between neighboring colonies and may cause the locations of colonies to change (Augustine et al. 2008). Moreover, past research indicates that plague is more likely to occur in large colonies than in small colonies (Cully and Williams 2001, Lomolino and Smith 2001, Collinge et al. 2005, Snäll et al. 2008). Because of the recurrent nature of sylvatic plague and because it decimates prairie dog colonies, it appears unlikely that prairie dog populations within the range of plague will attain preplague levels or be as abundant as in areas without plague (Antolin et al. 2002, Cully et al. 2006). We tested these assertions by comparing the distribution and area of prairie dog colonies from several areas within the range of plague to other areas that were historically free of plague. This study was designed to determine if empirical

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data supported a conceptual model based on black-tailed prairie dog colony distributions at Cimarron National Grassland, Kansas (Cully and Williams 2001). This model suggests that plague epizootics spread much more easily among colonies once a certain area and density of prairie dog colonies is present on the landscape. At low densities of small colonies, prairie dog colony area in a complex can grow until a density is reached that may allow an epizootic to spread among colonies, again reducing colony size and colony density, and thus regulating the prairie dog metapopulation size on that landscape. In this paper we compare colony sizes and spatial distributions of active colony area among five National Grasslands within the geographic range of plague with two areas that, at the time of observation, had no previous records of plague. We hypothesized that in the absence of plague, (1) individual colonies would be larger, (2) intercolony distances would be shorter, (3) overall colony density would be higher, and (4) colonies would cover a larger portion of suitable potential habitat on the landscape than at sites that lie within the historical range of plague.

We made three major assumptions when interpreting observed results. First, given that colonies are local populations and patches of occupied habitat, we assumed that colony area and straight-line distance to the nearest-neighboring colony are reasonable surrogates for population size and connectivity, respectively. Second, we assumed that changes in the colony area reflect changes in prairie dog population size. If colony area grows consistently at a high rate for several years at multiple colonies, it is fair to assume that the population is growing even if population growth is not consistently proportional to change in area. Third, we assumed that plague transmission between colonies increases as a function of density of colonies (inverse of intercolony distance) and individual colony sizes (large colonies are expected to produce more migrants and be exposed to more plague propagules than small colonies). If plague is transmitted among colonies by dispersing prairie dogs carrying infected fleas, then large colonies should produce and receive more dispersing prairie dogs than small colonies. Likewise, if predators are responsible for intercolony transmission by carrying infected prairie dog fleas, colony size should be important in that large colonies can be expected to attract larger numbers of predators than small colonies. In contrast, if prairie dogs contract plague from other rodent species that function as maintenance hosts, individual colony epizootics may or may not be independent of colony size and rather may depend on the presence of plague in the enzootic species at the location of the prairie dog colony. Colonies close together would still be expected to have a higher probability of

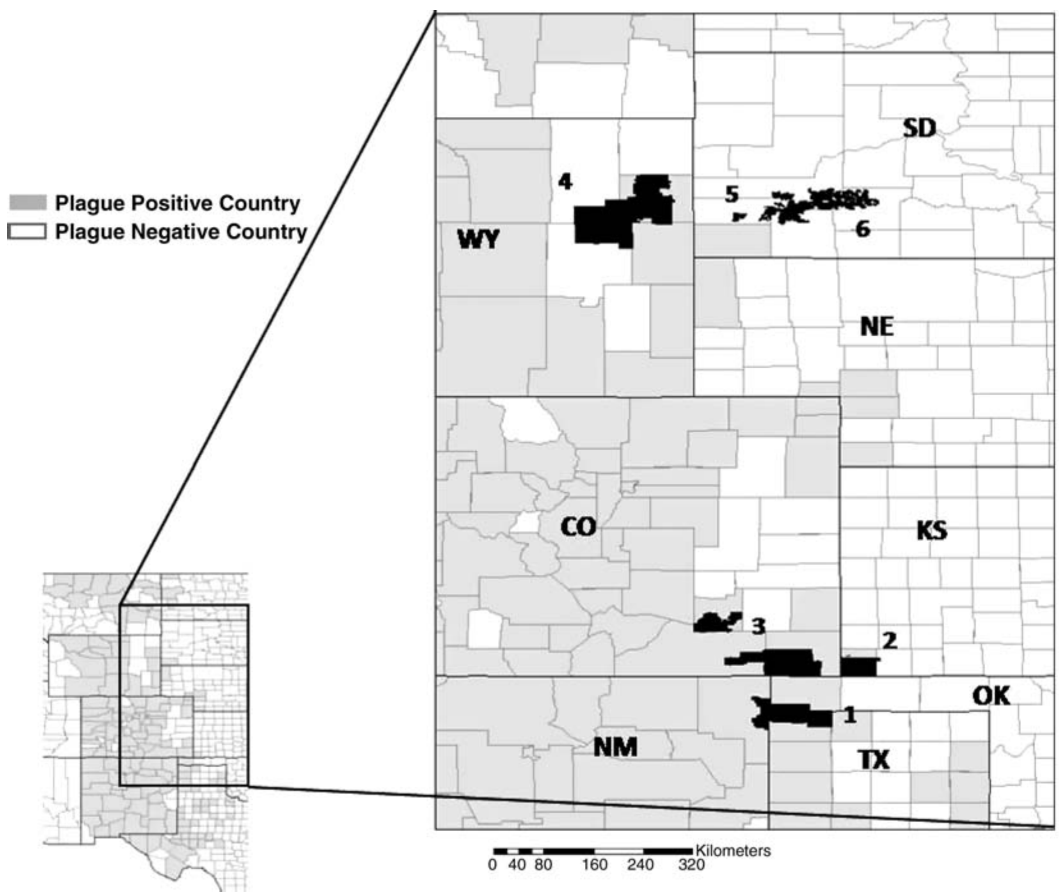

FIG. 1. Location of six study sites. Plague sites include: (1) Kiowa and Rita Blanca National Grasslands, Texas (TX), Oklahoma (OK), and New Mexico (NM); (2) Cimarron National Grassland, Kansas (KS); (3) Comanche National Grassland, Colorado (CO) showing the two management units, Carizo (south) and Timpas (north); and (4) Thunder Basin, Wyoming (WY). Historically plague-free sites located beyond the current distribution of plague include: (5) Wind Cave National Park, South Dakota (SD); and (6) Badlands National Park and Conata Basin, Buffalo Gap National Grassland, SD.

acquiring plague if at least one colony becomes infected. With these assumptions in mind, we mapped prairie dog colonies to investigate the potential for the bacterial pathogen, *Y. pestis*, to limit the size and spatial distribution of black-tailed prairie dog populations at sites within versus outside the geographic range of this pathogen in the western United States.

Methods

Colony spatial data

We assessed the impacts of sylvatic plague on black-tailed prairie dog populations by monitoring colonies on public land holdings for 6 years. We surveyed 815 prairie dog colonies on approximately 900,000 ha of public land on the western Great Plains at six complexes of black-tailed prairie dog colonies (Fig. 1). Four areas were located on the United States Department of Agriculture Forest Service property within the current distribution of plague, referred to hereafter as "plague sites." Plague sites included: (1) Cimarron National Grassland in Kansas, (2) Comanche National Grassland in Colorado, (3) Kiowa and Rita Blanca National Grasslands at the intersection of Texas, Oklahoma, and New Mexico, and (4) Thunder Basin National Grassland in Wyoming, referred to hereafter as Cimarron, Comanche, Kiowa/Rita Blanca, and Thunder Basin. Each of the plague sites has experienced plague during the past 10 years.

Two additional complexes were selected to represent "plague-free sites." Plague-free sites were (5) Wind Cave National Park, South Dakota, and (6) Badlands National Park and the Conata Basin, adjacent to Badlands National Park within Buffalo Gap National Grasslands, South Dakota. These plague-free sites are referred to hereafter as Wind Cave and Badlands/Conata Basin.

Although Thunder Basin experienced a plague epizootic in 2000–2001, it is not clear whether epizootics had occurred there prior to 2000. There were no records of plague in the core area of the grassland where most colonies occurred prior to the epizootic in 2000–2001 (Tim Byer, personal communication). However, there was at least one documentation of plague in prairie dogs from the eastern edge of the grassland in 1994 (USDA, Forest Service 2002), and there appeared to be epizootics, which were not confirmed, on nearby ranches during the 1980s (Dean Biggins, personal communication). Because we were unsure of the history of plague at Thunder Basin, we used two approaches. First, we included a separate analysis of 2001 data as a plague-free site. (Please see below for mapping methods and dates.) This was done to test whether the colony distribution at Thunder Basin in 2001 was similar to the plague-free sites. Second, we combined the 2001 data with data from 2002 to 2004 and analyzed them the same as data from the plague sites. Plague may have occurred at Thunder Basin, but a sufficiently long time ago that colonies had time to grow to large size. An important variable for which we have limited data is the frequency with which plague occurs at a site.

Management practices at all study sites were similar. No study site has been actively poisoned for prairie dog control for more than 10 years prior to mapping. Recreational shooting of prairie dogs has been allowed and continues at Cimarron, Kiowa/Rita Blanca, and portions of Thunder Basin. Shooting was not permitted at Comanche, Badlands/Conata Basin, or Wind Cave. Prairie dog shooting may depress colony annual growth rates below the 30–50% that we typically observed, but except at the smallest colonies, it is unlikely to cause the extreme population reductions or localization (spatial clumping) of survivors that could be confused with the effects of plague (Reeve and Vosburgh 2006, Pauli and Buskirk 2007). Cattle (*Bos taurus*) or bison (*Bison bison*) grazed all areas.

Colony mapping

We mapped prairie dog colonies in 1999 at Cimarron, Comanche, and Kiowa/Rita Blanca, and again between late May and early October 2001–2005. At Thunder Basin, we mapped colonies between June and August 2002–2004. Colonies were mapped by park or grassland staff at Badlands/Conata Basin in 2005, Wind Cave in 2003, and Thunder Basin in 2001. Prairie dog colonies were mapped on the publicly held portions of each park or grassland, using a hand-held Trimble GeoExplorer3* GPS unit (Trimble, Sunnydale, CA) set to obtain positional readings every second. Colony boundaries were delineated using an all-terrain vehicle. All study sites had inclusions of private land where we do not have data on the presence of colonies. It is possible that colonies present on inholdings could reduce intercolony distances, but our impression was that this would be a minor factor. Where we were aware of colonies on private land, they were generally small.

During 2001, Grassland staff mapped prairie dog colonies at Thunder Basin. Most large colonies present before the plague epizootic had small residual populations after the epizootic when mapped in 2001. Those colonies where no survivors were found were not mapped, but if survivors were seen, even on a small portion of the colony, the full previous extent of the colony where burrows could be found was mapped. We used the 2001 data as a conservative estimate of the preepizootic extent of colony acreage.

To investigate year-to-year changes in colony size, only the areas of each colony actively occupied by prairie dogs were mapped, except at Thunder Basin in 2001 as described above. Active colonies were identified by visually and audibly locating prairie dogs. The boundary of the active area was determined by signs of recent digging on and near burrow mounds, the presence of fresh prairie dog scat, and clipped vegetation indicating foraging activity or the characteristic "mowing" that prairie dogs undertake to enhance visibility on the colony (Hoogland 1995). Because plague is the only disease known to cause extensive die-offs among prairie dogs (Barnes 1993), we assumed that a die-off or the loss of a significant and contiguous portion of a colony was due to plague. We attempted to validate this assumption whenever a die-off was observed. Fleas were collected from burrows and sent to the Centers for Disease Control and Prevention, Division of Vector-borne Infectious Diseases, Ft. Collins, Colorado, where they were identified to species and screened for the presence of *Y. pestis*.

Spatial analyses

All spatial data were differentially corrected using Trimble Pathfinder software (Trimble) and information from base

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stations in Elkhart, KS, and Casper, WY (Trimble). Corrected GPS data on colony boundaries were incorporated into a geographic information system (Enviromental Systems Research Institute (ESRI), ArcView 3.2; projected to NAD 1927) to quantify two spatial characteristics for each colony in each year of the study: colony area (ha) and distance to the nearest-neighboring colony (m). Nearest-neighbor (edge-to-edge) distances were calculated using the Nearest Feature ESRI ArcScript (J. Jenness, www.jennessent.com/arcview/arcview_extensions.htm). Occasionally, colonies were located close (<75 m) to neighboring colonies. We treated colonies located <75 m apart as a single colony.

Following die-offs of very large colonies (>1000 ha) at Thunder Basin, small surviving or recolonized areas remained within the former colony boundaries. This resulted in smaller nearest-neighbor distances than occurred between the large colonies mapped prior to plague; the mean nearest-neighbor distance decreased, despite the reduction in overall colony area. This process of reestablishment at multiple locations within the area of a former single colony does not allow an appropriate test of our hypothesis regarding connectivity, so nearest-neighbor distances of colonies at Thunder Basin were not included in the comparison of nearest-neighbor distances between plague and plague-free sites. This was not a problem at other plague sites, where colonies did not attain large size.

Statistical analyses

Colony area and nearest-neighbor data were not normally distributed (as checked with Wilks–Shapiro test) and were log transformed. To determine whether (log-transformed) colony areas and nearest-neighbor distances varied among years within sites, we used one-way analysis of variance (ANOVA) assuming a significance (alpha) level of 0.05 (because colonies were only mapped once at the plague-free sites, repeated measures ANOVA was not possible). The Waller–Duncan K-ratio *t*-test was used to identify which years differed at each site (SAS v 9.1, SAS Institute, Inc., Cary, NC).

We asked if the distribution of colony sizes differed between study sites, and most importantly, between plague and plague-free sites. To test the hypothesis that colony sizes would be larger in plague-free areas, we used data from each site during the year when colony area was largest (for a conservative test) to calculate the frequency distributions of colonies in seven size categories (0–5, 5–10, 10–25, 25–50, 50–100, 100–250, and >250 ha). Size categories were not equal because of the large variation in colony size at all sites. At all sites, there were a large number of colonies in small size categories; however, these colonies contributed a small proportion of the total amount of colony area at each site. For example, at Badlands/Conata Basin 140 of the 303 colonies were <5 ha, and these contributed only 2% of the total colony area. Conventional frequency distributions (count per category) do not address the contribution of colonies of a given size category to the total area. To address this we calculated the percent of total colony area contained in each size category. The sum of all categories at each site is thus 100. We used the Cochran–Mantel–Haenszel chi-square test to identify differences in colony size distributions among sites (Stokes et al. 1995). This test allows for the comparison of multiple categories, and unlike Pearson chi-square, small counts in a few cells do not invalidate the test as long as the overall sample is large (Stokes et al. 1995). A Bonferroni correction was applied to pair-wise comparisons between sites (α/n; $n = 21$; 0.05/21; $\alpha = 0.002$).

We estimated the proportion of area of each plague or plague-free site that was occupied by active prairie dog colonies by dividing the occupied area by the total area of potential prairie dog habitat at each park or grassland. Potential habitat area figures were obtained from agency biologists for Cimarron, Comanche, and Thunder Basin National Grasslands and Wind Cave and Badlands National Parks and from the Grassland Management Plan published on the website for Kiowa Rita Blanca National Grasslands. Generally, potential habitat occurred on loamy soils with slopes <10%, with vegetation dominated by grasses. Variable densities of shrubs may have been present. The mean and maximum proportion of potential habitat occupied over all years mapped at sites within the range of plague were compared using ANOVA in program R (R Development Core Team 2006) with data supplied by Wind Cave National Park for 2003 and Badlands National Park and the Wall Ranger District of Buffalo Gap National Grassland in 2005. The proportion of potental habitat at each site occupied by prairie dog colonies was arcsin square root transformed prior to analyses.

Results

Plague occurrences

During this study, we observed prairie dog die-offs due to plague at Thunder Basin, Kiowa/Rita Blanca, Comanche, and Cimarron. There has been limited evidence of plague at Thunder Basin since 2001 (subsequently documented in mice or fleas in 2002 and 2004: Pauli et al. 2006, Thiagarajan et al. 2008). Colony area increased at Thunder Basin at a rate of 50%/year during 2002–2004 (Table 1); however, the largest colonies were still considerably smaller than they were when mapped in 2001 (<250 ha vs. >1000 ha). We first documented plague at Kiowa/Rita Blanca in 2002, where the severity and extent of colony die-off increased each year until 2005. Ten colonies were extirpated during 2002 and 2003 and despite this loss, total colony area on the grassland continued to increase. Plague was more widespread at Kiowa/Rita Blanca in 2004 and 2005, affecting 23 and 16 colonies, respectively, and reducing the active area of individual infected colonies by >90% annually. These dramatic reductions in colony area caused an overall reduction in colony area of >33% annually at Kiowa/Rita Blanca in 2004 and 2005 (Table 1). Colony extirpation as a result of plague was documented at Cimarron between 1997 and 2000 (Cully et al. 2000, Cully, unpublished data), and again in 2005. Between 2001 and 2005, colony area grew at an annual rate of 22% at Cimarron. At Comanche, there was an extensive die-off in 1995–1996. There were no subsequent die-offs noted until 2005, when epizootics reduced nine colonies near the center of the Carrizo Unit. Colony area grew at Comanche at an annual rate of 40% from 2001 to 2005.

Colony size

At sites with a history of plague, maximum and mean colony sizes were smaller than at sites with no history of plague and at Thunder Basin in 2001 (Table 1, Fig. 2). Mean colony size differed between years at all plague sites ($p < 0.0001$; Table 1). Significant differences in colony size among years at all plague sites reflect annual colony growth in the absence of plague and colony collapse in the presence of plague.

Table 1. Colony Area and Nearest-Neighbor Distances of Black-Tailed Prairie Dog Colonies at Plague and Plague-Free Sites

Study site	*Year*	*Habitat area (ha)*	*No. of colonies*	*Area (ha)*	*% Coverage*	*Mean area (ha)*	*SE area (ha)*	*Grouping area*	*Mean NN (m)*	*SE NN (m)*	*Grouping NN*
Plague-free sites											
BC	2004[a]	63,000	303	11,561	18.35	38	12.54		768	57.80	
WC	2003[a]	3468	19	756	21.8	39	16.92		863	189.90	
Plague present											
CIM	2001	34,174	49	1068	3.13	20	3.90	A	1538	183.87	
	2002		54	1344	3.93	24	4.22	AB	1332	155.46	
	2003		57	1622	4.75	28	4.79	AB	1308	143.63	
	2004		54	2280	6.67	42	7.01	B	1271	142.16	
	2005		51	2342	6.85	45	7.65	B	1319	148.43	
	Mean			1557	4.56	29			1405		
COM	1999[a]	155,016	78	799	0.52	10	1.40	A	2260	219.67	A
	2001		93	1757	1.13	18	2.12	B	2267	190.07	A
	2002		105	2497	1.61	23	3.02	BC	2219	191.30	A
	2003		111	2680	1.73	24	2.64	BC	1975	187.51	B
	2004		125	4810	3.10	40	4.37	C	1711	166.57	B
	2005		119	6323	4.08	46	6.13	C	1329	151.70	C
	Mean			3144	2.03	27			1960		
KRB	1999[a]	40,749	38	696	1.71	18	4.31	A	3016	935.84	
	2001		44	1663	4.08	38	5.36	B	2050	331.39	
	2002		64	2186	5.36	34	4.94	B	1815	221.64	
	2003		65	2740	6.72	42	6.16	B	1724	240.07	
	2004		71	1809	4.44	25	4.99	A	1481	199.32	
	2005		71	1236	3.03	17	4.48	C	1328	185.27	
	Mean			1721	4.22	29			1902		
TB	**2001**	157,852	96	9296	5.89	95	25.59	A	1664	174.22	
	2002		130	1750	1.11	13	3.11	B	1563	164.03	
	2003		135	2278	1.44	17	2.94	C	1597	163.01	
	2004		146	3847	2.44	26	4.06	C	1425	160.73	
	Mean			4292	2.72	38			1562		

At plague sites, bold for the year indicates that plague was active that year. Grouping indicates years that shared letters were not significantly different. If no letters are present for a site, then mean area or nearest neighbor (NN) distance did not differ among years.
[a]Data supplied by area staff.
BC, Badlands/Conata Basin; WC, Wind Cave; CIM, Cimarron; COM, Comanche; KRB, Kiowa and Rita Blanca; TB, Thunder Basin.

Colony size distributions

The area of prairie dog colonies in large size classes differed between plague and plague-free sites (Table 2, Fig. 2). Large colonies (>500 ha) occurred at the two plague-free sites when mapped, and at Thunder Basin in 2001. Among the plague sites, one colony at Thunder Basin was >250 ha in 2002, but it collapsed by 2003 and another colony reached 376 ha in 2004. After 10 years (1995–2005) there were three colonies at Comanche that had grown to ~250 ha, but they were decimated by plague during 2006–2007 (USDA, Forest Service, unpublished records). At the other sites, there was not adequate time for colonies to reach such large size before being reduced by plague. The colony size distribution was similar for all pair-wise comparisons of Cimarron, Comanche, Kiowa/Rita Blanca, and Thunder Basin postplague (Table 2). Likewise, size distributions of colonies at the plague-free sites, Badlands/Conata Basin, Wind Cave, and Thunder Basin 2001 were not significantly different. With Bonferroni correction, Wind Cave differed significantly from KRB, but not from the other plague sites. Wind Cave was similar to Badlands/Conata Basin and Thunder Basin 2001. In general, colonies at plague sites were smaller and further apart than at plague-free sites, even after several years of postplague colony growth.

Proportion of area occupied

The proportion of potential habitat occupied by black-tailed prairie dog colonies (Table 1) at their maximum extent in the plague areas was less than at the plague-free areas ($F_{(1,4)} = 75.02$, $p = 0.0010$). The proportion of potential habitat occupied by black-tailed prairie dogs in plague-free areas when mapped was 18.35% at Badlands/Conata Basin and 21.8% at Wind Cave (Table 1). Among the plague areas, Cimarron had the highest proportion of area occupied (6.85%). Cimarron, Comanche (4.08), Kiowa/Rita Blanca (6.72), and Thunder Basin (5.94) were similar to each other. Occupied area at Cimarron and Comanche was maximized in 2005, and Thunder Basin following plague, in 2004. Plague epizootics were identified at Cimarron and Comanche in 2005 (see above) and continued through 2008 (USDA Forest Service, unpublished records). Plague occurred at nine colonies in 2004 at Thunder Basin.

Nearest-neighbor distances

Mean nearest-neighbor distances were greater at Cimarron (1405 m), Comanche (1960 m), and Kiowa/Rita Blanca (1902 m) than at Badlands/Conata Basin (768 m), or Wind Cave (863 m;

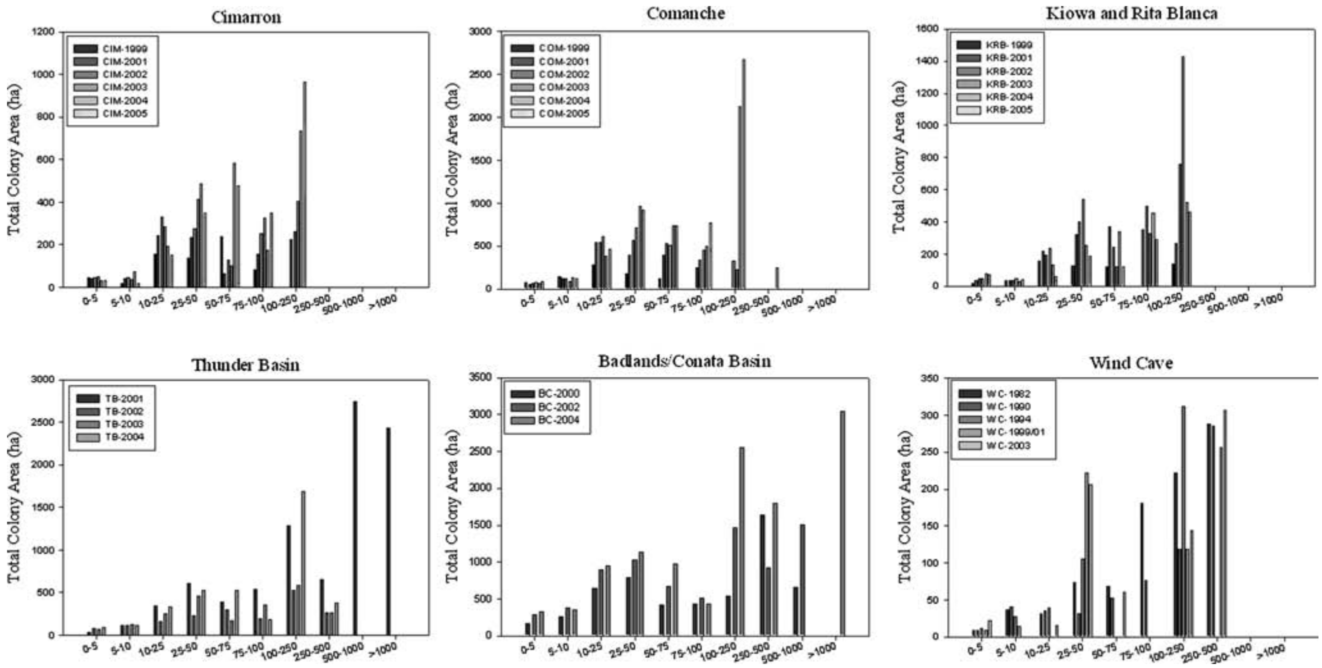

FIG. 2. Distribution of black-tailed prairie dog colony sizes at plague and plague-free sites. Areas with no history of plague (Badlands/Conata Basin and Wind Cave), as well as Thunder Basin in 2001, have colonies distributed throughout the range of colony sizes including >250 ha. With the exception of one colony at Thunder Basin after the 2001 epizootic, and one colony at Comanche in 2005, colony complexes with a history of plague (Cimarron, Comanche, Kiowa/Rita Blanca, and Thunder Basin 2002–2004) have all their colony area in colonies of 250 ha or less.

$p = 0.001$). Nearest-neighbor distances varied among years at Comanche ($p < 0.0001$).

Discussion

There were strong and significant differences in colony size distributions, proportion of potential habitat area occupied, nearest-neighbor distances, and presence of large colonies between black-tailed prairie dog colony complexes in areas with and without a history of plague. Comparisons of populations that have not been exposed to *Y. pestis*, populations that have a history of plague exposure, and populations that have recently experienced epizootics provided a unique opportunity to quantify the immediate and long-term effects of sylvatic plague on the spatial structure of black-tailed prairie dog colonies. In the absence of plague, colonies might have continued to grow, but at Cimarron and Comanche (2005–2008), and Kiowa/Rita Blanca (2002–2005), plague reduced or eliminated all large colonies. We have not analyzed data after 2004 at Thunder Basin.

As we predicted, sites with no history of plague maintained more total colony area in large colonies, and colonies covered a larger percentage of potential habitat on the landscape, at least in part because colonies in these areas were not periodically reduced by plague as they were in areas where plague was active. In areas where plague occurred, affected colonies were reduced by >90%, and because plague often affected multiple colonies and many colonies were extirpated or reduced to small sizes, the overall footprint of black-tailed prairie dogs on the landscape was reduced. Periodic reemergence of plague may be responsible for the result that, with one exception at Thunder Basin after 2001, the largest colony size within plague areas was ~250 ha, whereas some colonies were >500 ha within all plague-free areas. At Badlands/Conata Basin and at Thunder Basin in 2001, the largest colonies were >1000 ha (Fig. 2).

Where plague was present, the proportion of potential habitat occupied by prairie dog colonies, as well as the colony size distributions, was a function of the time since the last epizootic. In the absence of visible plague, between 2001 and 2005, colonies grew at an average annual rate of 22% at Cimarron and 40% at Comanche. At Thunder Basin, from 2002 to 2004, colony area grew at 50% annually. If these rates could be sustained, following a plague epizootic that reduced

Table 2. Pair-Wise Comparisons of Proportion of Colony Area Contributed to Each Site by Size Categories Using Cochran–Mantel–Haenszel Chi-Square Test

	KRB	*CIM*	*COM*	*TB-2001*	*TB*	*WC*	*BC*
KRB	–						
CIM	0.09	–					
COM	0.35	0.10	–				
TB-2001	14.64[a]	13.86[a]	12.25[a]	–			
TB	0.04	0.24	0.54	13.80[a]	–		
WC	9.58[a]	8.85	7.27	1.31	9.01	–	
BC	15.43[a]	14.78[a]	12.89[a]	0.05	14.28[a]	1.01	–

[a]Denotes significant difference with Bonferroni correction ($\alpha = 0.002$).

colony area by 95%, it would require 15 years at Cimarron, 9 years at Comanche, and 7 years at Thunder Basin for total colony area to be restored to the preepizootic area. This may be an especially important point for Thunder Basin, which lies within the geographic range of plague, but where plague has not been recorded (at least in the core colony area) for more than 10 years prior to the plague outbreak that occurred there in 2000–2001. Before that outbreak, colony area and the colony size distribution were similar to the plague-free sites. Where colony growth is slower and where plague occurs more frequently, colony area and colony sizes can be expected to be smaller.

Where plague occurs, the smaller sizes of colonies and the greater distances between colonies result in greater colony isolation, which likely lowers the probability of recolonization following a plague event. These changes in colony distribution may adversely affect the viability of prairie dogs, although they may also be beneficial for prairie dogs (see below), but the reduction of habitat area and increased habitat fragmentation for other, prairie dog–dependent species, such as black-footed ferrets (*Mustela nigripes*) or burrowing owls (*Athene cunicularia*), may result in additional serious conservation problems (Desmond et al. 2000, Lockhart et al. 2000).

Increased distances between colonies and decreased colony size may, however, lessen the impacts of subsequent plague epizootics. In the Oklahoma panhandle, in the presence of plague, the most isolated prairie dog colonies had the highest probability of persistence (Lomolino and Smith 2001). These results and ours suggest an intuitive explanation for the nonintuitive but general observation that species in decline are lost first within the more populous, central portions of their ranges (Lomolino and Channell 1995, Channell and Lomolino 2000). This pattern of range decline, which results in remnant populations located at the periphery of a species' former range, is general to many geographic regions and taxonomic groups (Channell and Lomolino 2000). Previous explanations for this pattern of range decline implicated "contagious" processes associated with human activity, such as habitat degradation and effects of introduced species (Channell and Lomolino 2000). We suggest that disease may be responsible for inverting the distribution of certain species. Disease, introduced or exacerbated by human activities, may spread more easily through the central portion of a species range, where there is higher connectivity among individuals and populations. Peripheral populations may remain unaffected by virtue of their relative isolation from this contagious process. This pattern has been reported at a local scale for Gunnison's prairie dogs (*C. gunnisoni*: Cully et al. 1997).

That infectious diseases may disrupt the distribution of species, especially where populations enjoy high connectivity, would seem to support the argument that connectivity increases the probability of disease transmission and possible extinction (Hess 1994, 1996). Isolated populations are still susceptible to disease, and without some connectivity among colonies, extirpated colonies cannot be recolonized following an epizootic (McCallum and Dobson 1995, 2002, Gog et al. 2002, Wagner et al. 2006). We have little information on the underlying disease dynamics of reservoir hosts and are unable to positively identify routes or sources of transmission among colonies. We can caution, however, that disease and other stressors may combine to thin and perhaps eradicate species where they were once common.

Our observations indicate that in areas where plague is present, highly connected complexes of large prairie dog colonies may actually be more susceptible to decline because the spread of plague is enhanced by increased connectivity among colonies. In these situations, effective conservation strategies may include the identification and monitoring of stepping stone colonies, which could be dusted for fleas, or eliminated in the presence of plague to reduce connectivity across large landscapes. This is the opposite of the usual perception that it is beneficial to population stability to maintain high levels of connectivity. Although fragmentation is often perceived as having a detrimental effect on populations, the disruption of dispersal of infectious animals among colonies, with the intent to control the spread of contagious disease, may be beneficial (Simberloff and Cox 1987, Saunders et al. 1991), especially with virulent exotic pathogens such as *Y. pestis* in North America. This argument assumes that plague is dispersed by prairie dogs. It may not apply if plague is carried between colonies by carnivores or raptors, which may be able to traverse long distances.

At the four plague sites, prairie dog abundance was less than at the plague-free sites. At least at Thunder Basin in 2001, we documented that abundance based on colony size distribution had the potential to duplicate than at the plague-free sites. At Comanche, colony area mapped in 1995 at 2186 ha was reduced by a plague epizootic during 1995–1996 (Augustine et al. 2008). Mapping did not resume there until 1999 when colony area was 799 ha, and subsequently grew at an annual rate of 40% to 6323 ha in 2005. (These figures are greater than reported by Augustine et al. [2008], because we include data from the Timpas Unit of the grassland which were not included in their analysis.) In the absence of the 2005 plague epizootic, it would have taken only one more year for colony distributions to nearly equal that observed in Thunder Basin in 2001. Although there may be differences in the distribution and quality of potential habitat among our sites, data from Thunder Basin and Comanche demonstrate that colony area could be substantially greater than what we observe in the presence of plague. The length of the epizootic interval—for which we have few data—appears to be a key variable governing the extent to which plague limits black-tailed prairie dog colony area below the potential carrying capacity.

Population regulation implies that populations are limited to a level below which they would attain in the absence of control, but are allowed to expand if the level drops below some threshold. Cully and Williams (2001) described prairie dog colony growth in the presence of plague at Cimarron during the 1990s when colonies were small and relatively isolated from one another. During 5 years without plague, 2001–2005, rapid colony growth occurred, and, when plague reappeared, total colony area declined from 2342 ha in 2005 to 541 ha in 2008 (Cimarron National Grassland, unpublished records). At Comanche, where colonies grew steadily from 1999 to 2005, plague returned in 2005 and reduced colony area during 2006–2008 from 6323 ha in 2005 to 1975 ha in 2008 (Comanche National Grassland, unpublished records). Plague had similar impacts at Kiowa/Rita Blanca and Thunder Basin when it appeared after an unknown interval of colony growth in the absence of plague. At the scale of the National Grasslands, it is clear that plague limits black-tailed prairie dog population size.

Black-tailed prairie dog colony spatial characteristics differed in areas with a history of plague from areas where plague has not been reported. We found that in areas with plague, mean colony sizes were smaller, the maximum sizes of colonies were smaller, and distances between colonies were greater. As a result, the proportion of potential habitat occupied by prairie dogs was less in areas with plague. These results indicate that prairie dogs are less abundant and may provide less benefit to dependent species in areas with plague. In contrast, because of the larger colonies and shorter nearest-neighbor distances outside the range of plague, these important areas may be at greater risk if plague does enter, perhaps as a result of changing climate.

Our results also indicate that plague may start by infecting small colonies and small numbers of colonies, as at Kiowa Rita Blanca in 2002–2003 and Cimarron 2005, before spreading more widely. With close monitoring of prairie dog colonies, early detection of plague may offer opportunities to intervene to slow or stop the epizootic by dusting burrows, application of vaccines to reduce susceptibility (when they become available), or perhaps other methods. Plague has devastating effects on prairie dogs, but the potential for management is improving.

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Research

Spatial variation in keystone effects: small mammal diversity associated with black-tailed prairie dog colonies

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Species with extensive geographic ranges may interact with different species assemblages at distant locations, with the result that the nature of the interactions may vary spatially. Black-tailed prairie dogs *Cynomys ludovicianus* occur from Canada to Mexico in grasslands of the western Great Plains of North America. Black-tailed prairie dogs alter vegetation and dig extensive burrow systems that alter grassland habitats for plants and other animal species. These alterations of habitat justify the descriptor "ecological engineer," and the resulting changes in species composition have earned them status as a keystone species. We examined the impact of black-tailed prairie dogs on small mammal assemblages by trapping at on- and off-colony locations at eight study areas across the species' geographic range. We posed 2 nested hypotheses: 1) prairie dogs function as a keystone species for other rodent species; and 2) the keystone role varies spatially. Assuming that it does, we asked what are the sources of the variation?

Black-tailed prairie dogs consistently functioned as a keystone species in that there were strong statistically significant differences in community composition on versus off prairie dog colonies across the species range in prairie grassland. Small mammal species composition varied along both latitudinal and longitudinal gradients, and species richness varied from 4 to 11. Assemblages closer together were more similar; such correlations approximately doubled when including only on- or off-colony grids. Black-tailed prairie dogs had a significant effect on associated rodent assemblages that varied regionally, dependent upon the composition of the local rodent species pool. Over the range of the black-tailed prairie dog, on-colony rodent richness and evenness were less variable, and species composition was more consistent than off-colony assemblages.

Keystone species (Paine 1969) are defined as those that have a disproportionate effect on the distribution and abundance of other species relative to their own abundance (Power et al. 1996), and that perform a role unlike any other species or process in the same ecosystem (Kotliar 2000). Prairie dogs (*Cynomys* spp.) often are considered ecosystem engineers (Jones et al. 1994, 1997, Ceballos et al. 1999, Wright et al. 2002, Bangert and Slobodchikoff 2006, Davidson and Lightfoot 2006, 2008, Davidson et al. 2008, VanNimwegen et al. 2008) as well as keystone species of short- and mixed-grass prairies (Miller et al. 1994, Kotliar et al. 1999) and desert grasslands (Ceballos et al. 1999, Davidson and Lightfoot 2006, 2008, Davidson et al. 2008). When prairie dogs colonize a new area, they create a significant and unique disturbance by reducing both dead and live vegetation cover and changing plant species composition (Coppock et al. 1983, Agnew et al. 1986, Whicker and Detling 1988, Winter et al. 2002). In addition, they excavate extensive underground burrow systems that provide refugia for other species (Hoogland 2006). Reduced vegetation height creates suitable habitat for species that prefer relatively open habitats, and burrows create shelter for insects (Kretzer 1999, Bangert and Slobodchikoff 2006, Davidson and Lightfoot 2007), reptiles and amphibians (Kretzer and Cully 2001, Shipley and Reading 2006, Davidson et al. 2008), and other animals (Kotliar et al. 1999) such as black-footed ferrets *Mustela nigripes* (Hillman and Clark 1980) and burrowing owls *Athene cunicularia* (Desmond et al. 2000, Winter and Cully 2007). Because black-tailed prairie dogs *C. ludovicianus* have a large geographic range (Fig. 1), they interact with different suites of species in different portions of their range. This variance in species associations may lead to spatial heterogeneity in their keystone role (Stapp 1998).

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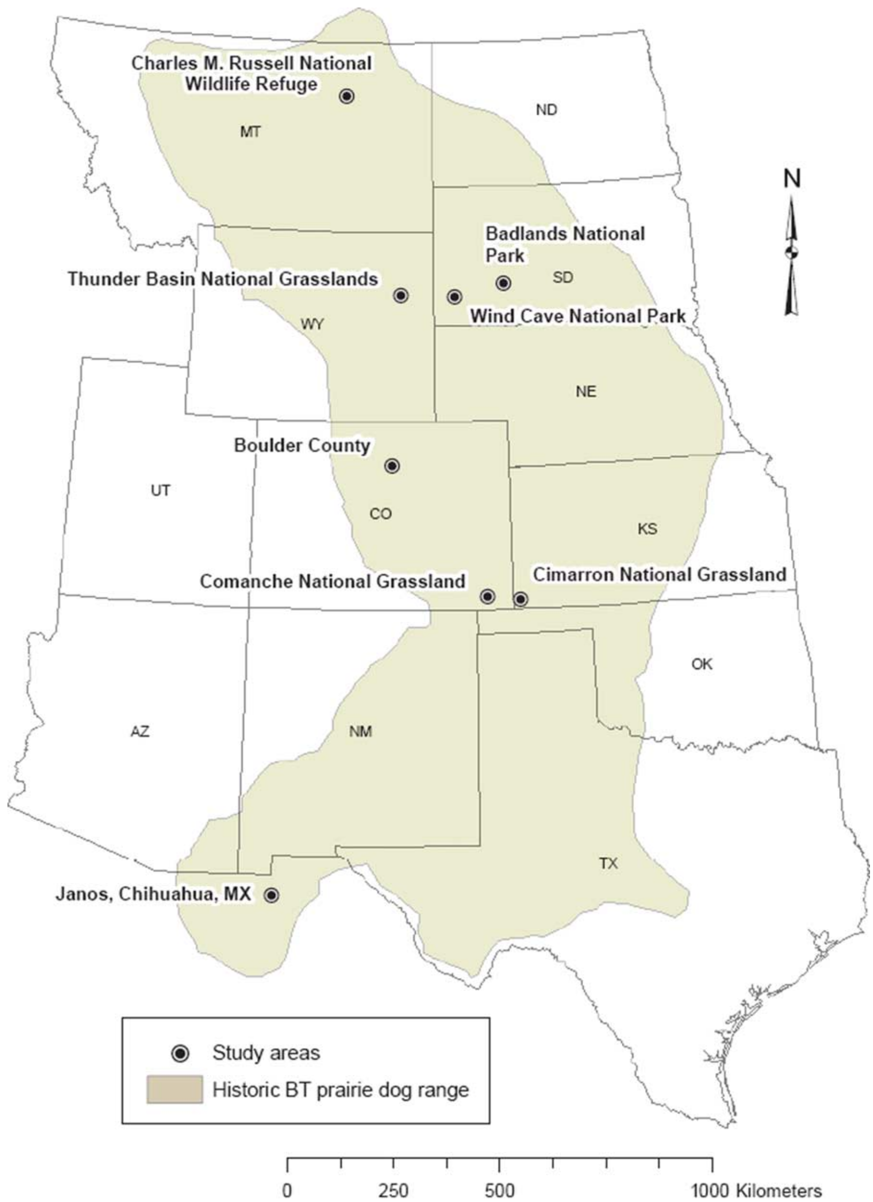


Figure 1. The geographic range of black-tailed prairie dogs in western North America showing the locations of our study areas.

The direction and magnitude of the effects of prairie dogs on ecological communities may depend on a number of ecological factors and may vary significantly in space and time (Menge et al. 1994, Navarrete and Menge 1996). If the ecological effects of a keystone species vary significantly across its geographic range, then community structure and species interactions may also differ both qualitatively and quantitatively across the range (Stapp 1998). Further, if a species has strong effects on community structure at a particular place and time, then the decline or local extinction of that species due to disease or other mortality factors may cause large shifts in community structure (Collinge et al. 2008).

Although the black-tailed prairie dog is often identified as a keystone species, this status has been questioned on the basis that too little was known about the functional relationship between prairie dogs and associated species (Stapp 1998), and in a recent literature review only 9 of 208 species previously claimed to be dependent on prairie dogs were found to be strongly associated with grasslands with prairie dog colonies (Kotliar et al. 1999). Nevertheless, as discussed above, prairie dogs have large effects on short- and mixed-grass prairie and desert grassland vascular plant, insect, bird, reptile, and amphibian community structure, and they perform roles unlike any other grassland species (Kotliar et al. 1999, Kotliar 2000, Davidson and Lightfoot 2006). At the scale of the geographic range of the species, significant changes in the number and distribution of black-tailed prairie dogs likely would result in significant changes in the nature of prairie ecosystems.

The effect of prairie dog colonies on small mammal diversity and composition has been studied separately in Mexico, Arizona, Oklahoma, Colorado, and South Dakota, with variable results (Table 1). Ceballos et al. (1999) reported that small mammal diversity was variable, but on average higher, on grasslands with black-tailed prairie dogs in

Table 1. Previous studies of prairie dog effects on small mammal assemblages.

Prairie dog species	Location	Sample size, on-colony/off-colony	Reference
Mexican	San Luis Potosí, MX	1/1/0*	Mellink and Madrigal 1993
Black-tailed	Oklahoma, USA	6/6	O'Melia et al. 1982
Black-tailed	South Dakota, USA	3/3	Agnew et al. 1986
Black-tailed	Chihuahua, MX	2/1	Ceballos et al. 1999
Black-tailed	Oklahoma, USA	36/36	Lomolino and Smith 2003
Black-tailed	Colorado, USA	3/2	Shipley and Reading 2006
Black-Tailed	Colorado, USA	18/6/7*	Stapp 2007
Gunnison's	Arizona, USA	15/15/15*	Bartz et al. 2007

*Active on-colony/inactive on-colony/off-colony.

northeastern Mexico. Density of small mammals also was significantly higher in grasslands with prairie dogs. However, their sample sizes were small (Table 1); the 2 sites with prairie dogs had variable species richness (4 and 10 species), whereas the site without prairie dogs had 6 species (Ceballos et al. 1999). Mellink and Madrigal (1993) reported that higher small mammal species richness and abundance occurred on an inactive Mexican prairie dog colony than on an active colony, but it was presumably prior habitat changes – caused by prairie dogs – that affected the small mammals. In Oklahoma, O'Meila et al. (1982) documented higher abundance but lower species richness of small mammals on 6 black-tailed prairie dog colonies relative to 6 off-colony grassland plots. In a more recent analysis of grassland vertebrates in the Oklahoma Panhandle, mammal diversity, including rodents and other species, was similar between prairie dog colonies and paired off-colony sites in summer, and lower on colonies during fall (Lomolino and Smith 2003). Shipley and Reading (2006) reported higher numbers of captures and higher species diversity of small mammals incidentally caught in their reptile and amphibian traps on than off prairie dog colonies in Colorado. Stapp (2007) did not observe differences in abundance, richness, or evenness among active colonies, inactive colonies or off-colony sites on the Pawnee National Grassland in northeastern Colorado, although there were differences in abundance of individual species. Likewise, for Gunnison's prairie dogs, Bartz et al. (2007) found that rodent species abundance richness and diversity did not vary among active prairie dog colonies, inactive colonies, and control sites. Agnew et al. (1986) found higher density of small mammals but lower species richness on prairie dog colonies in South Dakota, with northern grasshopper mice *Onychomys leucogaster* and deer-mice *Peromyscus maniculatus* more abundant on 3 prairie dog colonies than on 3 adjacent mixed-grass prairie sites. The above studies indicate that prairie dogs' effects on rodent communities vary spatially.

We sought to test the keystone role of prairie dogs for other rodent species over a large area across the majority of the species range. At 8 study areas in 6 U.S. states and Chihuahua, Mexico, we established live-trapping grids on prairie dog colonies and at nearby off-colony grassland sites to gather contemporaneous data to evaluate relationships between black-tailed prairie dogs and small mammal assemblages. We conducted a multivariate analysis of rodent assemblages on vs off colonies to see if prairie dogs structure rodent assemblages at the large scale of the black-tailed prairie dog range. Within each study area we evaluated differences in abundance, richness, diversity, and evenness of the small mammal assemblages on and off prairie dog colonies. We posed 2 nested hypotheses. First, black-tailed prairie dogs perform a keystone role in the grassland rodent assemblage. Second, because species composition changes across the range of the black-tailed prairie dog, characteristics of the keystone role vary spatially. Assuming the keystone role would vary spatially, we sought to identify possible sources for that variation, which might include a west-to-east moisture gradient, or a north-to-south gradient in seasonal temperature differences, day-lengths, and insolation. Both east-west and north-south gradients are associated with the geographic ranges of different species, which may interact differently with prairie dogs.

Methods

Keystone species

"As used by Paine and other ecologists, there are two hallmarks of keystone species. First, their presence is crucial in maintaining the organization and diversity of their ecological communities. Second, it is implicit that these species are exceptional, relative to the rest of the community, in their importance" (Mills et al. 1993, p. 219). We refer to Paine's definition to evaluate the role of prairie dogs structuring rodent assemblages across the black-tailed prairie dog species range as a multivariate phenomenon (see below). Power et al. (1996) identified 2 quantitative criteria to evaluate the keystone effects of a species: Overall Importance $OI_i = (t_N - t_D)/(t_N)$, where t_N is the community trait and t_D is the trait in the absence of species i, and Community Importance $CI_i = (OI_i)/(1/p_i)$, where p_i is the proportional abundance of species i. Power et al. (1996) considered the adjustment of Overall Importance by the abundance of the putative keystone species to be important to demonstrate that the effects are not simply a numerical response to the abundance of that species. Kotliar (2000) noted that for black-tailed prairie dogs, the assumption that community importance is a linear function of prairie dog density is inappropriate. Because our study design considered only the presence or absence of prairie dogs, we were unable to calculate Community Importance. However, we assume that it is not prairie dogs per se, but rather structural habitat changes (ecological engineering) brought about by prairie dogs (vegetation clipping, burrow excavation, etc.) that is important. We did not measure habitat variables, but we would not expect, nor did we observe, large differences among colonies in the structural impacts caused by prairie dogs; thus, we did not expect substantial variation among sites in prairie dog effects. When p_i does not vary, OI and CI are equivalent. Here we measure OI as the differences in abundance, species richness, diversity, and evenness of rodent assemblages at trap grids on and off colonies at individual study areas. We assume that significant effects of prairie dogs on the abundance of other species, on species richness, or on species evenness, imply a keystone effect (see below). Kotliar (2000) added a third criterion for keystone status: that the species perform unique and non-redundant functions in the ecosystem. For prairie dogs, those unique functions (clipping vegetation, excavation of extensive underground burrow systems) are well established (Whicker and Detling 1988, Ceballos et al. 1999, Davidson and Lightfoot 2006, VanNimwegen et al. 2008).

Study sites and trapping

We collected small mammal data from 8 study areas within the geographic range of the black-tailed prairie dog during 2003 (Fig. 1). The 8 study areas were: 1) Badlands National Park, South Dakota; 2) Wind Cave National Park, South Dakota; 3) Thunder Basin National Grasslands, Wyoming; 4) Comanche National Grasslands, Colorado; 5) Cimarron National Grasslands, Kansas; 6) Janos, Chihuahua, Mexico; 7) Boulder County, Colorado; and 8) Charles M. Russell National Wildlife Refuge and Southern Phillips County, Montana (Russell). We recorded the UTM coordinates for each study area (WGS84 projection; Zone 13N). Within the United States, colony sizes generally varied between 10 and 100 ha, although some may have been smaller or larger. We did not measure colony sites at all areas during 2003. The Mexican sites were more variable, with the largest colony reportedly $>10\,000$ ha. No colony had more than one trap grid (see below).

At each study area except Russell, which was an independent but methodologically similar study (Holmes 2003), we established several sampling sites, each consisting of one ''on-colony'' and one ''off-colony'' trapping grid, with off-colony grids located 500 m to 2 km from the edge of the colony in similar habitat and topography. Sampling grids at each study area were associated with different colonies so that the grids were independent of each other. Because our goal was to assess the impacts of prairie dog activities rather than general habitat differences on rodent species composition, we attempted to find off-colony grid locations that were similar in plant community type, soil type, and slope to the nearby on-colony grid. At Russell, we trapped similar numbers of grids on-colony ($n=29$) and off-colony ($n=28$), but off-colony grids were not associated with individual on-colony grids. At study areas 1–7, our sample sizes consisted of 4, 4, 6, 6, 6, 6 and 20 pairs of grids, respectively, where each square grid consisted of 7×7 ($n=49$) large Sherman live-traps ($7.6\times8.9\times22.9$ cm) spaced 20 m apart. At Russell, each square grid consisted of 10×10 ($n=100$) traps spaced 10 m apart. We trapped each site twice (early and late in the season) except at Russell and Janos, which were trapped once. Data from early and late sessions were combined for community analyses. Janos was trapped during the early session, and because of the large number of grids, Russell was trapped throughout the summer. The ''early'' trapping session was completed between 12 May and 29 June 2003 and the ''late'' trapping session was completed between 8 July and 12 September 2003. We trapped a total of 36 688 on-colony and 36 288 off-colony trap-nights.

During each session, we opened traps for three successive nights (four at Boulder and Russell). We set and baited traps with oatmeal in late afternoon, and usually checked and closed them within 2 h of sunrise the following morning. We identified animals to species, sex, and age (juvenile or adult), weighed them, and took standard measurements (total length, tail length, ear pinna, hind foot, and mass). At sites 1–6 we uniquely marked individuals with numbered aluminum ear-tags. At sites 7 and 8, we marked individuals uniformly by shaving a portion of the hindquarters. All animals were released at their point of capture. If a marked animal was captured in both early and late trapping sessions, it was counted once for each session (twice for the year). Few animals were captured in both sessions. All animal trapping and handling procedures were approved by the Institutional Animal Care and Use Committees at Kansas State Univ., the Univ. of Colorado, and the Univ. of Montana, and conformed to the Guidelines of the American Association of Mammalogists (Gannon et al. 2007).

In the following analyses, we use univariate and multivariate statistical frameworks to characterize spatial variation in the effects of prairie dog colonies on small mammal communities. We compared species abundance, species richness, diversity, and evenness at on- and off-colony grids within each study area. We used the number of unique individuals trapped (excluding recaptures) as an index of abundance in the analyses. For comparisons among sites, abundances were adjusted to standardize for trapping effort by dividing the number of animals caught by the number of trap-nights. Species richness (S) was the observed (not estimated) number of species on each grid. We used Shannon's diversity index (H′) and calculated evenness as $H'/\log_e S$ (Magurran 1988). To compare the relative role of prairie dog colonies and study area, we modeled each metric (abundance, richness, diversity, and evenness) as a function of colony status (on/off), study area, and their interaction using generalized linear models (GLMs). We did not use geographic coordinates as predictors for these models, having discovered a non-monotonic response to latitude in all 4 metrics. For abundance and richness, we used function glm with a quasipoisson error distribution and a log link function in R for Statistical Computing (R Development Core Team 2008). This model specification accommodated the positively-skewed integer distribution of these metrics and allowed for their overdispersion. For diversity and evenness, we used function glm with a Gaussian error and identity link. Evenness was almost normally distributed after a log transformation and diversity was bimodal; however, the residual plots from both Gaussian models lacked a clear pattern and subsequent results were corroborated graphically by interaction plots (Results), so we allowed moderate departure from our assumption of normally distributed errors for these linear models of diversity and evenness. Significant interactions were interpreted as regional variability in the effect of prairie dogs, whereas insignificant interactions were dropped from the model, which was then re-analyzed for main effects of colony status and study area.

We analyzed the multivariate response of small mammal species composition using several functions in the vegan package (Oksanen et al. 2008) for R. Function adonis implemented a non-parametric multivariate analysis of variance (np-MANOVA) as described by Anderson (2001). This method implements analyses similar to ANOSIM (Clarke 1993) but is more flexible in that distance matrices can be modeled with multiple continuous and categorical effects, including interactions. We used np-MANOVA to model community dissimilarity as a function of colony status, latitude, and longitude of study areas, and their interactions (colony × latitude and colony × longitude). Interactions were treated and interpreted in the same way as described for univariate analyses above; that is, a significant interaction would mean that prairie dog colonies affected small mammal composition differently in different regions of the prairie dog range.

To visualize the effect of colony status and geography on small mammal species composition, we coupled unconstrained ordination with environmental interpretation. Specifically, we used function metaMDS to perform non-metric multidimensional scaling (NMDS, Kruskal 1964) on our study areas in 3 dimensions. Upon that ordination, we plotted the variables of colony status, latitude, and longitude using function envfit. Three dimensions provided a reasonable NMDS goodness-of-fit diagnostic or "stress" of 5.4% (following Borg and Patrick 2005), and we used the Bray-Curtis distance metric based on its performance in simulations (Faith et al. 1987). Abundance was standardized to trapping effort (number of trap-nights) for each study area, then square root-transformed to downweight inordinately high counts. The ordination mapped our study areas in similarity space; i.e. areas near each other in the ordination had relatively similar species compositions, whereas those farther apart had relatively dissimilar compositions. Finally, we tested for decay-by-distance in community similarity by calculating a Mantel correlation between community distance (Bray-Curtis) and geographical distance (Euclidean). Function mantel in the vegan package computed this correlation and its permutation-based significance following the implementation of Legendre and Legendre (1998).

Results

We captured 25 species of small mammals at the 8 study areas, including 24 rodent species and 1 lagomorph, the desert cottontail *Sylvilagus audubonii.* Because rabbits, except young juveniles, were too large for our traps, and they were rarely caught, we excluded them from analyses. Species caught differed among areas (Table 2). Observed species richness varied from 4 species at Wind Cave to 11 species at Boulder. Janos, the southernmost study area, had the most "unique" species (4 species not captured at other areas), followed by Russell, the northernmost site with 3 unique species. The deermouse was the only species caught at all study areas, and the prairie vole *Microtus ochrogaster* was captured at all but Janos. The northern grasshopper mouse was absent from Boulder and Wind Cave, and the thirteen-lined ground squirrel *Spermophilus tridecemlineatus* was absent from Janos and Russell. The most abundant species was the deermouse with 2127 captures. Next was the northern grasshopper mouse (277 captures), which was consistently more abundant on colonies, followed by hispid pocket mice (113 captures) and thirteen-lined ground squirrels (77 captures), which were both most abundant off colonies. Other species were more local, caught in lower numbers, and most frequently caught at off-colony grids.

Small mammal abundance, richness, and diversity all varied significantly with colony status, study area, and colony-area interactions (Table 3) indicating an inconsistent effect of prairie dog colonies across study areas. Evenness varied with colony status and study area, but not with their interaction, indicating a consistent effect of prairie dogs, that being a higher evenness on average, across all study areas (Fig. 2).

Interaction terms from GLMs were study area-specific, and were further examined using interaction plots (Fig. 2). For both levels of colony status, the 4 responses were plotted against study areas, which were arranged by latitude to aid in geographical interpretation. Due to its apparent lack of colony effect (Fig. 2) and its extreme northern location, Russell was used as the reference level for GLM model terms containing study area. Compared to Russell, abundance was higher on prairie dog colonies, compared to off-colony grids, at the mid-latitude study areas, Boulder, Wind Cave, and Badlands, but not at Thunder Basin or further south at Janos, Cimarron, or Comanche. Richness and diversity showed an opposite response. Compared to Russell, these metrics were lower on prairie dog colonies at the mid-latitude study areas Boulder and Wind Cave, but did not differ from on colony grids at Thunder Basin, Badlands, or further south at Janos, Cimarron, and Comanche. Evenness responded somewhat consistently across all study areas: on average, evenness was higher on prairie dog colonies compared to Russell, with a marginally significant reversal of that effect at Badlands, and an insignificant reversal at Cimarron (Fig. 2).

Species composition varied with colony status, latitude, and longitude, and also with the colony × latitude interaction (Table 3, bottom). The colony × study area interaction was also significant, congruent with colony × latitude. The nature of the interaction can be visualized in the ordinations: the colony effect was present throughout ordination space, in that the confidence ellipses never intersect, and the strength of this effect increased in northern latitudes. The latitude and longitude arrows on the NMDS plots form a plane perpendicular to the direction of separation between on and off levels of colony status (Fig. 3A). These graphical observations indicate that all 3 variables suggest independent gradients (except for the colony × latitude interaction, congruent with results from np-MANOVA (Table 3).

Community dissimilarity increased with geographic distance among study areas (Mantel $r = 0.426$, $p = 0.004$). The correlation between dissimilarity and distance was stronger when only considering on-colony grids (Mantel $r = 0.671$, $p = 0.012$) or off-colony grids (Mantel $r = 0.765$, $p = 0.002$) in each study area.

Discussion

Black-tailed prairie dogs functioned as a keystone species across their range in that they consistently altered rodent

Table 2. Numbers of individual small mammals captured at each area at on-colony grids and (off-colony grids). Bad = Badlands, Cim = Cimarron, Com = Comanche, TB = Thunder Basin, WC = Wind Cave. Total species numbers are: on-colony/off-colony (total species).

Species	Common name	Bad	Boulder	Cim	Com	Janos	TB	WC	Russell	Total
Chaetodipus hispidus	Hispid pocket mouse	2(2)	24(58)	4(12)	4(6)			0(1)		34(79)
Dipodomys merriami	Merriam's kangaroo rat					5(48)				5(48)
Dipodomys ordii	Ord's kangaroo rat			6(15)	3(0)		8(0)			17(15)
Dipodomys spectabilis	Banner-tailed kangaroo rat					18(25)				18(25)
Lemmiscus curtatus	Sagebrush vole						0(2)			0(2)
Microtus montanus	Montane vole		0(3)							0(3)
Microtus ochrogaster	Prairie vole	3(7)	0(3)	0(1)	0(1)		0(1)	0(6)	1(23)	3(42)
Microtus pennsylvanicus	Meadow vole		0(3)							0(3)
Mus musculus	House mouse		0(4)		1(0)					1(4)
Neotoma albigula	White-throated woodrat					0(1)				0(1)
Neotoma cinerea	Bushy-tailed woodrat								0(2)	0(2)
Neotoma mexicana	Mexican woodrat		0(5)							0(5)
Neotoma micropus	Southern plains woodrat			3(0)						3(0)
Onychomys leucogaster	Northern grasshopper mouse	24(3)		95(33)	49(9)	0(2)	31(10)		17(4)	216(61)
Onychomys torridus	Southern grasshopper mouse					0(4)				0(4)
Perognathus fasciatus	Olive-backed pocket mouse								0(9)	0(9)
Perognathus flavus	Silky pocket mouse		0(1)	2(2)		2(18)				4(21)
Peromyscus leucopus	White-footed deermouse			2(5)						2(5)
Peromyscus maniculatus	North American deermouse	88(25)	604(143)	21(30)	1(36)	0(3)	113(159)	165(36)	325(378)	1317(810)
Reithrodontomys megalotis	Western harvest mouse		0(36)		0(1)				0(11)	0(48)
Reithrodontomys montanus	Plains harvest mouse			3(2)	1(0)					4(2)
Spermophilus spilosoma	Spotted ground squirrel					1(0)				1(0)
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel	2(8)	2(0)	6(7)	8(13)		9(18)	0(4)		27(50)
Tamias minimus	Least chipmunk								0(4)	0(4)
Total individuals		119(42)	630(256)	142(107)	67(66)	25(101)	161(190)	165(47)	343(431)	1652(1243)
Total species		5/5(5)	3/9(11)	9/9(10)	7/6(9)	4/7(8)	4/5(6)	1/4(4)	3/7(7)	14/22(24)

Table 3. Significance of univariate and multivariate responses from generalized linear models and non-parametric multivariate analysis of variance (np-MANOVA). Top: the generalized linear models test whether the 4 metrics (abundance, richness, diversity, and evenness) have main effect differences between on- and off-colony status (Colony), among study areas, or an interaction (colony effect differs among study areas). Bottom: the np-MANOVA tests whether the mammal communities, as multivariate phenomena, differ between on- and off-colony, by latitude, or by longitude. The interactions test whether the on-off-colony relationships change with latitude, longitude, or among study areas. Whole-term interactions (as opposed to area-specific interactions from GLMs) were obtained by analysis of deviance (function anova in R). Colony = colony status (on- vs off-colony). See text for study areas. Latitude and longitude = WGS84 Zone 13N UTM Easting and Northing coordinates for each study area.

Generalized linear models	Colony	Study area	Colony × study area
Abundance	0.006	<0.001	<0.001
Richness	<0.001	<0.001	0.003
Diversity	<0.001	<0.001	<0.001
Evenness	0.023	<0.001	0.426
np-MANOVA			
– Main effects	Colony	Latitude	Longitude
	<0.001	<0.001	<0.001
– Interactions	Colony × latitude	Colony × longitude	Colony × study area
	0.015	0.955	0.001

species composition on colonies compared to off-colony grassland sites. The impacts on abundance, richness, and diversity varied spatially (Fig. 2, Table 3). Rodent assemblage dissimilarity between study areas was correlated with distance; that is, areas close together were more similar than areas far apart. Species composition varied by prairie dog status (on- vs off-colony), latitude, and longitude.

Our use of the term keystone species follows the definitions offered in the Introduction, but differs in important ways from common usage in the conservation biology literature where a keystone species is expected to increase species richness or diversity. That expectation is not met in most instances between prairie dogs and other rodents. Prairie dogs do, however, show strong and

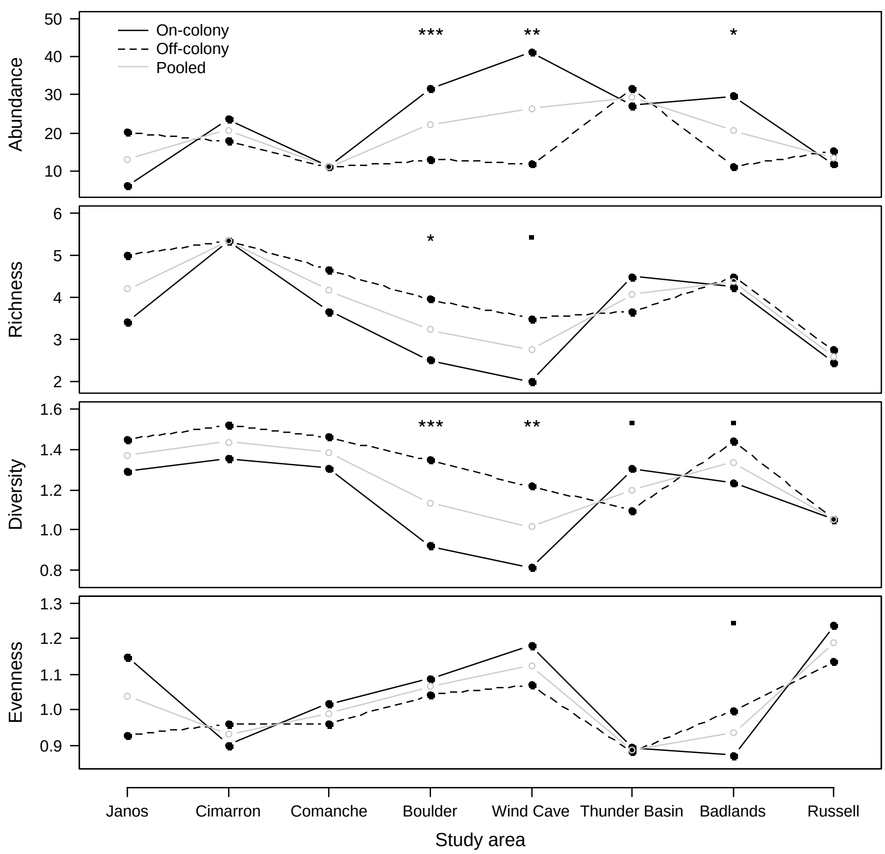
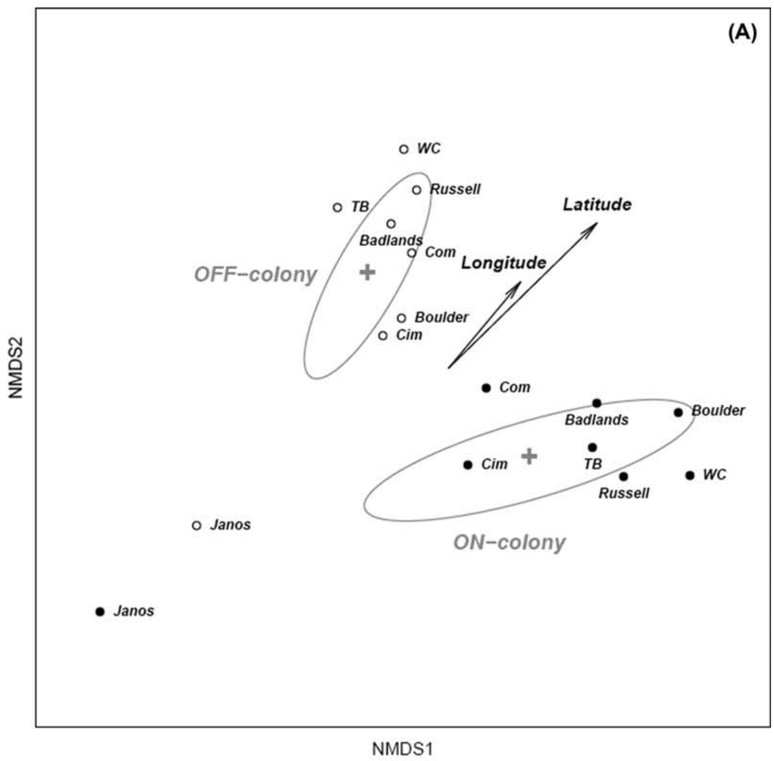


Figure 2. Interaction plots of 4 community response metrics: abundance, richness, Shannon's diversity (H′), and evenness. Interactions are between colony status (on/off) and study area, using the Russell study area as a reference level. Interaction significance codes: <0.001 (***), <0.010 (**), <0.050 (*), <0.100 (▪). The gray line indicates pooled response metrics for each study area had we ignored colony status.



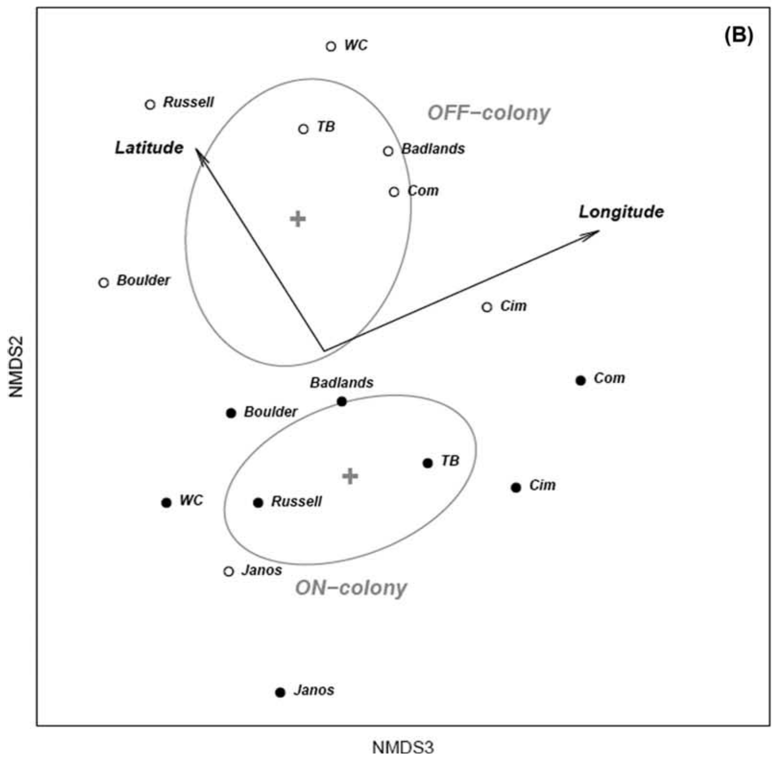


Figure 3. (A) NMDS ordination of study areas in dimensions 1 and 2, with regressed variables Latitude, Longitude (vectors), and Colony status (on/off centroids and ellipses). 95% confidence ellipses are for visualization only; reported significance values were obtained from np-MANOVA analysis (see text). Axis units are omitted due to their lack of information in distance-based ordinations: relative position of site scores provide more interpretive value. Open symbols are the off-colony grids at study areas (Badlands, Boulder = Boulder County, CIM = Cimarron, Russell = Charles M. Russell and southern Phillips County, COM = Comanche, Janos, TB = Thunder Basin, and WC = Wind Cave) and closed symbols on-colony grids. (B) NMDS ordination of study areas in dimensions 2 and 3 with regressed variables Latitude, Longitude (vectors), and Colony status (on/off centroids and ellipses). View is along the first dimension (previous plot turned 90 degrees clockwise looking down on its vertical axis). Confidence ellipses are for visualization only; reported significance values were obtained from np-MANOVA analysis (see text). Again, axis units are omitted due to their lack of information in distance-based ordinations: relative position of site scores are of more interpretive value.

consistent impacts on the rodent assemblages we encountered; in that context they meet our definition of a keystone species. Their effect is to enhance habitat for two of the dominant rodent species in short- and mixed-grass prairie-deermice and northern grasshopper mice. The reduction in usage for hispid pocket mice, thirteen-lined ground squirrels, and other, less common, grassland rodents that were rarely or never encountered on prairie dog colonies does not diminish prairie dogs' importance as ecosystem engineers and keystone species. The keystone role we observed was to produce consistent habitat patches in varied prairie settings. Such patches characteristically supported a limited, but important group of common species within a larger species pool that varied across the black-tailed prairie dog's range.

Prairie dog colonies affected small mammals at different spatial scales and at different population and community levels. At the Boulder study area, located near the geographic center of our region, abundance was markedly increased on prairie dog colonies, due to large populations of deermice, whereas species richness and Shannon's diversity were decreased. The same trend was noted to a lesser degree at Wind Cave and lesser still at Badlands (but without the effect on richness). Thus, this trio of study areas located at middle to northern latitudes showed a departure from the northern reference area (Russell) that disappeared farther south. Thunder Basin did not show a similar pattern despite its relative proximity to Wind Cave and Badlands, underscoring the geographic variability in the effect of prairie dogs on these metrics. Patterns at Thunder Basin in 2003 may have been influenced by a recent widespread epizootic of plague. In desert grasslands, keystone effects of Gunnison's and black-tailed prairie dogs varied spatially in that they interacted with complementary keystone effects of banner-tailed kangaroo rats *D. spectabilis*. Each species affected changes in lizard and arthropod assemblages, and the effects were synergistic where the 2 keystones occurred together (Davidson and Lightfoot 2006, 2007, Davidson et al. 2008).

Small mammal species composition also was affected by prairie dog colonies, but this effect did not vary across the geographic range of our study. Even though the regional species pool (represented by off-colony grids) changed along latitudinal and longitudinal gradients, the presence of prairie dog colonies always changed that composition at the local level. This multi-scale effect was also apparent in the correlations between community and geographic distances, which were nearly twice as high within a single treatment (on- vs off-colony) as when grids were pooled over both treatments.

Black-tailed prairie dogs had strong and significant effects on rodent species composition across their geographic range. The species composition at off-colony grids in the US varied both latitudinally and longitudinally, and was characterized by regionally abundant species. At the Cimarron National Grassland, the structure of the on-colony rodent assemblage was most likely a result of the presence of prairie dog burrows or other soil disturbance rather than effects of altered vegetation (VanNimwegen et al. 2008), and such may be the case in other study areas as well.

The multivariate analyses demonstrated a strong keystone effect. We suggest that prairie dogs demonstrated two important effects on small mammal assemblages. First, the observed spatial variation in the effects of prairie dogs on small mammals suggests that the effects were variable across the large scale of the western Great Plains of North America. Contrary to our expectations, there were qualitative differences in the effects of prairie dogs on small mammal assemblages across the range of the black-tailed prairie dog that were correlated with latitude and longitude. The variation in the keystone effect with latitude and longitude reflects the changes in composition of the species assemblages across the range of the black-tailed prairie dog. Abundance, evenness, and richness, where significant, were lower at on-colony grids at the three southern sites, as were richness and evenness at Boulder. Abundance was higher at on-colony grids at Boulder, Badlands, and Wind Cave, and unlike at the other sites, evenness was higher at on-colony grids at Thunder Basin (again, perhaps due to plague). Spatial variation in a keystone effect has rarely been studied. A notable exception involves large-scale studies of marine intertidal communities in Oregon and Washington, USA, which show that the effects of seastars on invertebrate communities vary both spatially and temporally (Menge et al. 1994, Navarrete and Menge 1996). For example, the intensity of seastar predation depends on wave exposure and rates of prey production at particular sites. These studies demonstrate that the impact of a keystone species may be high under some conditions but relatively modest under others. The same may be true of the effects (keystone or otherwise) of prairie dogs on small mammal assemblages, and spatial variation in the strength of these effects may have significant implications for disease dynamics or other ecological processes in this system. The abundance and species composition of small mammals within prairie dog colonies may critically affect the likelihood of prairie dogs contracting plague if the main route of transmission is through contact with these other rodent hosts.

Second, prairie dog colonies produced a consistent effect that differentiated small mammal species composition between on- and off-colony grids across the species range. The most important species in this regard were northern grasshopper mice and deermice. Where present, northern grasshopper mice were always more common on prairie dog colonies. Deermice were most common on prairie dog colonies where grasshopper mice were absent or occurred in low numbers. The other species either showed inconsistent patterns, or were more abundant at off-colony grids (Table 2).

Prairie dog alteration of grassland habitats is well documented. Numerous species of plants and both vertebrate and invertebrate animals benefit from the changes produced by foraging, vegetation clipping, and burrow digging activities of black-tailed prairie dogs (Whicker and Detling 1988, Ceballos et al. 1999, Kotliar et al. 1999, VanNimwegen et al. 2008). In addition, prairie dogs themselves are the most important occupants of colonies, and they were not considered in these analyses. We found clear and consistent differences in the rodent assemblages (composition) across the species range. However, the abundance, species richness, and diversity of small mammals were variable on prairie dog colonies compared to nearby off-colony sites; some species responded positively and some negatively to prairie dog-altered habitats.

Prairie dogs clearly altered habitat suitability for some rodent species, and their extensive manipulation of grassland structure and burrowing provided unique functions that were not provided by other species. The term keystone species is usually applied when the species effect is to increase diversity. The dichotomy of keystone versus non-keystone is oversimplified and the so-called keystone role is really a gradient of effect (Kotliar 2000, Soulé et al. 2003). Whether or not black-tailed prairie dogs are considered keystones depends on the definition chosen; what is clear is that they are an important, highly interactive species on the grasslands of the U.S. western Great Plains with regionally varying effects on rodents depending on the local species pool.

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SATELLITE BURROW USE BY BURROWING OWL CHICKS AND ITS INFLUENCE ON NEST FATE

MARTHA J. DESMOND AND JULIE A. SAVIDGE

Abstract. We examined the importance of satellite burrows to Burrowing Owls (*Athene cunicularia*) nesting in western Nebraska in 1991 and 1992. With few exceptions, prefledgling chicks used active black-tailed prairie dog (*Cynomys ludovicianus*) burrows either in greater proportion than their availability or in proportion to their availability within a 75-meter radius of the nest burrow. Successful owl nests (those fledging one or more chicks) had more active prairie-dog burrows within a 75-meter radius of the nest burrow than did unsuccessful nests. Efforts to control prairie-dog populations in the Great Plains states are detrimental to Burrowing Owl populations. State- and federally supported prairie-dog control programs should be reevaluated to ensure that adequate populations of prairie dogs and associated species can persist.

EL USO DE MADRIGUERAS ALTERNATIVAS DE LOS POLLOS DEL BÚHO LLANERO Y SU INFLUENCIA EN LA PRODUCCIÓN DEL NIDO

Sinopsis. Examinamos en 1991 y 1992 la importancia de las madrigueras alternativas para los Búhos Llaneros (*Athene cunicularia*) que hacen sus nidos en el oeste de Nebraska. Con pocas excepciones, los pollos en nido usaban madrigueras activas del perro llanero de cola negra (*Cynomys ludovicianus*) ya sea en proporción mayor a su disponibilidad o en proporción a ella dentro de un radio de 75 metros desde la madriguera del nido. Los nidos con éxito (aquellos que producen por lo menos un pollo volantón) tenían más madrigueras activas de perro llanero de cola negra dentro de un radio de 75 metros del nido que los nidos sin éxito. Los intentos para controlar las poblaciones del perro llanero de cola negra en los estados de la Gran Llanura han sido perjudiciales para las poblaciones de los Búhos Llaneros. Los programas de control del perro llanero de cola negra auspiciados por los gobiernos estatales y el gobierno federal requieren nuevas evaluaciones para asegurar la perduración adecuada de las poblaciones del perro llanero de cola negra y de sus especies asociadas.

Key Words: *Athene cunicularia*; *Cynomys ludovicianus;* prairie-dog colony; prairie-dog control; satellite burrow.

The western subspecies of Burrowing Owl (*Athene cunicularia hypugaea*) is a native grassland bird that depends heavily on black-tailed prairie dogs (*Cynomys ludovicianus*) for nest burrows in the Great Plains. Once abundant, black-tailed prairie dog populations have declined by 98% since the beginning of the twentieth century because of agriculture, disease, and control programs (Summers and Linder 1978, Miller et al. 1994). Today black-tailed prairie dog colonies are fragmented and degraded in quality. Federal- and state-sponsored control programs have played a major role in population reductions (Miller et al. 1990) and currently remain among the biggest threats to the fragmentation and loss of this ecosystem (Miller et al. 1994).

Most research on the nesting requirements of Burrowing Owls in prairie-dog ecosystems has addressed questions at the level of the prairie-dog colony (Butts 1973, Plumpton 1992, Hughes 1993, Pezzolesi 1994). Prairie-dog colonies are highly dynamic, and habitat characteristics can vary widely within a single town (Hoogland 1981). Little is known about owl nest choice within a town. Several authors have commented on satellite burrow use by Burrowing Owl chicks (Thomsen 1971, Butts 1973, Thompson 1984, Plumpton 1992), but use has not been examined quantitatively.

Ten to 14 d after hatching, Burrowing Owl chicks begin to emerge from their nest burrow. Although initially reluctant to move past the immediate vicinity of the nest burrow, they are quickly distributed among neighboring burrows. On one occasion, an adult female was observed using food to lure chicks away from the nest burrow to nearby burrows (M. Desmond, pers. obs.); this occurred at dawn and took 0.5 hr. Although we have observed this behavior only once, we think it is a common behavior for distributing chicks among burrows. As chicks become older, they readily move among burrows on their own. Butts and Lewis (1982) and Green and Anthony (1989) have suggested that using satellite burrows may reduce overcrowding in the nest burrow or may be a response to ectoparasite loads. Because of their terrestrial nature and large broods, prefledgling Burrowing Owls are often highly visible and thus vulnerable to predation. Using satellite burrows may be a defense against predation, as an entire brood is less likely to be lost to a predator if chicks are distributed among several burrows (Desmond 1991).

This paper examines the importance of prairie dogs and particularly satellite burrows to prefledgling Burrowing Owls. We have observed both adult and young owls using active prairie-dog burrows. Burrow use is particularly important to prefledgling Burrowing Owls because of their vulnerability to predation. We hypothesized that chicks would be selective in their choice of satellite burrows, and we predicted that they would exhibit a preference for active rather than inactive prairie-dog burrows because active burrows are better maintained. We also predicted that Burrowing Owl nest fate would be positively influenced by the number of active prairie-dog burrows in the vicinity of nest burrows.

STUDY AREAS AND METHODS

Research was conducted in 16 black-tailed prairie dog colonies in Banner, Box Butte, Morrill, Scotts Bluff, and Sioux Counties in western Nebraska in the spring and summer of 1991 and 1992. We searched prairie-dog colonies for nesting Burrowing Owls throughout the month of May each year. We located nests by carefully observing towns when the owls were courting and by walking line transects through each town such that we covered the entire town. Burrowing Owl nests were easily located because of the owls' propensity to line their nest entrances with shredded cow or horse dung. We mapped satellite prairie-dog burrow use by prefledgling owl chicks on a weekly or biweekly basis, depending on the location of the site, for 51 of 60 successful nests. Nine nests were omitted because of logistical problems in getting to the sites often enough and for long enough periods to record burrow use. Successful nests were defined as nests that fledged one or more chicks (42 d posthatch; Haug 1985). We measured the distance and angle from each owl nest burrow to each satellite prairie-dog burrow used by chicks, and we recorded the status of each satellite burrow as either active or inactive. Sighting of a prairie dog, fresh fecal pellets, or digging indicated active prairie-dog burrows; the presence of live, unclipped vegetation on the mound, spider webs covering or in the burrow entrance, or the absence of fresh fecal pellets indicated inactive burrows.

In late July we counted all satellite burrows within 75 m of each nest burrow and recorded their status as active or inactive. We chose 75 m because this typically was the farthest distance chicks ranged from their nest before fledging. Most 75-m circles around nests were non-overlapping; there were a few instances, however, where nests were close enough that the 75-m circles partially overlapped. In the latter cases, the direction in which the chicks spread out from the nest burrow may have been influenced by the presence of other owls rather than the number of active burrows. We used Chi-square contingency analysis for each nest ($N = 51$) to determine if Burrowing Owl chicks used active prairie-dog burrows in proportion to their availability. A Student's t-test was used to determine if there was a difference between the number of active prairie-dog burrows surrounding successful and unsuccessful nest burrows.

RESULTS

Burrowing Owls used a mean ($\pm$ SE) of 10 ± 0.98 satellite prairie-dog burrows (range 0–36) within a 75-m radius of the nest. Chicks at 29 nest burrows exhibited a preference for active prairie-dog burrows ($P < 0.05$). Chicks at two nest burrows used active burrows less than expected ($P < 0.05$); however, both of these nests were in heavily controlled prairie-dog colonies that had few remaining prairie dogs. Chicks at 11 nest burrows used active prairie-dog burrows in proportion to their availability. For 7 of these 11 nests, nearly 100% of the satellite burrows within 75 m of the nest were active prairie-dog burrows. Nine nest burrows did not have any active prairie-dog burrows within 75 m of the nest.

We monitored 164 nests over the 2-yr period. Successful nests (fledging ≥ 1 chicks; $N = 60$) had more active prairie-dog burrows within a 75-m radius of the nest burrow ($\bar{X} \pm$ SE $= 96 \pm 5.1$) than did unsuccessful nests (26 ± 3.8; $N = 104$; Student's t-test: $t = 7.6$, $df = 162$, $P < 0.001$).

DISCUSSION

Our data indicate that Burrowing Owl chicks preferentially used active prairie-dog burrows. Active prairie-dog burrows are better maintained than inactive burrows and therefore may be more suitable for owl occupation. In inactive burrows, vegetation may partially obstruct entrances, and tunnel systems may collapse with disuse. Burrow longevity is likely related to soil type (Thompson 1984) as well as to prairie-dog activity. In Oklahoma, Butts and Lewis (1982) noted that abandoned prairie-dog colonies were not recognizable as prairie-dog colonies within 3 yr of abandonment, and Butts (1973) observed that burrows were often useless to Burrowing Owls within 1 yr of a prairie-dog control program being instituted. Such observations indicate how quickly prairie-dog burrows may degenerate without active maintenance.

Prairie-dog activity in the vicinity of Burrowing Owl nests appears to strongly influence nest fate. In Colorado, Hughes (1993) found that Burrowing Owls nested at higher densities in towns where 90% or more of the prairie-dog burrows were active. Also in Colorado, Plumpton (1992) observed that Burrowing Owls nested in areas with higher burrow densities in 1 of the 2 yr of his study. Our results indicate that active prairie-dog burrow density in the immediate vicinity of a Burrowing Owl nest may have a strong impact on nest fate. Our mean of 96 active burrows within 75 m of successful nests was high compared to our mean of 26 for unsuccessful nests.

Burrowing Owls may benefit from the presence of prairie dogs. Prairie-dog alarm calls may alert the owls to predators. Also, the owls may benefit from the dilution effect. Predators may prey more heavily on prairie dogs because they are more abundant than Burrowing Owls (Desmond et al. 1995). Prairie dogs may also be a preferred food source because of their greater biomass. Numerous prairie-dog burrows in the vicinity of a Burrowing Owl nest allow an owl brood to be distributed among several burrows, reducing the chance that an entire brood will be lost to a predator.

Preferential use of active prairie-dog burrows by Burrowing Owl chicks, and the positive influence of prairie-dog activity on nest success, support the need to preserve prairie-dog colonies for Burrowing Owl populations. We suggest that conservation agencies closely monitor prairie-dog and associated owl populations. Such assessments should include the location of prairie-dog/Burrowing Owl colonies, sizes of colonies, and owl and prairie-dog densities. State- and federally supported control programs should be reevaluated to ensure that adequate populations of prairie dogs remain to support species associated with this ecosystem.

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Thunder Basin Ecology Factsheet #1

Notes from the field

The Sun isn't up yet: I know it, the birds know it, and my half-empty coffee cup is quickly coming to the same realization. But that's when a bird researcher has the most to learn — something my foggy brain is still coming to terms with as I load the truck.

Even if you manage a full night's sleep, the grassland doesn't always make life in the field easy. In early May, the Rochelle Hills are cloaked in chilling mist, and by July the grassland is parched and baking. Flood and drought, sun and snow, cheatgrass, prickly pear, mosquitoes, and the occasional rattlesnake can make some days feel as if they will never end.

But the grassland always rewards your efforts. In the summer heat, the reward is the resinous smell of ponderosa pine that wafts down from the hills, mixing with the pungent aroma of the sagebrush below. It might be catching the reflection of my headlights in a swift fox's eyes or a sage-grouse who seems to be struggling with the "chicken conundrum" about crossing roads. A bull elk might leap from any creek bottom, a golden eagle take flight from any bluff.

This landscape is a patchwork in every sense of the word. It's a place where grassland meets the sagebrush sea, where wildlife and livestock coexist, and where ranchers, researchers and energy executives share the goals of learning what the grassland has to teach and to work with the land so its wonders remain for generations to come.

— Courtney Duchardt

Swift fox pups

UW EXTENSION

Return to UW Extension publications site

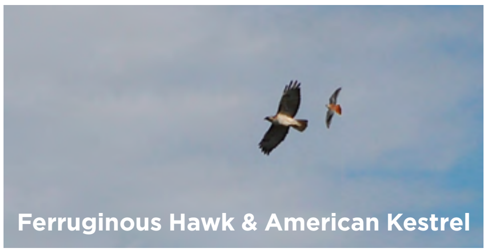
PUBLIC LANDS (STATE AND FEDERAL) HISTORY

The Thunder Basin National Grassland is a patchwork of state, federal, and privately-owned lands located in the eastern edge of the Powder River Basin of northeastern Wyoming. The public lands (state and federal) in this region are managed mostly by the U.S. Forest Service with an intermingling of privately-owned and state lands. This ownership pattern is largely a function of the federal government purchasing the land from homesteaders throughout the Great Plains in the 1930s Dust Bowl era in the effort to halt erosion from agricultural cultivation of portions of land to comply with requirements of the Homestead and other acts. The degraded lands of former farmsteads were revegetated. By 1960, a large portion of these restored lands were designated as Forest Service National Grasslands, including the area we know as Thunder Basin.

It is not surprising that maintaining crops in this region proved difficult for farmers — at approximately 12.5 inches of rainfall per year, the climate is semi-arid, with high winds, hot summers, and cold winters. Although these rangelands are ill-suited as cropland, Thunder Basin National Grassland currently supports both ranching and energy development. The rural landscape provides inherent diversity of plants and animals.

Golden Eagle

Greater Sage-grouse



Ferruginous Hawk & American Kestrel

LANDSCAPE

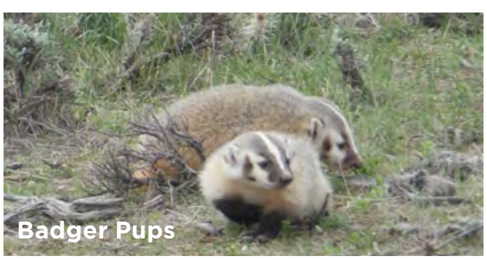
Thunder Basin National Grassland isn't only a grassland. The landscape is a mosaic of different habitat types characterized by patches of both mixed-grass prairie and sagebrush grassland that is different than the sagebrush steppe further to the west with areas of short-grass prairie.

The Thunder Basin National Grassland supports some of the largest black-tailed prairie dog complexes in North America, which are typified by shorter, sparser vegetation than the surrounding areas. Thus the Thunder Basin region is a complex landscape with heterogeneous ownership patterns, soils, vegetation structure, and wildlife species which all combined make resource management across these mosaics challenging.

Mixed-grass Landscape

Elevations in the Thunder Basin National Grassland range from 3,600 to 5,200 feet, and the landscape is dissected by the Rochelle and Red Hills, which support ponderosa pine and juniper plant communities. It is also bisected by creeks and rivers lined with cottonwoods and other moisture-loving vegetation. The name "Thunder Basin" is derived from the Little Thunder and Black Thunder creeks that run through the area.

A guiding principle in ecology is that areas with a lot of variety in habitat structure have more diverse animal communities. Because the Thunder Basin National Grassland contains many habitat types, wildlife diversity is also high.



Badger Pups

WILDLIFE

More than 100 species of birds have been observed on the grasslands, including ducks, hawks, eagles, owls, grouse, and songbirds.

Pronghorn, mule deer, elk, black-tailed prairie dogs, white-tailed jackrabbits, and cottontail rabbits can be found throughout the grasslands. Small mammals include kangaroo rats, thirteen-lined ground squirrels, and even bats. Mammalian predators include swift fox, red fox, coyotes, and badgers.

Cattle

Other species include short-horned lizard, prairie rattlesnake, tiger salamander, and the plains spadefoot toad.

LAND USE

While supporting a diverse array of wildlife, the Thunder Basin is also an important economic resource. Approximately 87 percent of the land is used as rangeland for cattle and sheep ranching. The five counties that make up the Thunder Basin — Campbell, Converse, Crook, Niobrara, and Weston — are home to more than 300,000 cows and calves and 100,000 ewe sheep and lambs. Of Wyoming's 23 counties, Converse County ranks number one for sheep production, and Campbell County ranks number five for cattle production. The foundation for these livestock operations is the native rangeland vegetation. (See Ecotones and the Thunder Basin National Grassland map page 4.)

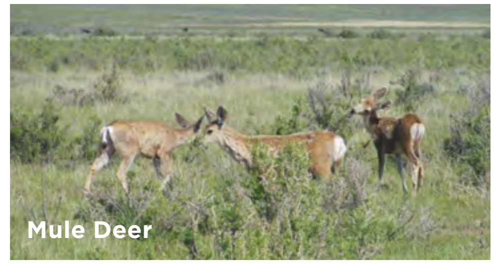
The name Thunder Basin is synonymous with coal. Rich fossil beds make the Thunder Basin an important source of oil, natural gas, and coal. In fact, North Antelope Rochelle Mine, located here, is the largest coal mine in the United States. If you ask the locals how you know you are in the Thunder Basin, they will tell you, "when you see loaded coal cars going south on the railroad and empty coal cars going north."

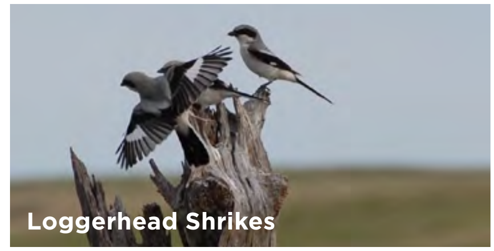
RESEARCH

Challenges in this landscape span conservation, agriculture, climate, and energy. Greater sage-grouse require sagebrush and tall vegetation, but mountain plovers require short vegetation – habitats established by different disturbance patterns. Livestock grazing must be compatible with wildlife management and increasing weather variability under predicted climate change. Finally, energy resources must be developed responsibly to sustain natural resources for wildlife and livestock. In 2014, a group of scientists, ranchers, energy companies, and consultants formed the Thunder Basin Research Initiative (TBRI) to develop a foundation of knowledge from which to address challenges in the Thunder Basin.

TBRI partners include the University of Wyoming, the United States Department of Agriculture (Agricultural Research Service - Rangeland Resources Research Unit), the United States Forest Service, the Thunder Basin Grasslands Prairie Ecosystem Association, local ranchers, and local energy companies. Together, they have begun basic and applied research to understand the complexity of Thunder Basin's resources and how to optimally manage such a special place for future generations to enjoy.


Sagebrush Grassland


Mule Deer

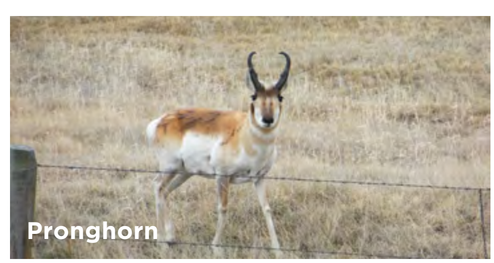

Loggerhead Shrikes


Research: Measuring the leg of a nesting mountain plover


White-tailed Jackrabbit

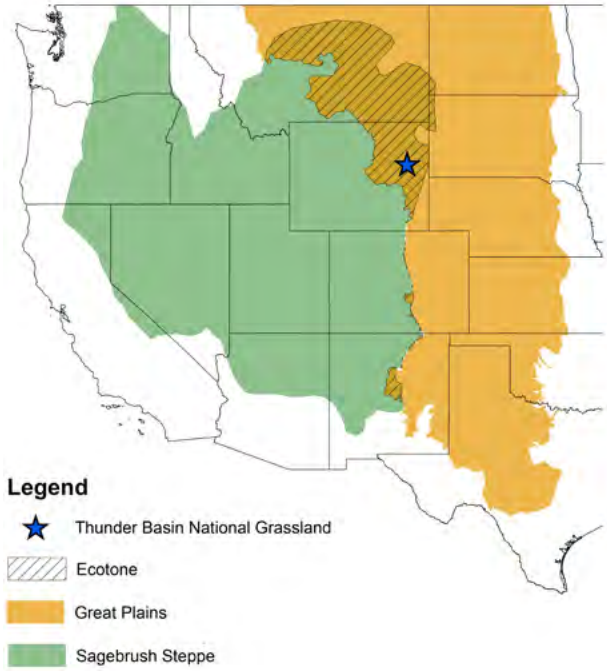

Prairie Rattlesnake


Plains Spadefoot Toad


Pronghorn

ECOTONES AND THE THUNDER BASIN NATIONAL GRASSLAND

An **ecotone** is a transitional zone between ecosystem types. Ecotones often occur along gradients of elevation, temperature, or precipitation.



Clockwise from top left: Wyoming big sagebrush seedling, silver sagebrush, scarlet globemallow, blue grama

At approximately 105 degrees west longitude, the Thunder Basin National Grassland is situated along the ecotone between the Great Plains and the sagebrush steppe. One of the gradients that influences the change between habitat types in this area is moisture; moving from east to west across the Great Plains, average rainfall decreases. Because tall and dense vegetation requires a lot of moisture, we see a transition from tallgrass prairie in the east, to mixed-grass and finally to shortgrass prairie in the drier regions to the west.

Thunder Basin also is located on a gradient of elevation and temperature; with an increase in average elevation and percentage of annual precipitation falling during the winter months (usually as snow), the mixed-grass and shortgrass prairie eventually transitions to shrubland.

In the sagebrush steppe, as in the Great Plains, these transitions shape the vegetation community. For example, the eastern edge of the sagebrush steppe is lower in elevation and receives proportionally more summer precipitation than the rest of the sagebrush steppe. Thus, silver sagebrush, which is more tolerant of wet summers than big sagebrush, is more abundant, often found in riparian zones along rivers and streams. Other sagebrush species found in this region are Wyoming big sagebrush, fringed sagewort, and birdsfoot sage.

UW EXTENSION

USDA United States Department of Agriculture
Agricultural Research Service

This is the first in a series of factsheets on the wildlife, ecology, and landscape of the Thunder Basin National Grassland in northeastern Wyoming.

Authors: Courtney Duchardt, Graduate Student, Ecology, Ecosystem Science and Management • John Derek Scasta, University of Wyoming Assistant Professor & Extension Rangeland Specialist. All photos courtesy Courtney Duchardt, Catherine Estep, Jacob Hennig, Sarah Newton, and John Derek Scasta.

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Issued in furtherance of extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Glen Whipple, director, University of Wyoming Extension, University of Wyoming, Laramie, Wyoming 82071.

United States Environmental Protection Agency
Prevention, Pesticides And Toxic Substances (7508W)
EPA 738-R-98-006
July 1998

EPA

Reregistration Eligibility Decision (RED)

Zinc Phosphide

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

OFFICE OF
PREVENTION, PESTICIDES
AND TOXIC SUBSTANCES

CERTIFIED MAIL

Dear Registrant:

I am pleased to announce that the Environmental Protection Agency has completed its reregistration eligibility review and decisions on the pesticide chemical case zinc phosphide. The enclosed Reregistration Eligibility Decision (RED), which was approved on September 30, 1997, contains the Agency's evaluation of the data base of these chemicals, its conclusions of the potential human health and environmental risks of the current product uses, and its decisions and conditions under which these uses and products will be eligible for reregistration. The RED includes the data and labeling requirements for products for reregistration. It also includes requirements for additional generic data on zinc phosphide to confirm the risk assessments.

To assist you with a proper response, read the enclosed document entitled "Summary of Instructions for Responding to the RED." This summary also refers to other enclosed documents which include further instructions. You must follow all instructions and submit complete and timely responses. **The first set of required responses is due 90 days from the date of your receipt of this letter. The second set of required responses is due 8 months from the date of your receipt of this letter.** Complete and timely responses will avoid the Agency taking the enforcement action of suspension against your products.

Please note that the Food Quality Protection Act of 1996 (FQPA) became effective on August 3, 1996, amending portions of both pesticide law (FIFRA) and the food and drug law (FFDCA). This RED takes into account, to the extent currently possible, the new safety standard set by FQPA for establishing and reassessing tolerances. However, it should be noted that in continuing to make reregistration determinations during the early stages of FQPA implementation, EPA recognizes that it will be necessary to make decisions relating to FQPA before the implementation process is complete. In making these early case-by-case decisions, EPA does not intend to set broad precedents for the application of FQPA. Rather, these early determinations will be made on a case-by-case basis and will not bind EPA as it proceeds with further policy development and any rulemaking that may be required.

If EPA determines, as a result of this later implementation process, that any of the determinations described in this RED are no longer appropriate, the Agency will pursue whatever action may be appropriate, including but not limited to reconsideration of any portion of this RED.

If you have questions on the product specific data requirements or wish to meet with the Agency, please contact the Special Review and Reregistration Division representative Mr. Frank Rubis at (703) 308-8184. Address any questions on required generic data to the Special Review and Reregistration Division representative Ms. Susan Jennings at (703) 308-7130.

Sincerely yours,

Lois A. Rossi, Director
Special Review and
Reregistration Division

Enclosures

SUMMARY OF INSTRUCTIONS FOR RESPONDING TO THE REREGISTRATION ELIGIBILITY DECISION (RED)

1. **DATA CALL-IN (DCI) OR "90-DAY RESPONSE"**--If **generic data** are required for reregistration, a DCI letter will be enclosed describing such data. If **product specific data** are required, a DCI letter will be enclosed listing such requirements. If **both generic and product specific data** are required, a combined Generic and Product Specific DCI letter will be enclosed describing such data. However, if you are an end-use product registrant only and have been granted a generic data exemption (GDE) by EPA, you are being sent only the **product specific** response forms (2 forms) with the RED. Registrants responsible for generic data are being sent response forms for both generic and product specific data requirements (4 forms). **You must submit the appropriate response forms (following the instructions provided) within 90 days of the receipt of this RED/DCI letter; otherwise, your product may be suspended.**

2. **TIME EXTENSIONS AND DATA WAIVER REQUESTS**--No time extension requests will be granted for the 90-day response. Time extension requests may be submitted only with respect to actual data submissions. Requests for time extensions for product specific data should be submitted in the 90-day response. Requests for data waivers must be submitted as part of the 90-day response. All data waiver and time extension requests must be accompanied by a full justification. All waivers and time extensions must be granted by EPA in order to go into effect.

3. **APPLICATION FOR REREGISTRATION OR "8-MONTH RESPONSE"--You must submit the following items for each product within eight months of the date of this letter (RED issuance date).**

a. **Application for Reregistration** (EPA Form 8570-1). Use only an original application form. Mark it "Application for Reregistration." Send your Application for Reregistration (along with the other forms listed in b-e below) to the address listed in item 5.

b. **Five copies of draft labeling** which complies with the RED and current regulations and requirements. Only make labeling changes which are required by the RED and current regulations (40 CFR 156.10) and policies. Submit any other amendments (such as formulation changes, or labeling changes not related to reregistration) separately. You may, but are not required to, delete uses which the RED says are ineligible for reregistration. For further labeling guidance, refer to the labeling section of the EPA publication "General Information on Applying for Registration in the U.S., Second Edition, August 1992" (available from the National Technical Information Service, publication #PB92-221811; telephone number 703-487-4650).

c. **Generic or Product Specific Data**. Submit all data in a format which complies with PR Notice 86-5, and/or submit citations of data already submitted and give the EPA identifier (MRID) numbers. Before citing these studies, you must **make sure that they meet the Agency's acceptance criteria** (attached to the DCI).

d. **Two copies of the Confidential Statement of Formula (CSF)** for each basic and each alternate formulation. The labeling and CSF which you submit for each product must comply with P.R. Notice 91-2 by declaring the active ingredient as the **nominal concentration**. You have two options for submitting a CSF: (1) accept the standard certified limits (see 40 CFR §158.175) or (2) provide certified limits that are supported by the analysis of five batches. If you choose the second option, you must submit or cite the data for the five batches along with a certification statement as described in 40 CFR §158.175(e). A copy of the CSF is enclosed; follow the instructions on its back.

e. **Certification With Respect to Data Compensation Requirements**. Complete and sign EPA forms 8570-34 and 8570-35 for each product.

4. **COMMENTS IN RESPONSE TO FEDERAL REGISTER NOTICE**--Comments pertaining to the content of the RED may be submitted to the address shown in the Federal Register Notice which announces the availability of this RED.

5. **WHERE TO SEND PRODUCT SPECIFIC DCI RESPONSES (90-DAY) AND APPLICATIONS FOR REREGISTRATION (8-MONTH RESPONSES)**

By U.S. Mail:

Document Processing Desk **(RED-SRRD-PRB)**
Office of Pesticide Programs (7504C)
EPA, 401 M St. S.W.
Washington, D.C. 20460-0001

By express:

Document Processing Desk **(RED-SRRD-PRB)**
Office of Pesticide Programs (7504C)
Room 266A, Crystal Mall 2
1921 Jefferson Davis Hwy.
Arlington, VA 22202

6. **EPA'S REVIEWS**--EPA will screen all submissions for completeness; those which are not complete will be returned with a request for corrections. EPA will try to respond to data waiver and time extension requests within 60 days. EPA will also try to respond to all 8-month submissions with a final reregistration determination within 14 months after the RED has been issued.

REREGISTRATION ELIGIBILITY DECISION

ZINC PHOSPHIDE

LIST A

CASE 0026

TABLE OF CONTENTS

ZINC PHOSPHIDE REREGISTRATION ELIGIBILITY DECISION TEAM

Office of Pesticide Programs:

Biological and Economic Analysis Assessment

William Gross	Herbicide and Insecticide Branch
Frank Hernandez	Economic Analysis Branch

Environmental Fate and Effects Risk Assessment

William Erickson	Environmental Risk Branch III
James Goodyear	Ecological Hazard Branch
Gail Maske	Environmental Risk Branch I

Health Effects Risk Assessment

John Redden	Risk Characterization and Analysis Branch
John Leahy	Chemistry and Exposure Branch I
Stanley Gross	Toxicology Branch II
David Hrdy	Chemistry and Exposure Branch II

Registration Support Risk Assessment

Daniel Peacock	Insecticide-Rodenticide Branch
William Jacobs	Insecticide-Rodenticide Branch

Risk Management

Susan Jennings	Reregistration Branch III
Dana Lateulere	Reregistration Branch III

GLOSSARY OF TERMS AND ABBREVIATIONS

ADI	Acceptable Daily Intake. A now defunct term for reference dose (RfD).
AE	Acid Equivalent
a.i.	Active Ingredient
ARC	Anticipated Residue Contribution
CAS	Chemical Abstracts Service
CI	Cation
CNS	Central Nervous System
CSF	Confidential Statement of Formula
DFR	Dislodgeable Foliar Residue
DRES	Dietary Risk Evaluation System
DWEL	Drinking Water Equivalent Level (DWEL) The DWEL represents a medium specific (i.e. drinking water) lifetime exposure at which adverse, non carcinogenic health effects are not anticipated to occur.
EEC	Estimated Environmental Concentration. The estimated pesticide concentration in an environment, such as a terrestrial ecosystem.
EP	End-Use Product
EPA	U.S. Environmental Protection Agency
FAO/WHO	Food and Agriculture Organization/World Health Organization
FDA	Food and Drug Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FFDCA	Federal Food, Drug, and Cosmetic Act
FQPA	Food Quality Protection Act
FOB	Functional Observation Battery
GLC	Gas Liquid Chromatography
GM	Geometric Mean
GRAS	Generally Recognized as Safe as Designated by FDA
HA	Health Advisory (HA). The HA values are used as informal guidance to municipalities and other organizations when emergency spills or contamination situations occur.
HDT	Highest Dose Tested
LC_{50}	Median Lethal Concentration. A statistically derived concentration of a substance that can be expected to cause death in 50% of test animals. It is usually expressed as the weight of substance per weight or volume of water, air or feed, e.g., mg/l, mg/kg or ppm.
LD_{50}	Median Lethal Dose. A statistically derived single dose that can be expected to cause death in 50% of the test animals when administered by the route indicated (oral, dermal, inhalation). It is expressed as a weight of substance per unit weight of animal, e.g., mg/kg.
LD_{lo}	Lethal Dose-low. Lowest Dose at which lethality occurs.
LEL	Lowest Effect Level
LOC	Level of Concern
LOD	Limit of Detection
LOEL	Lowest Observed Effect Level
MATC	Maximum Acceptable Toxicant Concentration
MCLG	Maximum Contaminant Level Goal (MCLG) The MCLG is used by the Agency to regulate contaminants in drinking water under the Safe Drinking Water Act.
µg/g	Micrograms Per Gram
µg/L	Micrograms per liter
mg/L	Milligrams Per Liter
MOE	Margin of Exposure
MP	Manufacturing-Use Product
MPI	Maximum Permissible Intake
MRID	Master Record Identification (number). EPA's system of recording and tracking studies submitted.
N/A	Not Applicable

GLOSSARY OF TERMS AND ABBREVIATIONS

NOEC	No Observable Effect Concentration
NPDES	National Pollutant Discharge Elimination System
NOEL	No Observed Effect Level
NOAEL	No Observed Adverse Effect Level
OP	Organophosphate
OPP	Office of Pesticide Programs
Pa	pascal, the pressure exerted by a force of one newton acting on an area of one square meter.
PADI	Provisional Acceptable Daily Intake
PAG	Pesticide Assessment Guideline
PAM	Pesticide Analytical Method
PHED	Pesticide Handler's Exposure Data
PHI	Preharvest Interval
ppb	Parts Per Billion
PPE	Personal Protective Equipment
ppm	Parts Per Million
PRN	Pesticide Registration Notice
Q^*_1	The Carcinogenic Potential of a Compound, Quantified by the EPA's Cancer Risk Model
RBC	Red Blood Cell
RED	Reregistration Eligibility Decision
REI	Restricted Entry Interval
RfD	Reference Dose
RS	Registration Standard
RUP	Restricted Use Pesticide
SLN	Special Local Need (Registrations Under Section 24 © of FIFRA)
TC	Toxic Concentration. The concentration at which a substance produces a toxic effect.
TD	Toxic Dose. The dose at which a substance produces a toxic effect.
TEP	Typical End-Use Product
TGAI	Technical Grade Active Ingredient
TLC	Thin Layer Chromatography
TMRC	Theoretical Maximum Residue Contribution
torr	A unit of pressure needed to support a column of mercury 1 mm high under standard conditions.
WP	Wettable Powder
WPS	Worker Protection Standard

ABSTRACT

The U. S. Environmental Protection Agency has completed its reregistration eligibility decision of the pesticide zinc phosphide. This decision includes a comprehensive reassessment of the required target data and the use patterns of currently registered products. Zinc phosphide is a rodenticide that reacts with the acidic conditions in the gut to form phosphine gas, which interferes with cell respiration. Zinc phosphide is formulated as a bait/solid, dust, granular, pellet/tablet or wettable powder. The rodenticide may be used to control many species of rodents, including mice, ground squirrels, prairie dogs, voles, moles, rats, muskrats, nutria and gophers. Zinc phosphide may be used as an indoor or outdoor spot treatment for rodents as well as around burrows or underground in orchards, vineyards, various food crops, rangelands, and non-crop areas. Zinc phosphide is also applied as a broadcast treatment by ground or aerial applications.

The Agency has concluded that zinc phosphide, labeled and used as specified in this Reregistration Eligibility Decision document, will not cause unreasonable risks to humans or the environment and that all uses are eligible for reregistration. To support broadcast applications, the Agency is requiring additional aquatic toxicity data and further use information. The eligible uses include: indoor and outdoor residential and agricultural areas (including in and around homes, lawns, bulbs, in and around outside buildings/barns, rights-of-ways/fencerows/hedgerows), indoor and outdoor commercial or institutional premises and equipment, golf courses, and reforestation areas. The Agency has determined that certain application methods, in conjunction with certain use restrictions, do not result in residues of zinc phosphide on food crops. Therefore, these uses are not considered food uses for the purpose of tolerance or dietary risk assessment. These "non-food" crop uses are eligible for reregistration, provided they employ the application methods and other restrictions specified in this document. These crops include: alfalfa, barley, berries, oats, wheat, no-till corn, macadamia nut orchards, orchards/groves (post-harvest and dormant), sugar maple, and timothy (hay). In addition, the following crop uses that are considered food uses of zinc phosphide are eligible for reregistration: grapes, rangeland grasses and sugarcane. Artichokes and sugar beets have regional tolerances established for use in California; currently there are no labels that include the use on artichokes.

Although zinc phosphide is primarily used in agricultural and non-residential settings, rodenticides that are used in and around the home are responsible for a high number of accidental exposures each year. EPA is concerned about the continued risk of exposure to humans, especially children, from rodenticides used in residential settings as well as the cost and trauma associated with treating those who might have been accidentally exposed. Although there are not many incidents associated with zinc phosphide *per se*, the Agency believes that the common use pattern should be the primary determining factor shaping the regulatory decision regarding these rodenticides used in and around the home. Additionally, a margin of exposure (MOE) of 0.5 was calculated for zinc phosphide based on an acute neurotoxicity study and accidental ingestion of the bait formulation by a child. Generally, the Agency seeks to ensure that exposures have an MOE of 100 or greater. The Agency has also determined that a single swallow of zinc phosphide bait may be fatal to a young child.

To mitigate the potential risk to children from accidental ingestion of baits, the Agency is requiring several mitigation measures to be implemented in two phases. During Phase I the Agency will require zinc phosphide products, as well as those of several other rodenticides, to incorporate indicator dye (to help identify whether a child or pet has actually consumed the pesticide) and bittering agents into their formulations. These formulation changes are required of all zinc phosphide products, except for those used exclusively in an agricultural setting. In addition, registrants must

update their product labels to include the protective statements addressed in Section V of this document. During Phase II EPA will form a stakeholder group (including industry, states, various poison control centers, rodent control experts, the medical community and other interested parties) to develop additional means of significantly reducing exposures to children and pets. It is the Agency's intent that, within nine months or less from the issuance of the RED, the stakeholder group will conclude with recommendations on how to mitigate risk to children and pets. Possible outcomes of this group include: requiring all rodenticide baits used in residential settings to be placed in disposable, child-resistant bait stations or equivalently protective mechanisms; develop an exhaustive educational and outreach program for consumers and enhanced training for certified applicators; tamper-resistant bait stations; and additional labeling improvements. To monitor the progress of the measures prescribed during both phases, the Agency is also requiring registrants to submit annual American Association of Poison Control Center Data for years 1999 through 2009. Registrants are encouraged to share the cost of generating data and new technologies, whenever appropriate.

In establishing or reassessing tolerances, the Food Quality Protection Act (FQPA) requires the Agency to consider aggregate exposures to pesticide residues, including all anticipated dietary exposures and other exposures for which there is reliable information, as well as the potential for cumulative effects from a pesticide and other compounds with a common mode of toxicity. The Act further directs the Agency to consider the potential for increased susceptibility of infants and children to the toxic effects of pesticide residue.

Zinc phosphide, aluminum phosphide and magnesium phosphide all generate phosphine gas. The Agency believes the generation of phosphine should be considered as part of its aggregate assessment. Other chemicals may share a common mode of toxicity with phosphine gas. In general, after EPA develops a methodology for applying common mechanism of toxicity issues to risk assessments, the Agency will develop a process (either as part of the periodic review of pesticides or otherwise) to reexamine those tolerance decisions made earlier. However, with respect to zinc phosphide tolerance reassessment, any future cumulative risk determination regarding other chemicals that have a common mode of toxicity with phosphine will not include the uses of zinc phosphide discussed in this document because the exposures to phosphine from zinc phosphide are so unlikely.

The Agency has determined that acute or chronic dietary exposure associated with the use of zinc phosphide is unlikely. Of those commodities designated as food uses for zinc phosphide, only three were found to have detectable residues after application (grasses, sugar beets, sugarcane). Since these three crops are not direct human food items, no acute or chronic dietary consumption of zinc phosphide is expected. Also, zinc phosphide will not concentrate during the processing of any commodity because the act of processing will not allow for unreacted zinc phosphide to remain in or on processed food items. No drinking water risk assessment was performed for zinc phosphide because no residues are expected in either ground or surface water. Exposure, other than accidental ingestion, is not expected. EPA does not believe "accidental ingestion" of baits should be considered in the FQPA determination for tolerance setting. Notwithstanding the absence of exposure, the Agency established an RfD for zinc phosphide. FQPA provides that EPA apply an additional tenfold margin of safety for infants and children to account for pre- and post-natal toxicity and the completeness of the toxicity and exposure database, unless EPA determines that a different margin of safety will be safe for infants and children.

The available data base for zinc phosphide does not indicate a potential for an increased sensitivity to infants or children, however, it does not include a developmental study in rabbits or a two-generation reproductive study in rats. The available data provided no indication of increased sensitivity of fetal rats to *in utero* exposure to zinc phosphide.

The prenatal exposure developmental toxicity study in rats demonstrated no developmental effects at the highest dose tested, which was maternally toxic. The Agency is not requiring additional developmental or reproduction studies at this time because exposure from food sources is expected to be minimal to non-existent, however, the Agency has established an RfD of 0.0001 mg/kg based on a subchronic oral study that showed no effects at 0.1 mg/kg. The Agency found, in its evaluation of dietary risk for zinc phosphide subsequent to the RfD determination, that no dietary or drinking water exposure is expected and no risk assessment is necessary. Should a risk assessment be required in the future, due to treated food crops, an additional uncertainty factor of 10 would be applied to the Reference Dose calculation. This uncertainty factor would account for the extrapolation from subchronic to chronic exposure, the lack of reproductive toxicity data, and the lack of chronic toxicity data in a non-rodent species. The RfD of 0.0001 mg/kg reflects this additional uncertainty factor. If food uses showing dietary exposure are proposed for registration, a risk assessment will have to be performed. If risks are unacceptable using the current RfD, which reflects an additional uncertainty factor of 10, further studies will be required.

To mitigate the potential exposure to handlers of particulate dusts from baits, tracking powders and wettable powders the Agency is requiring, among other changes, the use of dust/mist filter respirators and protective gloves.

To mitigate the potential exposure of the rodenticide to non-target animals in an agricultural setting, the Agency is retaining the requirement that all zinc phosphide products labeled for field use (except those limited to underground baiting for pocket gophers and moles) must be restricted to use by pesticide certified applicators, or persons under their direct supervision.

Because the use of zinc phosphide will still present a hazard to non-target animals, the Agency is seeking ways to minimize exposure to these animals. The Agency is especially concerned about the broadcast use of zinc phosphide as it allows large tracts of land to be treated. However, the available data do not show that hand-baiting will necessarily result in reduced exposure to non-target animals. Rather than impose specific use restrictions at this time, the Agency will continue its evaluation of the risks associated with hand baiting versus broadcast applications and may impose additional data requirements or label amendments at a later date.

Although the use of zinc phosphide does present a risk to non-target wildlife, the Agency has determined that these adverse effects are not unreasonable due to the benefits of zinc phosphide. The use of the broadcast application allows the treatment of vast tracts of land where hand baiting is not feasible. In addition, the Agency believes that limiting the broadcast uses may indirectly encourage the use of other pesticides that are more hazardous to non-target animals than zinc phosphide.

Before reregistering the products containing zinc phosphide, the Agency is requiring that product specific data, revised Confidential Statements of Formula (CSF) and revised labeling be submitted within eight months of the issuance of this document. These data include product chemistry for each registration and acute toxicity testing. After reviewing these data and any revised labels and finding them acceptable in accordance with Section 3(c)(5) of FIFRA, the Agency will reregister a product. Those products which contain other active ingredients will be eligible for reregistration only when the other active ingredients are determined to be eligible for reregistration.

I. INTRODUCTION

In 1988, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was amended to accelerate the reregistration of products with active ingredients registered prior to November 1, 1984. The amended Act provides a schedule for the reregistration process to be completed in nine years. There are five phases to the reregistration process. The first four phases of the process focus on identification of data requirements to support the reregistration of an active ingredient and the generation and submission of data to fulfill the requirements. The fifth phase is a review by the U.S. Environmental Protection Agency (referred to as "the Agency") of all data submitted to support reregistration.

FIFRA Section 4(g)(2)(A) states that in Phase 5 "the Administrator shall determine whether pesticides containing such active ingredient are eligible for reregistration" before calling in data on products and either reregistering products or taking "other appropriate regulatory action." Thus, reregistration involves a thorough review of the scientific data base underlying a pesticide's registration. The purpose of the Agency's review is to reassess the potential hazards arising from the currently registered uses of the pesticide, to determine the need for additional data on health and environmental effects, and to determine whether the pesticide meets the "no unreasonable adverse effects" criterion of FIFRA.

On August 3, 1996, the Food Quality Protection Act of 1996 (FQPA) (Public Law 104-170) was signed into law. FQPA amends both the Federal Food, Drug, and Cosmetic Act (FFDCA), 21 U.S.C. 301 *et seq.*, and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), 7 U.S.C. 136 *et seq.* The FQPA amendments went into effect immediately. As a result, EPA is embarking on an intensive process, including consultation with registrants, States, and other interested stakeholders, to make decisions on the new policies and procedures that will be appropriate as a result of enactment of FQPA. This process will include a more in depth analysis of the new safety standard and how it should be applied to both food and non-food pesticide applications. The FQPA did not, however, amend any of the existing reregistration deadlines in section 4 of FIFRA. Therefore, the Agency will continue its ongoing reregistration program while it continues to determine how best to implement FQPA.

This document presents the Agency's decision regarding the reregistration eligibility of the registered uses of zinc phosphide, including the risk to infants and children for any potential dietary, drinking water, dermal or oral exposures, and cumulative effects as stipulated under the FQPA. The document consists of six sections. Section I is the introduction. Section II describes zinc phosphide, its uses, data requirements and regulatory history. Section III discusses the human health and environmental assessment based on the data available to the Agency. Section IV presents the reregistration decision for zinc phosphide. Section V discusses the reregistration requirements for zinc phosphide. Finally, Section VI is the Appendices which support this Reregistration Eligibility Decision. Additional details concerning the Agency's review of applicable data are available on request.

II. CASE OVERVIEW

A. Chemical Overview

The following active ingredient is covered by this Reregistration Eligibility Decision:

- **Common Name:** Zinc Phosphide
- **Chemical Name:** Zinc Phosphide
- **Chemical Family:** Inorganic compound
- **CAS Registry Number:** 1314-84-7
- **OPP Chemical Code:** 088601
- **Empirical Formula:** Zn_3P_2
- **Trade and Other Names:** n/a
- **Basic Manufacturers:** Bell Laboratories, Inc. and HACCO Inc.

B. Use Profile

The following is information on the currently registered uses with an overview of use sites and application methods. A detailed table of the uses of zinc phosphide that were considered for reregistration is in Appendix A.

For zinc phosphide:

Type of Pesticide: Rodenticide

Use Sites:
Nonfood: Indoor and outdoor residential and agricultural areas (including in and around homes, on lawns, around bulbs, in and around outside buildings/barns, rights-of-ways/fencerows/hedgerows), indoor and outdoor commercial or institutional premises and equipment (including food handling establishments), golf courses, reforestation areas, alfalfa, barley, berries (dormant), oats, sugar maple, wheat, no-till corn, macadamia nut orchards, orchards/groves (post-harvest and dormant), timothy (hay). Zinc phosphide can also be used as a general, wide area, Public Health Use pesticide.

Food: grapes, rangeland grasses, and sugarcane. Artichokes and sugar beets have regional registrations in California; currently there are no labels that include use on artichokes.

Target Pests: black-tail jack rabbit, black-tail prairie dog, chipmunk, columbian ground squirrel, cotton rat, field mice, ground squirrels, Guanosine's prairie dog, house mouse, jack rabbits, marmot, meadow mouse, meadow vole, mice, microtus, muskrats, Norway rat, nutria, pine (woodland) vole, pine vole, pocket gophers, pocket gophers (plains), prairie dogs, red squirrel, Richardson ground squirrel, roof rat, southern pocket gopher, squirrels, white-tailed prairie dog, wood rats, yellow-faced pocket gopher.

Formulation Types Registered: bait/solid (1 - 2%), dust (10 - 63%), granular (2 - 63%), pellet/tablet (2%), wettable powder (80% as pre-mix for bait)

Method and Rates of Application:

Equipment -	aircraft, bait box, duster, hand bulb duster, hand probe, hand at bait stations, hand probe, hand treatments, mechanical burrow builder, mechanical granule applicator, or mechanical broadcast.
Method and Rate -	rates of application vary by pest with the highest of 0.2 lb/A on a wide variety of crops.
Timing -	zinc phosphide is typically applied when infestation is noticed.

Use Practice Limitations: All labels include hazard statements for humans and domestic animals requiring that the product be kept away from humans, domestic animals, and pets. The use in some crop areas must be when the crop or orchard is dormant.

C. Estimated Usage of Pesticide

This section summarizes the best estimates available for the pesticide uses of zinc phosphide. These estimates are derived from a variety of published and proprietary sources available to the Agency. The data, reported on an aggregate and site (crop) basis, reflect annual fluctuations in use patterns as well as the variability in using data from various information sources.

Zinc phosphide is a rodenticide used almost exclusively by the agricultural industry. Very little zinc phosphide is used residentially. About half of the total volume is used in or around farm structures, and the other half is applied to various agricultural sites. There is limited information available on the market share and usage of rodenticides. The following table estimates zinc phosphide usage by site:

Zinc Phosphide Use by Site		
Site	**Pounds Applied (% of total)**	**Acres Treated (% of site acres)**
Sugar beets	10	< 1
Wheat, Barley and Oats	10	< 1

Rangeland	10	< 1
Landscape (turf, golf courses)	10	N/A
Farm Structures (barns, sheds, etc.)	40	N/A
Residential	5	N/A
Other (less than 5% per site of all others)	15	N/A

D. Data Requirements and Regulatory History

Zinc phosphide was first registered in the United States in 1947 by the United States Department of Agriculture (USDA) for use as a rodenticide. A Registration Standard was issued for zinc phosphide in June 1982. The Standard evaluated the available data with other relevant information on zinc phosphide and required the submission of additional data to maintain the existing registrations. A DCI was issued in 1987 and another in 1991 requiring further data for reregistration. This Reregistration Eligibility Decision reflects a reassessment of all data which were submitted in response to the Registration Standard and the two DCIs.

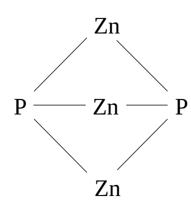
Following the issuance of the 1991 DCI, the Zinc Phosphide Consortium was formed. The consortium is made up of technical, formulator, as well as end-use product registrants. The USDA APHIS (Animal and Plant Health Inspection Service) is the consortium leader.

III. SCIENCE ASSESSMENT

A. Physical Chemistry Assessment

IDENTIFICATION OF ACTIVE INGREDIENT

Zinc phosphide:



Empirical Formula: Zn_3P_2
Molecular Weight: 258.09
CAS Registry No.: 1314-84-7
OPP Chemical No.: 088601

Technical zinc phosphide is a gray to black powder with a phosphine odor and melting point of 420 C. Zinc phosphide is insoluble in water and ethanol, and soluble in benzene and carbon disulfide. Zinc phosphide is stable in dry conditions, but reacts slowly with water (including atmospheric moisture) to form phosphine gas

(PH_3). In the presence of acids or strong bases, phosphine gas is generated rapidly and may be spontaneously flammable or explosive. Technical zinc phosphide is classified as a flammable solid by the U.S. Department of Transportation.

Manufacturing-use Products

There are three registered zinc phosphide manufacturing-use products (MPs). A list of the MPs subject to this reregistration eligibility decision is presented in the following table:

MPs subject to this reregistration eligibility decision		
% AI	**EPA Reg. No.**	**Registrant**
93%	61282-3	HACCO, Inc.
80%	61282-13	HACCO, Inc.
80%	12455-24	Bell Laboratories, Inc.

Additional generic and product-specific data are required for all three of the above products. In addition to submitting the required data, the registrants must certify that the suppliers of beginning materials and the manufacturing processes for the zinc phosphide products have not changed since the last comprehensive product chemistry review. Alternatively, the registrants may elect to submit complete updated product chemistry data packages for their products. The Agency considers these data to be confirmatory and does not expect them to alter the risk eligibility decision for zinc phosphide.

B. Human Health Assessment

1. Toxicology Assessment

The toxicological data base on zinc phosphide is adequate and will support reregistration eligibility. No further data are required at this time.

a. Acute Toxicity

The acute toxicity testing for zinc phosphide is summarized in the following table and satisfy the requirements for acute toxicology data for zinc phosphide.

Acute Mammalian Toxicity				
Test	**% AI**	**MRID**	**Results**	**Category**
Oral LD_{50} - rat	89%	00085366	21 (13-35) mg/kg	I
Dermal LD_{50} - rabbit	94%	00006030	2000 - 5000 mg/kg	III
Inhalation LC_{50}			waived	I*
Eye irritation - rabbit**	94%	00029247	Slight conjunctival redness, chemosis and discharge	IV
Dermal irritation - rabbit**	94%	00006029	non irritating	N/A
Skin sensitization**			waived	----
Acute Neurotoxicity	97%	43284301	NOEL = 5, LEL =10 mg/kg (myelin debris and vacuoles in peripheral nerves of 2 female rats)	N/A

* In lieu of performing study, compound was designated as Toxicity Category I.

** Data pertaining to eye irritation, dermal irritation and dermal sensitization are not required to support the TGAI. These data are presented for informational purposes.

b. Subchronic Toxicity

In a 90-day rat study zinc phosphide technical (97% AI) was administered by oral gavage to rats (10/sex/dose) at doses of 0, 0.1, 1.0, or 3.0 mg/kg/day for 91 days. Mortality (5 females and 1 male) and moribundity (1 male) were reported in the high-dose group. One mid-dose male was sacrificed moribund on Day 54. Clinical signs of excessive salivation and "cool to the touch" were observed at 1.0 mg/kg/day and above. Hydronephrosis and pyelonephritis were detected by microscopic histopathology in male kidneys at 3.0 mg/kg/day, and hydronephrosis was also observed at 1.0 mg/kg/day. Neither lesion was observed at 0.1 mg/kg/day. This study established a NOEL and LEL of 0.1 mg/kg/ day and 1.0 mg/kg/day, respectively, based on increased mortality and on kidney hydronephrosis in male rats.

A 90-day neurotoxicity study was also submitted and will be discussed later in this document. All other subchronic toxicity studies were waived in the 1982 Registration Standard. (MRID 43436601)

c. Chronic Toxicity and Carcinogenicity

Although zinc phosphide is registered for use on food crops, no chronic toxicity or carcinogenicity studies are required because chronic exposure to zinc phosphide or its byproducts is expected to be negligible.

d. Developmental Toxicity

In a developmental toxicity study mated female rats (25/group) were administered zinc phosphide in single daily doses by gavage at levels of 0, 1, 2 or 4 mg/kg on days 6 through 15 of gestation. Nine maternal animals from the 4.0 mg/kg group were found dead between days 10 and 16 of gestation. The cause of death was not apparent from a gross examination. Mean body weight and food intake reductions in the 4.0 mg/kg group females were significantly lower for gestation days 6-10 but not altered by the end of the treatment period. The maternal NOEL was 2.0 mg/kg and the LEL was 4.0 mg/kg based on mortality. The developmental NOEL was at or above 4.0 mg/kg, which was the highest dose test. No further data are required at this time. (MRID 43083501)

Although the database did not include a developmental study on a non-rodent species, as residues are expected to be negligible the requirement is waived. If new uses result in detectable residues, then this requirement will be reinstated.

e. Reproductive Toxicity

Although the database did not include a two-generation reproductive toxicity study in rats, as residues are expected to be negligible the requirement is waived. If new uses result in detectable residues, then this requirement will be reinstated.

f. Mutagenicity

AMES SALMONELLA. Salmonella TA-strains of bacteria were exposed to zinc phosphide (97% AI) suspended in DMSO, at doses of up to 5000 μg/plate, with and without metabolic activation (S9). No increased revertants were induced. Zinc phosphide was negative for gene mutation in the Ames test. (MRID 42987301)

MOUSE LYMPHOMA. Mouse lymphoma cells were exposed to zinc phosphide (97% AI) with and without mammalian metabolic activation (S9). Increased mutants at the thymidine kinase locus (TK) were induced in a dose-dependent manner at doses of 10 through 80 μg/ml (+/- S9). Zinc phosphide was positive for gene mutation in this mouse lymphoma assay. (MRID 42987302)

CHROMOSOME ABERRATIONS. Mice were treated with zinc phosphide (97% AI) suspended in corn oil up to severely toxic levels (150 mg/kg). No increased aberrations (micronuclei) were induced. Zinc phosphide was negative for mutagenicity in this micronucleus test. (MRID 42987303)

These studies satisfy the requirements for mutagenicity testing.

g. Metabolism

Since residues are expected to be minimal or nonexistent, the requirement for a metabolism study with zinc phosphide has been waived. If new uses result in detectable residues, then this requirement will be reinstated.

h. Neurotoxicity

Acute

In an acute range-finding study, rats zinc phosphide was administered by gavage to rats at dose levels of 1, 2, 3, 4, 8 and 10 mg/kg/day. There were no changes in toxicity, body weight or food consumption initially and 7 days after, nor were there any neurotoxicity effects. Although this study is not guideline, it does establish an LOEL of greater than 10 mg/kg. (MRID 4328301)

Subchronic

In a 13-week subchronic neurotoxicity study, rats (11/sex/group) were dosed by gavage with zinc phosphide (97% AI) daily via oral gavage at levels of 0, 0.1, 0.5, or 2 mg/kg. A positive control group was included using trimethyltin chloride in water administered by gavage at 4.5 mg/kg (11/sex), one dose weekly for three weeks starting at week 8 of the dosing period. Although no dose range finding study was referenced in the report to establish the high dose set at 2 mg/kg/day, the Agency agrees with the high-dose setting based on a 90-day study that had been previously submitted.

Each rat was observed twice daily for mortality and overt signs of toxicity. Routine functional observational batteries and motor activity assessments were carried out one week before dosing and during experimental weeks 4, 8 and 13. Following the in-life neurotoxicity evaluation, six rats per sex from each test group (except for the positive control group males) were randomly selected for necropsy and neuropathology evaluation. Eight of the positive control females euthanized in extremis and the one surviving male were necropsied and prepared for neuropathology analysis.

One male and one female from the low-dose groups and one male from the high dose group died of causes unrelated to the zinc phosphide administration. There were no adverse effects that could be ascribed to zinc phosphide. All of the animals in the positive control group were normal until dosing with trimethyltin chloride during week 8. They exhibited signs of overt toxicity beginning in week 9, becoming irritable, emaciated and unkempt in appearance. Three of the positive control males were found dead in their cages and the other 8 males were sacrificed in extremis by week 11. All of the positive control females survived longer but had to be euthanized in extremis by week 12.

Neuropathological examinations on some of the peripheral nerve sections in all treatment groups were incomplete because of inadequate tissue fixation. None of the neuropathological examinations that were performed on the zinc phosphide treated animal tissues showed any lesions that could be related to the treatment. The cerebral cortex of the positive control animals showed hemorrhage of the choroid plexus, necrosis of the hippocampus and dilation of the lateral ventricles. The findings in the other sections of the trimethyltin chloride treated animals were either within normal limits, not diagnostic secondary to inadequate fixation or revealed artifacts of preparation (vacuoles and myelin debris). This study is not acceptable due to inadequate neuropathological analyses, however, it is sufficient to show systemic, behavioral and neuropathological NOELs of 2 mg/kg/day, the highest dose tested.

A second 13-week subchronic neurotoxicity study in rats (MRID #43903802) was a partial repeat of the first study that was necessary due to inadequate fixation of nervous tissues during the neuropathology component in the initial study. In this study, rats (11/sex/group) were dosed daily with zinc phosphide (95% AI) via oral gavage (2 ml/kg) at levels of 0, 0.1, 0.5, or 2 mg/kg. A positive control group (initial study only) using trimethyltin chloride in water administered by gavage at 4.5 mg/kg (11/sex), one dose weekly for three weeks starting at week 8 of the dosing period.

Each rat was observed twice daily for mortality and overt signs of toxicity. Routine observations, functional observational batteries and motor activity assessments were carried out one week before dosing and during weeks 4, 8 and 13 of the study. Eight days after the final set of neurobehavioral evaluations, 6 animals per sex per group were randomly selected for neuropathology evaluation. No postmortem examination was reported for the remaining animals.

Four animals died of causes unrelated to the zinc phosphide administration. Clinical signs, body weights and food consumption in the treated animals were comparable to control animals. Cause of the animals death was not reported, however, except for one mid-dose female all tissues were reported to be normal.

Neurobehavioral observations were comparable to control animals, except for assessments of alterations of posture, rearing, touch, click and pinch observations which were statistically altered in the mid- or high-dose animals. Neuropathological examination of the control and high-dose animals suggested no adverse changes in morphology. Although neither 13-week subchronic neurotoxicity study is satisfactory, together the two studies provide sufficient information to fulfill the guideline requirements for a subchronic neurotoxicity study. Due to the inconclusive findings in these studies, the overall NOEL for subchronic neurotoxicity was established at 0.1 mg/kg/day, the lowest dose tested. (MRIDs 43903801 and 43903802)

2. Toxicological Endpoints for Risk Assessment

a. Acute Dietary

No acute endpoints were identified; therefore, an acute dietary risk assessment is not required. An acute endpoint was identified for accidental poisoning. The NOEL is 5 mg/kg based on the occurrence of myelin debris and bubbles in peripheral nerves of two females in the high dose group of the acute neurotoxicity study and supporting information from the subchronic neurotoxicity test.

b. Short and Intermediate Term Occupational Endpoints

No short- or intermediate-term dermal or inhalation endpoints were identified for zinc phosphide; therefore this risk assessment is not required.

c. Chronic Occupational/Residential (Non-Cancer) Endpoints

No chronic occupational endpoints were identified; therefore, this risk assessment is not required.

d. Reference Dose

A chronic dietary reference dose (RfD) was established for zinc phosphide at 0.0001 mg/kg/day, based on the NOEL of 0.1 mg/kg/day in the subchronic oral toxicity study in rats. The LEL in this study is 1.0 mg/kg/day, based on increased mortality and kidney hydronephrosis. The RfD includes an uncertainty factor of 100 to account for the interspecies extrapolation and intraspecies variability. The RfD also includes an additional uncertainty factor of 10 to account for the extrapolation from subchronic to chronic exposure, the lack of reproductive toxicity data, and the lack of chronic toxicity data in a non-rodent species. This second uncertainty factor will also accommodate the inability to assess the potential for increased sensitivity of infants and children due to the lack of sufficient animal data on *in utero* and early postnatal exposure to zinc phosphide.

The Agency has determined that a chronic dietary risk assessment is not required because dietary residues are expected to be minimal. Zinc phosphide has not been reviewed by the FAO/WHO Joint Committee Meeting on Pesticide Residue (JMPR) and no acceptable daily intake (ADI) has been established by that Committee.

e. Carcinogenic Classification

The requirement for carcinogenicity studies has been waived for zinc phosphide because chronic exposure is expected to be negligible.

3. Dietary Exposure, Risk Assessment and Characterization

a. Dietary Exposure from Food Sources

GLN 860.1200: Directions for Use

The reregistration of zinc phosphide in the United States is being supported by the Zinc Phosphide Consortium (ZPC). For the purposes of reregistration, the ZPC has provided the Agency with a summary of food and non-food uses it seeks to support, and current labels and proposed label changes. The ZPC has indicated that they will support the following crop uses: artichokes, grapes, grasses (rangeland), sugar beets, and sugarcane. The ZPC also supports many crop uses that have been designated as non-food. These designations are based on labeling requirements and application methods. For the purposes of reregistration, the Agency has evaluated the available residue chemistry database to support the use patterns classified as food uses. For the reregistration of end-use products, labeling must bear the corresponding restrictions, rates and methods as specified for the food and non-food designations.

Determination of food versus non-food uses: According to OPPTS GLN 860.1000, the application of a rodenticide as a bait around the borders of cropland or in a tamper-resistant bait box within cropland is considered a non-food use while application of the bait directly to the crop is considered a food use. Specific examples of food vs. non-food use determinations have been summarized by the Agency in connection with registrations for the rodenticides sodium fluoroacetate and strychnine.

EPA considers the following to be food uses: (I) any aerial applications where food or feed crops or livestock are present; (ii) broadcast and above-ground spot baiting on pastures or rangeland; (iii) broadcast applications to food or feed crops; (iv) applications in livestock areas; and (v) broadcast applications to ditch banks.

EPA considers the following to be non-food uses: (I) underground applications; (ii) applications to buffer zones (perimeters of a field) where grazing can be restricted; (iii) orchard uses where the bait is placed on the ground (with appropriate grazing restrictions); (iv) applications to bare ground around animal burrow entrances, dens, tunnels, and animal nests; (v) spot baiting applications to ditch banks; (vi) applications on non-crop land and in non-agricultural areas where no livestock are present; and (vii) baitbox applications and applications in V-shaped above-ground troughs.

Non-food uses of zinc phosphide: The Agency has determined that the use of zinc phosphide at the following sites should be classified as non-food use, based on examination of the registered and proposed use patterns: alfalfa (including alfalfa grown for seed), barley, berry production areas, bulbs, corn (no-till), oats, orchards and groves (including macadamia nut and sugar maple orchards), timothy, wheat, and buildings (including outside buildings). The justifications for classifying uses on these crops as non-food uses are presented in Table 4. Although no residue chemistry data are required for reregistration of the non-food uses, label amendments are required to support the non-food use classification of uses on orchards and buildings.

Current Zinc Phosphide Non-Food Uses Sites (no tolerances required)	
Site	**Basis for Non-Food Designation**
Alfalfa (seed crop)	Applied only underground or in burrow builder.
Alfalfa	Applied only underground, in bait stations, or in burrow builder
Barley, Oats, Wheat	Applied only underground or in burrow builder. Dormant season use only.
Berry Production Areas	Applied only underground, in bait stations, or in burrow builder. Applied in fair weather after harvest while crop is in a nonbearing phase.
Bulbs	Can not be applied in gardens or areas where food or feed may be contaminated.
Corn, no-till	For pre-plant or at-plant application only. May not be applied to areas inhabited by livestock. Animals may not be grazed in treated areas.
Macadamia nut orchards	Bait applied only by broadcast or in burrow builder. Animals can not be grazed in treated areas and bait must be removed from trees prior to harvest. May not be broadcasted over growing crop when bait may lodge in plant.
Maple, sugar	Application is made only in bait stations. Stations must be placed so that the bait will not come in contact with the harvested commodity or tubing that harvests commodity.
Orchards/groves	Is only applied after harvest or any time during the dormant season. Can not be broadcasted over growing crops or bare ground and animals may not be grazed in treated areas.
Timothy	Is applied only during crop dormancy and not over growing crops. Animals may not be grazed in treated areas.

Current Zinc Phosphide Non-Food Uses Sites (no tolerances required)	
Site	**Basis for Non-Food Designation**
Buildings	The use directions must restrict the use in food/feed handling establishments as specified in Section V.

Food uses of zinc phosphide: The Agency has determined that application of zinc phosphide on artichokes (globe), grapes, grasses grown in pastures and rangelands, sugar beets and sugarcane should be classified as food uses based on established policy, as outlined in OPPTS GLN 860.1000 and noted above. The Agency required crop field trials for these food uses and detectable residues were found on grasses, sugar beets and sugarcane. No detectable residues were found on artichokes or grapes. Tolerances were established for all of these crops based on their designation as a food crop, as is Agency policy. The tolerances were set on the actual detected residues or based on the limit of detection.

A label amendment is required to support the use of zinc phosphide on grasses. Although zinc phosphide is not currently registered for use on artichokes (globe), the Zinc Phosphide Consortium has indicated that they wish to reinstate this use and retain the established regional tolerance for artichokes. The use of zinc phosphide on artichokes (globe) may be reinstated provided the application method is restricted to satisfy the requirements for a non-food use site.

Although several time-limited tolerances are in place to allow for emergency exemption (or section 18) applications of zinc phosphide on several crops, these crops were not included in the risk assessment as the corresponding residues are expected to be negligible.

GLN 860.1300: Nature of the Residue - Plants

The reregistration requirements for additional plant metabolism data are waived based on a zinc phosphide radiotracer study which demonstrated that sugarcane will absorb and translocate [^{32}P] phosphine, but not as phosphine *per se*. The ^{32}P was shown to be thermally stable and non-volatile, and was assumed to be translocated through plants as phosphate. Based on this radiotracer study, the Agency has determined that the residue of concern is the unreacted zinc phosphide, measured as phosphine. The current tolerance expression for plants is appropriate and no changes are required.

GLN 860.1300: Nature of the Residue - Livestock

The reregistration requirements for animal metabolism data are waived. The Agency does not expect secondary residues in meat, milk, poultry, and eggs. Residues of zinc phosphide ingested by livestock would be immediately converted to phosphine and metabolized to naturally occurring phosphorous compounds.

GLN 860.1340: Residue Analytical Methods

The reregistration requirements for residue analytical methods are fulfilled. Acceptable methods are available for enforcement and data collection purposes for plant commodities. The Pesticide Analytical Manual

(PAM) Vol. II lists, under aluminum phosphide, a colorimetric method and a GLC method with flame photometric detection as Methods A and B, respectively, for the enforcement of tolerances. Both methods determine the level of phosphine liberated when zinc phosphide is exposed to dilute acid solutions. Method A remains a lettered method because of variable recoveries observed in an Agency method try-out, however, the method has been determined to be acceptable for enforcement because phosphine gas is highly reactive and finite residues are not expected. Data submitted in support of the established tolerances were collected by one of these two methods.

GLN 860.1360: Multiresidue Methods

Because zinc phosphide is an inorganic compound, recovery of residues using FDA Multiresidue Protocols is not expected and the requirement for such data is waived.

GLN 860.1380: Storage Stability Data

The reregistration requirements for storage stability data are partially fulfilled. Adequate storage stability data have been submitted to support frozen storage of sugar beet and alfalfa samples for 6 months; these data may be translated to grass forage and sugarcane. Adequate storage stability data have also been submitted to support storage of artichokes for 16 months.

To fully satisfy reregistration requirements, the registrant(s) must provide information concerning the length and conditions of sample storage for grapes, rangeland grass forage, and sugarcane; dates of harvest and analysis are also required for sugarcane. If samples were stored for longer than 30 days (grapes) or 6 months (grass forage and sugarcane) prior to analysis, then additional crop field trial data will be required.

GLN 860.1460: Food-Handling

The reregistration requirements for magnitude of the residue in food-handling establishments will be considered fulfilled pending appropriate label revisions in order to reinforce the non-food use classification on/in buildings. The use directions on some tracking powder labels are not sufficiently restrictive to preclude the need for residue data on food-handling establishments. Please see Section V (Actions Required of Registrants) for exact labeling language.

GLN 860.1480: Meat, Milk, Poultry, and Eggs

The reregistration requirements for data on magnitude of the residue in animals are waived. There is no reasonable expectation of residues in meat, milk, poultry, or eggs [Category 3 of 40 CFR §180.6(a)]. Residues of zinc phosphide ingested by livestock would be immediately converted to phosphine and metabolized to naturally occurring phosphorus compounds.

GLN 860.1500: Crop Field Trials

The reregistration requirements for magnitude of the residue in/on grapes, grasses, and sugarcane will be considered fulfilled pending resolution of storage stability issues. The available field trial data for these raw agricultural commodities (RACs) have been reevaluated for purposes of tolerance reassessment. Overall, acceptable field trials reflecting the maximum registered use patterns and conditions under which the pesticide could be applied were conducted. The geographic representation for each commodity is generally adequate, and a sufficient number of trials reflecting representative formulation classes was conducted. Refer to "Tolerance Reassessment Summary" section for recommendations with respect to established tolerance levels.

Adequate field trial data are available to support the reinstatement of zinc phosphide use on artichokes (globe) and sugar beets. If the registrant(s) wishes to retain the tolerances with regional registration established for sugar beet tops, and sugar beet root, then they must propose use directions reflecting the use patterns for which adequate residue data from the original tolerance petitions are available.

GLN 860.1850: Confined Accumulation in Rotational Crops

Data for confined accumulation in rotational crops has been waived because the physical properties of zinc phosphide precludes transfer of residues to rotated crops.

GLN 860.1520: Processed Food/Feed

The reregistration requirements for magnitude of the residue in sugarcane processed commodities are fulfilled. A processing study showed no concentration of residues in the processed fractions. Tolerances for sugarcane processed fractions are not required.

No processing data are needed for grapes, provided the field trial samples were analyzed within 30 days of sample collection.

The data requirements for a sugar beet processing study has been waived. The Agency believes that the refining process of sugar beets will remove any unreacted zinc phosphide from refined sugar.

b. Dietary Exposure from Drinking Water

Zinc phosphide degrades rapidly to phosphine (PH_3) and zinc ions (Zn^{2+}), both of which sorb strongly to soil and are common nutrients in soil. Zinc phosphide and its degradation products appear to have a low potential for ground and surface water contamination. Therefore, dietary exposure is not expected from either ground or surface water fed drinking water.

c. Dietary Risk Assessment and Characterization

The food crop uses which are being supported for reregistration are grapes, grasses (rangeland), sugarcane, globe artichokes, and sugar beet (roots and tops). These uses have all been designated as food uses, based on the application methods and OPPTS policy GLN 180.1000, and have tolerances.

There were no detectable residues of zinc phosphide in grape and artichoke samples following application of zinc phosphide as bait by hand application (globe artichokes) or to the ground by a spreader (grapes).

Residue studies show there were quantifiable residues in sugarcane, sugar beets, and grasses. Since these crops are not direct human foods, no acute dietary consumption is expected. Also, there is no likelihood of residues of zinc phosphide or phosphine being found through transfer of residues on grasses to meat and milk. The Agency has determined that there is no likelihood of residues of zinc phosphide occurring in any processed commodities.

4. Occupational and Residential Exposure, Risk Assessment and Characterization

a. Occupational and Residential Exposure

At this time, some products containing zinc phosphide are intended primarily for occupational use and some are intended primarily for homeowner use.

(1) Handler Exposures and Assumptions

Based on the use patterns and potential exposures described above, several exposure scenarios were identified for occupational and/or homeowner handlers of zinc phosphide: (1) mixing the dry concentrate into wet bait, (2) loading dry bait (granular/pellet) formulation to support aerial and ground equipment applications, (3) applying the wet and dry baits by hand (spoon) as spot treatments, (4) applying tracking powders by hand, (5) applying tracking powders using hand-bulb and bellows-type dusters, (6) applying dry baits by hand as broadcast treatments, (7) applying dry baits with hand-held mechanical baiting device, (8) applying dry baits with cyclone and end-gate seeders, tractor-drawn granular spreaders, and other ground-driven bait dispensing devices, (9) applying dry baits with fixed- or rotary-wing aircraft, (10) applying dry baits with whirly-bird spreaders, (11) applying dry baits with push-type spreader, and (12) flagging for aerial applications.

Although the Agency has not identified any endpoints of concern from which to perform a handler exposure and risk assessment, it is concerned for inhalation exposure of occupational workers to the particulate fines or dust that may be generated from the mixing and loading of the dust-concentrate or wettable-powder formulations and from applying the pellet and bait formulations. The Agency is confident that current labeling restrictions, when combined with those required by this document, are adequate and will require these formulation specific protections for all appropriate products.

(2) Post-Applications Exposure and Assumptions

Residential: There is the possibility of post-application exposures, if (1) baits or tracking powders applied indoors are not placed out of reach of children and pets or are not placed in tamper-resistant bait stations, as specified in labeling; (2) baits applied outdoors are not applied underground and deep enough to prevent children and pets from finding and eating the baits; (3) baits are available to homeowners in packages which are not tamper resistant and could be accessible to children or pets prior to application; and (4) baits resemble food (e.g., peanuts), are brightly colored, or are packaged in a way in which they could be appealing to children or mistaken by children for food or candy.

Occupational: The Agency has determined that there is potential for post-application exposure to zinc phosphide in occupational settings, such as workers reentering areas following all of the above-ground applications.

b. Occupational and Residential Risk Assessment/Characterization

There were no endpoints identified for use in an occupational or residential risk assessments except for accidental ingestion of a bait, however, the Agency has identified several occupational scenarios where inhalation of particulates and/or dusts may occur. In order to minimize these occurrences, the Agency is adopting labeling requirements for several formulations. See Section V for specific labeling requirements.

(1) Risk from Post-Application Exposures

Occupational: Because no toxicological endpoints were identified for occupational exposures, a risk assessment was not performed.

Residential: The Agency has performed a risk assessment based on the possibility of accidental ingestion of zinc phosphide. This assessment estimates that a 10 kg child could consume 5 grams of product in one swallow. This provides for an estimated dose of 500 mg/kg. A two percent bait would then result in a dose of 10 mg/kg of active ingredient. For zinc phosphide, a NOEL for accidental ingestion has been set at 5.0 mg/kg. This results in a margin of exposure (MOE) of 0.5. Generally, the Agency considers MOE's of less than 100 as posing an unacceptable risk.

Restricted Entry Intervals

There are currently no restricted entry intervals for any zinc phosphide products and the Agency is not requiring any at this time.

Incident Reports

The American Association of Poison Control Centers reported a total of 106 exposures to zinc phosphide in 1996. Six of these cases were suicide attempts. Approximately 80% of exposures occurred in residences and 62% of all cases involved children younger than 6 years of age. Ingestion was reported as the route of exposure in 60.5% of these cases inhalation 18.4%, dermal 14%, ocular 2.6% and unknown in the remaining

3.5%. Excluding the suicide attempts, 13% reported symptoms that were considered potentially related to their exposure when they first contacted the Poison Control Center.

The Agency also consulted four incident databases and searched available literature. The OPP Incident Data System reports incidents submitted to the Agency since 1992 from various sources, including: registrants, other federal and state health and environmental agencies and individual consumers. The California Environmental Protection Agency (formerly the California Department of Food and Agriculture) has collected uniform data on suspected pesticide poisonings since 1982. In California, physicians are required to report all occurrences of illness suspected to be related to pesticide exposure; the majority of these occurrences involve occupational workers. The National Pesticide Telecommunications Network (NPTN) is a toll-free information service supported by OPP that includes incident reporting.

The limited information on human incidents is difficult to interpret. Many cases have been documented by the WHO, all prior to 1967. The high dosage associated with all of these cases (ten were fatal, ten non-fatal) would seem to indicate suicide or suicide attempts. The animal incidents identified by the databases are predominantly due to misuse or accidental exposure, with many of the exposures resulting in the death of the exposed animal.

On the list of the highest 200 chemicals for which NPTN received calls from 1984-1991, zinc phosphide was reported to be involved in 16 human incidents and nine animal incidents. Zinc phosphide ranked 165th in a ranking of 200 chemicals by the number of calls received.

Incident data from Poison Control Centers was collected for 1989 and compared to the number of containers in U.S. homes in 1990. Of 83 compounds examined, zinc phosphide ranked 21st for number of exposures per million containers in homes, which was not unexpected for a bait product. None of the top ten compounds were rodenticide baits. For the 12 zinc phosphide cases where the exact product name was provided and an outcome determined, 2 cases reported minor and 1 case reported moderate effects. There were no major life threatening cases. No childhood deaths have been reported due to zinc phosphide since 1983 when the Poison Centers began systematic data collection.

Other Rodenticide Incidents

Data collected by the American Association of Poison Control Centers (AAPCC) for 1995 show 17,187 human exposures to all rodenticides. Of concern to EPA is the number of exposures to children younger than six years-old; in 1995, these totaled 14,900 or approximately 87% of all exposures. Of the total number of human exposures to rodenticides, almost 6500 were significant enough to result in treatment at a health care facility. Even though these reports do not identify zinc phosphide *per se* and most of the incidents are reported to have occurred with anticoagulant rodenticides, the Agency is concerned about the use pattern. The Agency would anticipate higher incidences of zinc phosphide poisoning if it were more widely used in residential settings.

Data collected by the AAPCC for 1996 indicate that 17,601 exposures occurred to humans. Of these exposures, over 13,000 occurred in children younger than six years of age. Approximately 5,300 exposures resulted in people seeking treatment at a health care facility.

5. Food Quality Protection Act Considerations

The Food Quality Protection Act of 1996 (FQPA) amended the FFCDA by setting a new safety standard for the establishment of tolerances. In determining whether a tolerance meets the new safety standard, section 408(b)(2)(c) directs EPA to consider information concerning the susceptibility of infants and children to pesticide residues in food, available information concerning aggregate exposure to infants and children of such residues, as well as the potential for cumulative effects from pesticide residues and other substances that have common mechanisms of toxicity. EPA does not believe "accidental ingestion" of baits should be included in the FQPA determination for tolerance setting.

The FQPA amendments to section 408(b)(2)(C) require the EPA to apply an additional 10-fold uncertainty factor (safety) unless reliable data demonstrate that the additional factor is unnecessary to protect infants and children.

Section 408(b)(2)(D) established factors that the Agency must consider in determining whether the safety standard is met in deciding to issue or reassess tolerances. These factors include the consideration of available information on the aggregate exposures to the pesticide from dietary sources, including drinking water, as well as non-occupational exposures such as those derived from pesticides uses in and around the home. The Agency must also consider the potential cumulative effects of the pesticide for which a tolerance is being sought as well as other substances that have a common mechanism of toxicity.

a. Potential Risks to Infants and Children

In determining whether an additional uncertainty factor is or is not appropriate for assessing risks to infants and children, EPA considers all reliable data and makes a decision using a weight-of-evidence approach taking into account the completeness and adequacy of the toxicity data base, the nature and severity of the effects observed in pre- and post-natal studies, and other information such as epidemiological data.

Under the directive of the Food Quality Protection Act (FQPA) recently enacted as an amendment to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Agency determined the following:

1) The toxicology data base, though adequate for the registration of a non-food use chemical, did not include a two-generation reproductive toxicity study in rats or a developmental toxicity study for a non-rodent species.

2) The data provided no indication of increased sensitivity of fetal rats to *in utero* exposure to zinc phosphide. In the prenatal exposure developmental toxicity study in rats, no developmental effects were observed at the highest dose tested (4.0 mg/kg/day) which was shown to be maternally toxic (maternal

deaths, decreased body weight and food consumption during treatment). There was no assessment of *in utero* exposure to non-rodents (rabbits), nor was there an assessment of early postnatal exposure.

The Agency is not requiring these studies because exposure from food sources is expected to be minimal to non-existent. However, an additional uncertainty factor of 10 was applied to the Reference Dose calculation to account for the extrapolation from subchronic to chronic exposure, the lack of reproductive toxicity data, and the lack of chronic toxicity data in a non-rodent species. This additional uncertainty factor will also accommodate the inability to assess the potential for increased sensitivity of infants and children, because of the lack of sufficient animal data on *in utero* and early postnatal exposure to zinc phosphide (a prenatal developmental toxicity study in rabbits and a two generation reproductive toxicity study in rats).

Although residue studies show there were quantifiable residues in sugarcane, sugar beets, and grasses; these commodities are not direct human foods and no dietary consumption is expected. Also, there is no likelihood of residues of zinc phosphide or phosphine being found through transfer of residues on grasses to meat and milk. The Agency has determined that there is no likelihood of residues of zinc phosphide occurring in any processed commodities.

b. Aggregate Exposure

In examining aggregate exposure, FQPA directs EPA to take into account available information concerning exposures from pesticide residues in food and other exposure for which there is reliable information. These other exposures may include drinking water and non-occupational exposure, such as from pesticides used in and around the home, but do not include accidental ingestion.

The Agency also believes that in aggregating exposures it is appropriate to include exposures from other chemicals, metabolites, degradates that are the same as the substance of toxic concern. For example, if chemical A and chemical B both produce the same metabolite of concern, C, then a risk assessment aggregating all exposures to metabolite C will be conducted. As noted earlier, the compound of toxic concern with zinc phosphide is phosphine. Two fumigants, aluminum and magnesium phosphide, also act by generating phosphine. Tolerances for all three pesticides are expressed in terms of phosphine which would suggest that an aggregate exposure/risk assessment for phosphine is appropriate. However, the Agency did not aggregate exposures of phosphine from the diet, drinking water or residential uses of zinc phosphide because the likelihood of exposure is so low. Actual residues of phosphine were only found in rangeland grasses, sugar beets and sugarcane. None of these commodities are consumed directly by humans. There is no expectation of the transfer of phosphine residues to meat and milk as any phosphine residues would be metabolized to naturally occurring phosphorous compounds and processing of sugarcane and sugar beets would remove any zinc phosphide/phosphine residues.

An aggregate exposure assessment for the various possible sources of phosphine from the uses of zinc phosphide is not warranted, because as discussed above, the likelihood of exposure is so low/unlikely. The Agency has not yet evaluated exposures from the use of aluminum and magnesium phosphide. However, when it conducts a tolerance reassessment for aluminum and magnesium phosphide, the Agency will only aggregate exposures from those uses as the zinc phosphide uses will have no effect on the aggregate exposure as discussed above. Consequently, if a reasonable certainty of no harm finding cannot be made, action will be taken only on the aluminum and/or magnesium phosphide tolerances, not the zinc tolerances. For the purposes of this decision, all zinc phosphide tolerances are assumed to be reassessed.

c. Cumulative Risk

Section 408(b)(2)(d)(v) requires that, when considering whether to establish, modify, or revoke a tolerance, the Agency consider "available information" concerning the cumulative effects of a particular pesticide's residues and "other substances that have a common mechanisms of toxicity." The Agency believes that "available information" in this context might include not only toxicity, chemistry, and exposure data, but also scientific policies and methodologies for understanding common mechanisms of toxicity and conducting cumulative risk assessments. For most pesticides, although the Agency has some information in its files that may turn out to be helpful in eventually determining whether a pesticide shares a common mechanisms of toxicity with any other substances, EPA does not at this time have the methodologies to resolves the complex scientific issues concerning common mechanism of toxicity in a meaningful way. EPA has begun a pilot process to study this issue further through the examination of particular classes of pesticides. The Agency hopes that the results of this pilot process will increase the Agency's scientific understanding of this question such that EPA will be able to develop and apply scientific principles for better determining which chemicals have a common mechanism of toxicity and evaluating cumulative effects of such chemicals. The Agency anticipates, however, that even as its understanding of the science of common mechanism increases, decisions on specific classes of chemicals will be heavily dependent on chemical specific data, much of which may not be presently available.

Zinc phosphide, aluminum phosphide and magnesium phosphide all generate phosphine gas. The Agency believes the generation of phosphine should be considered as part of its aggregate assessment. Other chemicals may share a common mode of toxicity with phosphine gas. In general, after EPA develops a methodology for applying common mechanism of toxicity issues to risk assessments, the Agency will develop a process (either as part of the periodic review of pesticides or otherwise) to reexamine those tolerance decisions made earlier. However, with respect to zinc phosphide tolerance reassessment, any future cumulative risk determination regarding other chemicals that have a common mode of toxicity with phosphine will not include the uses of zinc phosphide discussed in this document because the exposures to phosphine from zinc phosphide are so unlikely.

C. Environmental Assessment

The environmental fate and effects database on zinc phosphide is adequate and will support reregistration eligibility. Since contamination of the aquatic environment is likely from broadcast bait applications by either air or ground, additional toxicity data for aquatic organisms is required. To support broadcast applications, the following ecological effects studies are required:

72-1a	Acute Fish Toxicity (bluegill sunfish)
72-1c	Acute Fish Toxicity (rainbow trout)
72-2	Acute Aquatic Invertebrate Toxicity

Additionally, the Zinc Phosphide Consortium must consult with EPA prior to initiating these studies to ensure agreement on the appropriate test material and test protocols. These data are necessary to adequately evaluate the risk of zinc phosphide to aquatic organisms.

1. Environmental Fate

The environmental fate assessment for zinc phosphide is based on a review of data available in the open literature. The Agency reviewed these data and considers the studies submitted by USDA/APHIS (MRIDs 43466302 and 43466303) adequate to define the environmental fate and transport of zinc phosphide for its current uses. The hydrolysis requirement was previously fulfilled (MRID 00068028). No additional environmental fate data are required at this time.

a. Environmental Chemistry, Fate and Transport

(1) Degradation

Hydrolysis (161-1): Hydrolysis is reported to be the major route of dissipation, resulting in the formation of volatile phosphine and zinc ions. The rate of hydrolysis is believed to be pH dependent, with the fastest degradation rate occurring in acid solutions. The rate of hydrolysis of the degradation product, phosphine, appears to be pH and soil moisture dependent, with the rate increasing as the pH increases or decreases from neutrality.

Photodegradation in Water (161-2): Since data indicate that zinc phosphide has no chromophoric groups, it is expected to degrade by hydrolysis prior to photolysis. Therefore, photolysis is not expected to be a route of dissipation for zinc phosphide.

Photodegradation on Soil (161-3): The data indicate that zinc phosphide does not degrade by photolysis before degrading by hydrolysis, however, zinc phosphide in bait formulations appears to decompose slowly when exposed to either ambient soil moisture or dried soil. Bait formulations exhibited only 12 to 39% reduction of parent material due to climatic conditions during exposure periods of 21 to 27 days. It is likely that hydrolysis was the principal decomposition mechanism and that the sluggish decomposition rate was due to protection of zinc phosphide by formulation additives and packaging. In addition, experiments conducted with UV-C light wavelengths show PH_3 photolysis produces phosphates under oxygen-enriched conditions or hydrogen and PH_2 or PH^{2-} radicals under oxygen-deprived conditions. Soil photolysis, such as that occurring through photo-sensitized hydrolysis, is expected to be minor compared to the extensive hydrolysis that occurs in wet soil without exposure to light.

(2) Metabolism

Aerobic Soil Metabolism (162-1): The data indicate that zinc phosphide at high concentrations may effect the viability of soil organisms, such as soil algae. Soil organisms should be able to utilize the decomposition products of zinc phosphide at the registered application rates, since they are essential micronutrients for plant life. In addition, the data indicate that parent zinc phosphide at low concentrations is either relatively stable to aerobic soil metabolism or hydrolyzes before any biotic processes occur.

Anaerobic Soil Metabolism (162-3): Although microbiological-mediated processes cannot be eliminated in the decomposition of zinc phosphide, no potential mechanism has been proposed. Zinc phosphide degrades by hydrolysis, but appears to be pH (degrading under acid and alkaline pHs) and temperature dependent. Since zinc phosphide is relatively stable at pH 7, it may not readily decompose in fresh or sea water. Degradation in neutral water is believed to be mainly by sediment decomposition. Therefore, zinc phosphide appears to degrade under anaerobic conditions in the presence of moisture, without requiring microorganisms assistance. Furthermore, phosphine does not appear to be toxic (absorbed) in the absence of oxygen.

Aerobic Aquatic Metabolism (162-4): Additional data indicated that no discernible residues, including phosphine, were present seven days after aerial broadcast of 2% bait. Data also showed that zinc phosphide baits (1.4% to 3.8%) degraded slowly when submerged in an unknown water for 4 to 10 days (≈20% decline in 10 days).

(3) Mobility

Leaching/adsorption/desorption (163-1): No data exist on the sorption of parent zinc phosphide, but it is considered relatively non-mobile. In moist soils, zinc phosphide rapidly degrades to phosphine (PH_3) which sorbs to soil and oxidizes to phosphate ions and phosphorus. The sorption of the degradation products appears to increase with temperature, however, sorption of degradation products may not be pH dependent. On dried soil zinc phosphide appears to be moderately persistent (half-lives may be greater than 1 month). Since moisture rapidly degrades zinc phosphide, mobility on dried soil has not been addressed. In addition, based on the degradation processes in aqueous conditions, zinc phosphide is expected to have a low potential for remaining in soil and water environments to cause ground or surface water contamination or creating bioaccumulation hazards.

Volatility-Lab (163-2): The data indicate that in moist soils zinc phosphide degrades to a volatile product, phosphine (maximum concentration 32% of applied). The rate of volatility appears to be dependent on soil moisture and the pH of the system. Appreciable amounts of phosphine were shown to evolve from moist, acidic or basic soils, however, phosphine concentrations from bait use on dried soils or neutral waters appear negligible and are liberated too slowly to be discernible. Under normal use conditions bait formulations may be moderately persistent. Most of the phosphine released during incubation may be reabsorbed and oxidized to the ions.

Terrestrial field dissipation (164-1): The field data appear to confirm the laboratory data. Zinc phosphide was reported to dissipate with half-lives of one month or longer in dry soils, which may cause the bait formulations to be moderately persistent under some environmental conditions. In moist soils, zinc phosphide was reported to dissipate with half-lives of less than 1 week. Data indicate that the application rate will generally be low enough that residues will not be detectable in plants or soil after a period of time (≈1 to 2 weeks). In addition, the phosphate and zinc ion decomposition products in soil may be utilized by plants as elemental zinc or phosphorus.

Aquatic field dissipation (164-2): Zinc phosphide was determined to hydrolyze in aquatic systems. Hydrolysis results in the liberation of phosphine (at most ≈32% of applied) and the release of zinc ions, which may partially convert to zinc phosphate, in suspended or bottom sediments. The rate of dissipation appears to depend on the pH of the aquatic systems. Decomposition of zinc phosphide was reported to increase as the pH strayed from neutrality (from no detection to ≈32% of applied as phosphine). Zinc phosphide was shown to be relatively stable (half-life may be longer than a month in bait formulation) in neutral aquatic systems.

b. Environmental Fate Assessment

The environmental fate assessment is based on the review of available literature and is not supported by guideline studies. The major route of degradation/dissipation of zinc phosphide is hydrolysis, which results in the formation of volatile phosphine and zinc ions. Zinc phosphide and its residues appear to be non-persistent under most environmental conditions and relatively immobile (zinc ions and dissolved phosphorus readily sorb onto soil) in laboratory and field data. When applied to dry soil environments, zinc phosphide may be moderately persistent (≈40% of applied remaining at 30 days post-treatment). The rates of hydrolysis and volatilization of phosphine appear to be pH and soil moisture dependent with the hydrolysis rate increasing as the pH increases or decreases from neutrality. There are limited data available on the metabolism (microbial mediated processes) of zinc phosphide. It is believed that zinc phosphide hydrolyzes prior to biotic metabolism, however, a potential metabolism process has not been described. It has been noted that in the presence of oxygen, soil organisms appear to utilize the decomposition products when present at low concentrations. Zinc phosphide degrades rapidly to Zn^{2+} and PH_3, which sorb strongly to soil and are common nutrients in soil. Zinc phosphide and its degradation products appear to have a low potential for ground water or surface water contamination.

2. Ecological Effects

a. Toxicity to Terrestrial Animals

(1) Birds, Acute and Subacute

An acute oral toxicity study using the technical grade of the active ingredient (TGAI) is required to establish the toxicity of zinc phosphide to birds. The preferred test species is either mallard duck (a waterfowl) or bobwhite quail (an upland gamebird). Results of this test are tabulated below.

Avian Acute Oral Toxicity				
Species	**% AI**	**LD_{50} mg/kg**	**Toxicity Category**	**MRID**
Northern bobwhite quail *(Colinus virginianus)*	TGAI	12.9 (12.0-13.9)	High	00006032
Mallard duck *(Anas platyrhynchos)*	TGAI	67.4 (56.3-80.9)	Moderate	00006033

Since the LD_{50} falls in the range of 12.0 to 13.9 mg/kg, zinc phosphide is Highly Toxic to avian species (Bobwhite quail) on an acute oral basis. The guideline (71-1) is fulfilled. (MRIDs 00006032 and 00006033)

Two subacute dietary studies using the TGAI are required to establish the toxicity of zinc phosphide to birds. The preferred test species are mallard duck and bobwhite quail. Results of these tests are tabulated below.

Avian Subacute Dietary Toxicity				
Species	**% AI**	**5-Day LC_{50} (ppm)***	**Toxicity Category**	**MRID**
Northern bobwhite quail *(Colinus virginianus)*	TGAI	469 (356 - 546)	High	00006031
Mallard duck *(Anas platyrhynchos)*	TGAI	2885 (1970 - 4329)	Slight	00006025

* Test organisms observed an additional three days while on untreated feed.

Zinc phosphide, especially at higher doses, repels and has an emetic effect on birds. Mallards are particularly susceptible, indicating that the actual LC_{50}s are probably lower than those recorded under laboratory conditions. Since the LC_{50} for Bobwhite quail is 468.5 ppm, zinc phosphide is considered to be highly toxic to avian species on a subacute dietary basis. The guideline (71-2) is fulfilled. (MRID 00006025)

(2) Birds, Chronic

Avian reproduction studies for a chemical are required when any of the following conditions are met: (1) birds may be subject to repeated or continuous exposure to the pesticide, especially preceding or during the breeding season, (2) the pesticide is stable in the environment to the extent that potentially toxic amounts may persist in animal feed, (3) the pesticide is stored or accumulates in plant or animal tissues, and/or, (4) information derived from mammalian reproduction studies indicates reproduction in terrestrial vertebrates may be adversely affected by the anticipated use of the product. The preferred test species are mallard duck and bobwhite quail.

Although zinc phosphide bait will eventually degrade in the field, it may be stable under dry conditions at levels known to kill non-target animals for more than a month. Although some species of birds are exposed during their breeding season, any bird that eats the bait is expected to die from acute poisoning. Chronic effects are not expected. Avian reproduction studies are not required at this time.

(3) Mammals, Acute and Chronic

Wild mammal testing is required on a case-by-case basis, depending on the results of lower tier laboratory mammalian studies, intended use pattern and pertinent environmental fate characteristics. In most cases, rat or mouse toxicity values required for the Agency's human health assessment substitute for wild mammal testing. As reported earlier, zinc phosphide in laboratory rats was shown to have an LD_{50} of 21 mg/kg, when administered by gavage. (MRID 00085366)

No studies have been submitted on the acute toxicity of zinc phosphide to wild mammals. Some LD_{50}s reported in the literature also have been listed to aid the decision to require acute or chronic mammalian toxicity studies and to help interpret the secondary poisoning studies.

Wild Mammal Toxicity*

Species	LD_{50} (mg/kg)	Species	LD_{50} (mg/kg)
Desert kit fox	93.0	Meadow vole	18.0
California ground squirrel	33.1	Nutria	5.55
Black-tailed prairie dog	18.0	Woodrat (LD_{100})	25.0
Northern pocket gopher	6.8	Black-tailed jackrabbit	8.25
Norway rat (wild)	27-40	Polynesian rat	23.0
Roof rat	2.9-40.5		

* Prevention and Control of Wildlife Damage (Zinc Phosphide, p. G-58), Timm (ed.), 1994

The results from the above studies indicate that zinc phosphide is highly to very highly toxic to small mammals on an acute oral basis. No chronic studies have been reviewed or required. Due to the fatal nature of zinc phosphide poisonings, chronic studies are not necessary.

(4) Terrestrial Testing

The Zinc Phosphide Consortium is currently conducting two terrestrial field studies. One study is to determine the residues available on alfalfa following broadcast applications of a 2% bait in flood irrigated and sprinkler irrigated alfalfa fields. The other study is to determine nontarget hazards to pheasants in alfalfa fields that have been treated with a broadcast application of 2% zinc phosphide. The testing is expected to be completed within a year.

b. Toxicity to Freshwater Aquatic Animals

Zinc phosphide has a very low water solubility. When water is acidic or basic, zinc phosphide disassociates rapidly and produces phosphine gas (a toxic degradate that kills the target rodents). Zinc phosphide is believed to be toxic to aquatic organisms, however, it is unclear what agent is responsible for the toxicity. Currently there are no acute or chronic aquatic toxicity data available. Due to the uncertainties, test protocols must be agreed upon before initiation of any aquatic tests.

(1) Freshwater Fish, Acute

Two freshwater fish toxicity studies using the TGAI are required to establish the toxicity of zinc phosphide to fish. The preferred test species are rainbow trout (a coldwater fish) and bluegill sunfish (a warmwater fish). No acceptable acute freshwater fish studies have been submitted. These data are now required.

(2) Freshwater Fish, Chronic

A freshwater fish early life-stage (guideline 72-4) test is not required at this time because the Agency does not expect chronic aquatic exposure from zinc phosphide use. Once the acute toxicity testing is performed, the Agency will determine whether chronic testing is needed. The preferred test species is rainbow trout.

(3) Freshwater Invertebrates, Acute

A freshwater aquatic invertebrate toxicity test (guideline 72-2) using technical grade active ingredient is required to establish the toxicity of zinc phosphide to aquatic invertebrates. The preferred test species is *Daphnia magna*. No acceptable studies have been submitted.

3. Exposure and Risk Characterization

a. Primary Exposure and Risk to Nontarget Terrestrial Animals

Primary nontarget exposure is the ingestion of a toxicant by an animal other that the target species. The following table summarizes three non-guideline studies that address exposure and risk in field uses of zinc phosphide:

Primary Non-Target Exposure and Risk to Animals		
Study Name	**MRID**	**Conclusions**
Primary and secondary hazards of zinc phosphide to nontarget wildlife	42306201	Little non-target poisoning
Nontarget hazards to ring-necked pheasants and California quail	43586602	Broadcast application killed Ring-necked pheasants, but not California quail
Hazards to Pheasant and Cottontail rabbits associated with zinc phosphide	00005918	Nontarget mortality occurred

One submitted study reviewed the literature on zinc phosphide use submitted by the Animal and Plant Health Inspection Service of USDA (APHIS). These studies covered various habitats with various zinc phosphide poisoning regimes. Some studies were specifically designed to investigate the effects of zinc phosphide usage while others reported on it as incidental to their primary purpose. Mortality of nontarget rodents during the management of prairie dog and ground squirrel colonies from zinc phosphide applications was documented. Baiting in orchards produced mortality in rabbits, gallinaceous birds, and grain-eating passerine birds. Six birds of a group of 24 found dead in a sugar cane field that was treated with zinc phosphide were found to have eaten the bait. Mortality from zinc phosphide applications also was documented for deer, chickens, upland game birds, waterfowl, and aquatic invertebrates in Hawaii. Canada geese were killed in baited alfalfa enclosures.

The general finding is that after the experimenters put down poison, very few, if any, primary nontarget victims were discovered. Any bodies found were considered to be isolated occurrences of little importance and concluded that the populations were not effected. "Because many species of rodents are associated with prairie dog and ground squirrel colonies, several instances of mortality to these species from zinc phosphide applications have been documented. Most mortality to nontarget rodents, however, has been localized and involved only a few individuals." (MRID 42306201)

In another study, 2% zinc phosphide grain bait was applied by broadcast per label directions in 2-ha enclosures. Ring-necked pheasants were killed, but California quail were not because they did not eat the poisoned grain. The study did not address nontarget hazards to voles, but implies that voles would be killed as a nontarget species if they were in the treated areas. (MRID 43586602)

A separate study baited an orchard with air and ground broadcast equipment at a rate of five to ten pounds of zinc phosphide per acre. Intensive ground searches of 672 acres from day-1 to day-159 revealed that 1 of 5 radio tracked Ring-necked pheasants was killed by zinc phosphide. Four dead rabbits, 3 Deer mice and 1 Blue jay also were found to contain zinc phosphide residues. (MRID 00005918)

Generally the experimenters in the submitted studies distributed poison but didn't find any (or very few) primary nontarget victims. They considered any bodies they found to be isolated occurrences that were of little importance and concluded that the populations were not effected. The Agency does not necessarily agree with these conclusions but will consider the findings of these studies useful in risk assessments.

The reviewed literature suggests that waterfowl and some passerines appear to be relatively sensitive to zinc phosphide. It was also reported that many birds appear capable of distinguishing treated from untreated bait, and prefer untreated grain when given a choice. The study authors suggest several factors that influence the magnitude of effects, including prior exposure to untreated bait, nutritional condition of the bird when provided treated baits, availability of alternate food sources, and ability to regurgitate treated baits.

The Agency has concluded that the studies reviewed (including supplemental and published studies) show that the use of zinc phosphide in agricultural fields will likely kill nontarget birds and mammals. Zinc phosphide is a very toxic substance and will kill most animals to which it is administered. Rodents are more sensitive than carnivores. Although gallinaceous birds (pheasants, turkeys, other large terrestrial birds) are more sensitive than other avian species, some passerines such as Red-winged blackbirds are also sensitive.

b. Secondary Exposure/Risk to Nontarget Terrestrial Animals

If a target animal eats the toxicant and is subsequently eaten by a predator or a scavenger, secondary poisoning may occur to the predator or scavenger. The following table summarizes studies that have been submitted to address the extent of secondary poisoning that occurs with zinc phosphide:

Secondary Exposure and Risk to Animals			
Study Name	**MRID**	**Study Classification**	**Conclusions**
Primary and secondary hazards of Zinc phosphide to nontarget wildlife	42306201	Supplemental	Little nontarget poisoning, no secondary poisoning
Black-tailed prairie dog - domestic ferret secondary poisoning study	41507401	Core	no secondary poisoning, residues in stomach, ferrets regurgitated poison
Responses of Siberian ferrets to secondary Zinc phosphide poisoning	00151407	Core	Non-lethal acute intoxication of Siberian ferrets

One study presents a long list of LD_{50} and other toxicity tests done with zinc phosphide. Most of the experimenters conducted informal studies to use up excess specimens or were incidental to other studies. Although few of the LD_{50} or LC_{50} values are definitive, some may be useful as a guide. (MRID 42306201)

Secondary poisoning experiments have been conducted with a variety of carnivorous mammals and birds. The risk of secondary poisoning is low because zinc phosphide does not accumulate in the tissues of the target animals. The primary source of zinc phosphide to a carnivorous or scavenging animal is the digestive tract of the target animal, where unreacted zinc phosphide may remain. Most animals, when given a choice, refuse to eat the digestive tract of poisoned animals. Even if the digestive tract is eaten, the poison decomposes further in the digestive tract of the second animal. Zinc phosphide has a strong emetic action and frequently causes regurgitation. These studies concluded that, "secondary poisoning is reduced because mammalian predators appear to be less susceptible to zinc phosphide than other species."

One study reviewed studies conducted in various habitats with various zinc phosphide poisoning regimes. Some studies were specifically designed to investigate the effects of zinc phosphide usage while others report it as incidental to their primary purpose. The general finding is that the experimenters distributed poison, but uncovered few if any secondary or nontarget victims. The carcasses found were considered to be isolated occurrences and of little importance. The papers reviewed do not describe how intensively or extensively the experimenters searched for dead animals. None of the papers dealt with the mathematical reasoning behind the choice of poisoning regime, plot extent, or body search plan. (MRID 42306201)

The study comments on several reports of incidents involving zinc phosphide. However, the study authors could not prove that zinc phosphide was responsible for the kill, whether the kill was due to misuse or following outdated label instructions. "Many cases of secondary poisoning have involved cats and dogs, possibly because these species have been noted to consume stomach contents of poisoned animals in laboratory studies, whereas wild carnivores tend to avoid consuming the GI tract."

Matschke and Andrews (1990) found that: (1) No poisoning symptoms were observed in the ferrets that were fed the prairie dogs; (2) 96% of the zinc phosphide residues in the rodents were found in the stomach; (3) the ferrets regurgitated gavaged zinc phosphide; therefore, a good LD_{50} was not (and probably cannot) be determined. "The low amounts of zinc phosphide remaining in the carcasses and the absence of mortality, poisoning symptoms or emesis, in spite of the emetic properties of zinc phosphide, suggest that the risk of secondary poisoning from zinc phosphide is low." (MRID 41507401)

Hill and Carpenter's (1982) study demonstrated evidence of acute intoxication of Siberian ferrets fed zinc phosphide-poisoned rats. Overt evidence of acute intoxication was emesis by the ferrets. Subacute zinc phosphide toxicity in the ferrets was indicated by significant decreases in hemoglobin, cholesterol, and triglycerides. The study demonstrates that ferrets, or other species with a sensitive emetic reflex, may be afforded some degree of protection from secondary acute zinc phosphide poisoning due to its emetic action. However, the study also clearly demonstrates the potential for secondary exposure of nontarget animals to zinc phosphide. The study provides no data indicative of zinc phosphide residues to which predators and scavengers may be secondarily exposed, nor does it provide an indication of the relative sensitivity of Siberian ferrets to zinc phosphide poisoning. (MRID 00151407)

The Agency concludes that predators or scavengers who eat a target animal that has been killed by zinc phosphide will not be killed. They may become ill, listless, and regurgitate. Further studies on secondary poisoning are not necessary.

c. Exposure and Risk to Nontarget Freshwater Animals

The Agency presumes that aquatic exposure may occur from aerial and ground broadcasting of zinc phosphide baits, however, risk cannot be assessed until acceptable toxicity data are submitted. No presumption of risk to aquatic organisms is made for hand-placed applications, because minimal exposure of aquatic organisms is expected when baits are placed by hand.

d. Endangered Species Concerns

Zinc phosphide was addressed in the "U.S. Fish and Wildlife Service Biological Opinion March, 1993" document. That Opinion is based on zinc phosphide's use for control of rodents in/on orchards, rangeland, forests, vineyards, sugarcane, macadamia nuts, agricultural crops, ornamentals, lawns, golf courses, recreational areas, rights-of-way, animal burrows, and in and around all types of buildings. The Service made a "jeopardy" determination for 35 species that were determined to be potentially exposed from these uses. Of these 35 species, 29 (20 mammalian, 9 avian) were determined to be in a "jeopardy" status. Other species were considered either not at risk of exposure or not likely to be affected. See Section IV for a description of the Agency's Endangered Species Program policy.

IV. RISK MANAGEMENT AND REREGISTRATION DECISION

A. Determination of Eligibility

Section 4(g)(2)(A) of FIFRA calls for the Agency to determine, after submission of relevant data concerning an active ingredient, whether products containing the active ingredient are eligible for reregistration. The Agency has previously identified and required the submission of the generic (i.e. active ingredient specific) data required to support reregistration of products containing zinc phosphide as the active ingredient. The Agency has completed its review of these generic data, and has determined that the data are sufficient to support reregistration of products containing zinc phosphide. Appendix B identifies the generic data requirements that the Agency reviewed as part of its determination of reregistration eligibility of zinc phosphide, and lists the submitted studies that the Agency found acceptable.

The data identified in Appendix B were sufficient to allow the Agency to assess the registered uses of zinc phosphide and to determine that zinc phosphide, labeled and used as specified in this document, can be used without resulting in unreasonable adverse effects to humans and the environment. Therefore, the Agency finds that products containing zinc phosphide as the active ingredient are eligible for reregistration. The reregistration of particular products is addressed in Section V of this document.

The Agency made its reregistration eligibility determination based upon the target data base required for reregistration, the current guidelines for conducting acceptable studies to generate such data, published scientific literature, etc. and the data identified in Appendix B. Although the Agency has found that all uses of zinc phosphide are eligible for reregistration, it should be understood that the Agency may take appropriate regulatory action, and/or require the submission of additional data to support the registration of products containing zinc phosphide, if new information comes to the Agency's attention or if the data requirements for registration (or the guidelines for generating such data) change.

B. Determination of Eligibility Decision

1. Eligibility Decision

Based on the reviews of the generic data for the active ingredient zinc phosphide, the Agency has sufficient information on the health effects of zinc phosphide and on its potential for causing adverse effects in fish and wildlife and the environment. The Agency has determined that zinc phosphide products, labeled and used as specified in this Reregistration Eligibility Decision, will not pose unreasonable risks or adverse effects to humans or the environment. Therefore, the Agency concludes that all products containing zinc phosphide are eligible for reregistration.

2. Eligible and Ineligible Uses

The Agency has determined that all uses of zinc phosphide, as specified in this document, are eligible for reregistration. These uses include: indoor and outdoor residential and agricultural areas (including in and around homes, lawns, bulbs, in and around outside buildings/barns, rights-of-ways/fencerows/hedgerows), indoor and outdoor commercial or institutional premises and equipment, golf courses, reforestation areas. The following crop uses are eligible and are regarded as non-food uses because the application method and other label restrictions do not result in residues: alfalfa, barley, berries (dormant), oats, sugar maple, wheat, no-till corn, macadamia nut orchards, orchards/groves (post-harvest and dormant), timothy (hay). Food uses for zinc phosphide include: grapes, rangeland grasses and sugarcane. Artichokes and sugar beets have regional tolerances for use in California; currently there are no labels that include use on artichokes.

C. Regulatory Position

The following is a summary of the regulatory positions and rationales for zinc phosphide. Where labeling revisions are imposed, specific language is set forth in Section V of this document.

1. Food Quality Protection Act Findings

a. Determination of Safety for U.S. Population

EPA has determined that the established tolerances for zinc phosphide, with amendments and changes as specified in this document, meet the safety standards under the FQPA amendments to section 408(b)(2)(D) for the general population. In reaching this determination, EPA has considered the available information on the aggregate exposures (both acute and chronic) from non-occupational sources, food and drinking water.

For zinc phosphide, there is little likelihood of residues in water, on food items or processed food items and non-accidental residential exposure will be minimal. Therefore, no acute or chronic dietary, or drinking water, risk assessments were conducted and aggregate risk assessments are not necessary for zinc phosphide at this time.

Zinc phosphide, aluminum phosphide and magnesium phosphide all generate phosphine gas. The Agency believes the generation of phosphine should be considered as part of its aggregate assessment. Other chemicals may share a common mode of toxicity with phosphine gas. In general, after EPA develops a methodology for applying common mechanism of toxicity issues to risk assessments, the Agency will develop a process (either as part of the periodic review of pesticides or otherwise) to reexamine those tolerance decisions made earlier. However, with respect to zinc phosphide tolerance reassessment, any future cumulative risk determination regarding other chemicals that have a common mode of toxicity with phosphine will not include the uses of zinc phosphide discussed in this document because the exposures to phosphine from zinc phosphide are so unlikely. For the purposes of this decision, all zinc phosphide tolerances are assumed to be reassessed.

b. Determination of Safety for Infants and Children

EPA has determined that the established tolerances for zinc phosphide, with amendments and changes as specified in this document, meet the safety standards under the FQPA amendments to section 408(b)(2)(C) for infants and children. The safety determination for infants and children considers the factors noted above for the general population, but also takes into account the possibility of increased dietary exposure due to the specific consumption patterns of infants and children, as well as the possibility of increased susceptibility to the toxic effects of zinc phosphide residues in this population subgroup.

In determining whether or not infants and children are particularly susceptible to toxic effects from zinc phosphide residues, EPA considered the completeness of the database for developmental and reproductive effects, the nature and severity of the effects observed, and other information.

The toxicology data base, though adequate for the registration of a non-food use chemical, did not include a two-generation reproductive toxicity study in rats, nor did it include a developmental toxicity for a non-rodent species. The data provided no indication of increased sensitivity of fetal rats to *in utero* exposure to zinc phosphide. In the prenatal exposure developmental toxicity study in rats, no developmental effects were observed at the highest dose tested (4.0 mg/kg/day) that was shown to be maternally toxic (maternal deaths, decreased body weight and food consumption during treatment).

The Agency is not requiring these studies at this time because exposure from food sources is expected to be minimal to non-existent, however, the Agency established an RfD based on the anticipation that a chronic dietary risk assessment would be required. The RfD is 0.0001 mg/kg based on a subchronic oral study that showed no effects at 0.1 mg/kg. The Agency found, in its evaluation of dietary risk for zinc phosphide subsequent to the RfD determination, that no dietary or drinking water exposure will be expected and no risk assessment is necessary. Should a risk assessment be required in the future, due to treated food crops, an additional uncertainty factor of 10 would be applied to the Reference Dose calculation. This uncertainty factor would account for the extrapolation from subchronic to chronic exposure, the lack of reproductive toxicity data, and the lack of chronic toxicity data in a non-rodent species. The RfD of 0.0001 mg/kg reflects this additional uncertainty factor. If food uses showing dietary exposure are proposed for registration, a risk assessment will have to be performed. If risks are unacceptable using the current RfD, which reflects an additional uncertainty factor of 10, further studies will be required.

The Agency does not believe that exposure from the accidental ingestion of baits should be used in making the tolerance safety finding under FQPA. These exposures are accidental in nature and should not be considered as part of the FQPA calculus for non-occupational exposure. The dietary and drinking water contributions from zinc phosphide are negligible.

In deciding to continue to make reregistration determinations during the early stages of FQPA implementations, EPA recognizes that it will be necessary to make decisions relating to FQPA before the implementation process is complete. In making these early, case-by-case decisions, EPA does not intend to set broad precedents for the application of FQPA to its regulatory determinations. Rather, these early decisions will be made on a case-by-case basis and will not bind EPA as it proceeds with further policy development and rulemaking that may be required.

EPA may determine, as a result of this later implementation process, that any of the determinations described in this RED are no longer appropriate. In this case, the Agency will consider itself free to pursue whatever action may be appropriate, including but not limited to, reconsideration of any portion of this RED.

c. Effects to the Endocrine System

EPA is required to develop a screening program to determine whether certain substances (including all active ingredient pesticides and inerts) "may have an effect in humans that is similar to an effect predicted by a naturally occurring estrogen, or such other endocrine effect." The Agency is currently working with interested stakeholders, including other government agencies, public interest groups, industry and research scientists in developing a screening and testing program and a priority setting scheme to implement this program. Congress has allowed 3 years from the passage of FQPA (August 3, 1999) to implement this program. At that time, EPA may require further testing of this active ingredient and end-use products.

2. Benefits of Rodenticides

Toxic rodenticides are the most efficient available means for controlling existing infestations of large numbers of pest rodents. These agents also may be the method of choice in controlling certain smaller rodent infestations and often are needed to control individuals that cannot be removed by use of traps.

People control rodent pests primarily because these animals (1) are associated with the spread of many types of serious diseases; (2) bite humans; (3) damage private and commercial property; (4) destroy and contaminate millions of tons of agricultural crops annually, both in the field and in storage; and (5) are generally unwelcome in homes, schools, places of business, and other areas occupied or frequented by humans.

The diseases vectored by rodents include: plague, Rickettsial diseases (e.g., murine typhus, Rickettsialpox), leptospirosis, rat bite fever, Salmonellosis, hantavirus, Lyme disease, granulocytic Ehrlichosis, relapsing fever, and others. Rodents transmit diseases either directly or indirectly, via ectoparasites such as fleas, ticks or mites, or bodily waste products and secretions.

Many rodent-vectored diseases recently have been held in check through the private and public use of toxic rodenticides, along with other pest and disease control and management practices. Government agencies at times conduct rodent control programs in communities or parks, but actions of private citizens may affect the outcomes of such efforts significantly. Improved pest management, including coordination of rodenticide use and other rodent abatement practices, is a principal reason why numbers of cases and deaths associated with many rodent-vectored diseases have been much lower in the latter part of the twentieth century than was the case in prior decades. For example, there were 3,700 reported cases of murine typhus in the U.S. in 1942 but only 12 reported cases in 1987. In recent decades, however, "new" rodent-vectored diseases such as Lyme disease and hantavirus have emerged, primarily in rural and semi-rural areas in the U.S. Of these diseases, the HPS hantavirus strains appear to be the most serious, with a composite fatality rate of approximately 45% for the 170+ human cases reported since 1993.

Approximately 14,000 humans are bitten by rats each year. Recent information on this subject may not be available on a nationwide basis.

Rodents damage structures by gnawing on integral parts and as a result of contamination from bodily waste products and other secretions. Rodents can gnaw through wood, concrete, asphalt, sheet rock, plumbing, and soft metals. Rodent damage to electrical wiring has been cited as the probable cause for certain fires and explosions, as well as an instance of shutting down the Internet. When buildings, including residences, are heavily infested, poisoning generally is an integral component of successful abatement programs.

"Field" rodents such as ground squirrels, voles, and native mice and rats cause significant damage to crops and rangelands. Certain crops, such as sugarcane, are heavily damaged in the field by commensal rats and mice. Commensal rodent species are primarily responsible for vertebrate pest damage to stored food and feed in the U.S. Zinc phosphide plays an important role in the management of rodents associated with agricultural crops.

Commensal rats and mice are not particularly "liked" by humans. This circumstance may be a factor in rodenticide use, however, disease concerns and desires to protect self and property also are likely to be valid in most cases in which rodenticide baits are used.

Rodenticide baits also are used in certain special circumstances, such as managing or eradicating non-native rodent species at sites where such rodents jeopardize the continued existence of certain threatened or endangered species. Control programs of this nature are run by government agencies and typically are limited to offshore islands or other refuge areas.

3. Tolerance Reassessment

Tolerances for residues of zinc phosphide in/on plant commodities [40 CFR §180.284 (a) and (b)] are expressed in terms of phosphine resulting from use of zinc phosphide. The table following the tolerance discussion presents a summary of zinc phosphide tolerance reassessments as well as corrections to definitions of some commodities.

Tolerances Listed Under 40 CFR §180.284 (a)

Pending resolution of storage stability issues, adequate data are available to reassess the established tolerances for the following commodities, as defined: grapes, grasses (rangeland), and sugarcane.

Available sugarcane processing data suggest that tolerances for sugarcane processed fractions are not required. No grape processing data will be required, provided grape field trial samples were analyzed within 30 days of collection.

Tolerances Listed Under 40 CFR §180.284 (b)

Adequate data are available to reassess the established tolerances with regional registration, in accordance with 40 CFR §180.1 (n), for the following commodities, as defined: artichoke (globe), sugar beet (roots), and sugar beet (tops). Zinc phosphide is not presently registered for use on artichokes. If the registrant(s) wish to retain the tolerances with regional registration established for these commodities, then they must propose use directions reflecting the use patterns for which adequate residue data from the original tolerance petitions are available. Alternatively, registrant(s) may wish to register zinc phosphide products for non-food uses only with concurrent revocation of existing tolerances. Discussion of non-food uses appears under GLN 860.1200 in Section III of this RED.

Tolerances Needed as a Result of Uses in Food Handling Establishments

Some currently registered uses of zinc phosphide normally require tolerances and supporting data for Food Handling Establishment tolerances. Based on labeling restrictions for those products that are used in these areas, the Agency will waive this requirement provided that all products for use in food-handling establishments sufficiently restrict their application such that the use is considered non-food. Specific requirements have been outlined in Section IIIB and labeling in Section V.

Tolerance Reassessment Summary For Zinc Phosphide			
Commodity	**Current Tolerance (ppm)**	**Tolerance Reassessment (ppm)**	**Comment */ *[Correct Commodity Definition]***
Tolerances Listed Under 40 CFR §180.284 (a):			
Grapes	0.01	0.01	
Grasses (rangeland)	0.1	0.1	*[Grass, forage]*
Grasses (hay)		0.4	*[Grass, hay]*
Sugarcane	0.01	0.01	
Tolerances Listed Under 40 CFR §180.284 (b):			
Artichoke (globe)	0.01	0.01 **	*[Artichoke, globe]*
Sugar beet (roots)	0.04	0.04 **	*[Sugar beet, roots]*
Sugar beet (tops)	0.02	0.02 **	*[Sugar beet, tops]*

* All tolerance reassessments are tentative pending adequate resolution of storage stability issues.

** If the registrant(s) wish to retain the tolerances with regional registration established for these commodities, then they must propose use directions reflecting the use patterns for which adequate residue data from the original tolerance petitions are available. Alternatively, registrant(s) may register zinc phosphide products for non-food uses only with concurrent revocation of existing tolerances. For discussion of non-food uses see GLN 860.1200 in Section III. RED.

4. Codex Harmonization

No Codex MRLs have been established for zinc phosphide; therefore, issues of compatibility between Codex MRLs and U.S. tolerances do not exist.

5. Summary of Risk Management Decisions

a. Human Health

(1) Dietary

Acute Dietary

The Agency has determined that acute dietary exposure and risk associated with the use of zinc phosphide is negligible. Of those commodities designated as food uses for zinc phosphide, three were found to have detectable residues after application (grasses, sugar beets, sugarcane). Since these three crops are not direct human food items, acute dietary consumption is not expected.

Chronic Dietary (including cancer)

The Agency has determined that there will be no chronic dietary exposure or risk associated with the use of zinc phosphide. Residues are not expected on raw food items, as noted above. Also, zinc phosphide will not concentrate during the processing of any commodity because the act of processing will not allow for unreacted zinc phosphide to remain on the fractions. Since chronic exposure and risk associated with the use of zinc phosphide is negligible, no risk of cancer is expected from the use of zinc phosphide.

(2) Accidental Residential Exposure

Rodenticides, when used as currently sold and marketed, are associated with a high number of human incidents and accidental exposures each year. Although the number of incidents attributable to zinc phosphide is limited, EPA is concerned that the small numbers do not reflect a limited risk, but rather a limited market share in residential settings. Therefore, EPA remains concerned about the continued risk of exposure to humans, especially children, from rodenticides used in residential settings. For zinc phosphide, an MOE of 0.5 was determined for accidental ingestion of the bait formulation by a child. This calculation was based on an acute neurotoxicity study and an estimate of how much a child could accidentally ingest. Generally, the Agency considers an MOE of 100 or more to be protective of public health. The Agency has also determined that a single swallow of zinc phosphide bait may be fatal to a young child. There is also considerable trauma and expense associated with medical treatment of children thought to have been exposed to rodenticides. To mitigate the potential risk to children from accidental ingestion of baits, the Agency is requiring several mitigation measures that will be implemented in two phases that will be discussed shortly.

EPA expressed its concern regarding human exposures and incidents to rodenticides used in and around the home in PR Notice 94-7. This Notice, entitled Label Improvement Program for the Revision of Use Directions for Commensal Rodenticides and Statement of the Agency's Policies on the Use of Rodenticide Bait Stations, was issued by the Agency on September 16, 1994, and required registrants of certain rodenticide products that claimed to control commensal rodents to revise the labeling of such products to bear certain statements concerning "tamper-resistant bait stations." The Notice also informed rodenticide registrants, applicants, and other interested persons of EPA's continued concern for the safe use of rodenticides. Moreover, PR Notice 94-7 outlined EPA's policies regarding the isolation of commensal rodenticides from children, dogs, other pets, domestic animals, and non-target wildlife. PR Notice 94-7, in part, stated:

"Historically, more than 1000 incidents of human exposure to rodent poisons have been reported annually in the U.S. Numbers of human incidents reported have increased greatly in recent years with the advent of a new reporting network. In 1988, more than 10,000 rodenticide incidents were reported in the American Association of Poison Control Center's National Data Collection System. Nearly 90% of these cases involved children under six years of age. Nearly all of such exposures are classed as accidents. The human exposure incidents that are reported may represent less than half of those which occur. Well over 80% of reported human rodenticide exposures involve anticoagulant compounds.

Young children thought to have been exposed to rodenticides are often given some medical attention, although symptoms of poisoning usually are not observed, especially in cases involving anticoagulants which act very slowly. Although young children have been killed by rodenticides, most rodenticide-related deaths of humans result from intentional ingestions by persons much older than five years of age.

While reports summarizing incidents typically do not indicate exactly how exposures have occurred, it is likely that most accidents are related to improper use rather than to improper storage. Accidents of both types are preventable. EPA believes that the large numbers of exposure incidents provide evidence that current policies for promoting bait protection have not been sufficient and, therefore, that tougher, more explicit policies are needed. EPA has not been persuaded by contentions that the relatively low incidences of serious human illnesses caused by accidental exposures to compounds such as warfarin justify selective relaxations of requirements for bait protection..."

Risk to Household Pets

As with human exposures, EPA is concerned about the increased risk posed to non-target domestic animals to rodenticides used in and around the home. When used as currently sold and marketed, rodenticides account for a high number of non-target animal incidents and accidental exposures every year. PR Notice 94-7 stated in part that:

"Dog incidents account for more than 80% of the reported exposures of nontarget animals to commensal rodenticides. Most dog exposures are believed to be accidental. The annual number of incidents of animals being exposed to rodenticides is not known, but over 4,000 rodenticide-related inquiries were made to the Illinois Animal Poison information Center in each of the years from 1986 to 1988, with a high of 6,272 inquiries having been made in 1987.

Symptoms of rodenticide poisoning are detected more frequently in reported animal cases than in child cases. A larger percentage of asymptomatic exposures of animals may go undetected as pets and livestock generally are not watched as closely as children. Dogs may die as a result of rodenticide exposures, especially if acute poisons are involved.

Extended Vitamin K1 therapy may be needed for dogs that have been exposed to certain anticoagulants, such as brodifacoum or diphacinone, which are retained in the body for a relatively long time. For animal exposures reported in 1987 (and probably in other years as well), the animal's owner typically was the source of the rodenticide. Most of these exposures were accidental and occurred in or around human residences."

In the recent past, poison control centers have enhanced their ability to capture incident data. This improved data collection indicates that the high number of human unintentional or accidental exposures to rodenticides are not going down. From the number of exposures to children, it is clear that children younger than six years of age are at a disproportionately higher risk from the continued use of these products in and around the home. Based on these findings and the additional information on risk to household pets, EPA is requiring the risk mitigation measures in the following discussion.

(3) Accidental Residential Risk Mitigation

The Agency is requiring several risk mitigation measures for zinc phosphide products. The Agency is requiring the identical risk mitigation measures to the registrations of other rodenticide active ingredients such as warfarin and salts, difethialone, vitamin D-3, red squill, as well as those contained in the rodenticide cluster (brodifacoum, bromethalin, bromodiolone, chlorophacinone, diphacinone and salts, and pival and salts). As appropriate, these measures will also be required of registrations of new rodenticide active ingredients to be used in and around the home.

To address the risk concerns posed from the use of rodenticide products and still maintain the benefits afforded by their use, the Agency developed a two-phased approach minimizing exposure that is aimed particularly at protecting infants and children. The first phase is designed to address short-term measures that will aid in identifying when an actual exposure has occurred, to lessen the degree of such an exposure and to monitor exposures. The second phase will reduce the opportunity for exposures in the long term. Ideally, the Agency would have preferred to impose measures to immediately reduce opportunities for exposure, however, it recognizes that technologies may not exist and may need to be developed while maintaining the efficacy of the product. The Agency has developed the following phased approach to allow time for the development and testing of products that deliver bait and are packaged in such a way as to reduce exposure while maintaining sufficient efficacy.

During Phase I the Agency will require all zinc phosphide, non-agricultural products and products covered by the rodenticide cluster to incorporate indicator dye (to help identify whether a child or pet has actually consumed the pesticide) and bittering agents into their formulations. The indicator dye and bittering agent must be incorporated into all zinc phosphide products, other than those used exclusively in agricultural settings. During Phase II EPA will form a stakeholder group (including industry, states, various poison control centers, rodent control experts, the medical community and other interested parties) to develop additional means of significantly reducing exposures to children and pets. It is the Agency's intent that, within nine months or less from the issuance of the RED, the stakeholder group will issue its recommendations. Possible outcomes of this group include: requiring all rodenticide baits used in residential settings to be placed in disposable, child-resistant bait stations or equivalently protective mechanisms; development of an exhaustive educational and outreach program for consumers and enhanced training for certified applicators; tamper-resistant bait stations; and additional labeling improvements.

Indicator Dye and Bittering Agent

All registrants of rodenticides, other than those with products used exclusively at agricultural sites, must incorporate an indicator dye into their formulations. The dye is intended to help identify whether a child or household pet has actually consumed a rodenticide by dying their mouth and/or hands a bright color. EPA believes the dye will play a critical role in identifying when an exposure has occurred, thereby helping to determine if treatment is required. Typically, it is very difficult for parents and guardians of children and pet owners to discern whether an exposure or ingestion has actually occurred, which may lead to unnecessary treatment at a medical facility as a precautionary measure. In turn, the Agency believes this measure will also enable parents and guardians of children and pet owners to seek medical or veterinarian attention sooner rather than later and avoid a serious medical episode.

All registrants of rodenticides, other than those with products used exclusively at agricultural sites, must incorporate a bittering agent into their formulations to make the bait unpalatable to humans and household pets. EPA believes that the bittering agent will cause some children to expel the bait if placed in the mouth. The Agency is fully aware that children younger than one year old do not have fully formed taste buds and may not be fully protected by this measure. However, this measure should prevent some exposures to children older than one year of age. Likewise, the EPA is also aware that this measure may not affect exposures to non-target household animals.

The Agency is aware that all mitigation measures required during Phase I may not be feasible within the 8 month timeframe usually accorded by the RED process to submit labeling changes. While registrants will still be required to submit revised labeling as detailed in Section V within the 8 month timeframe, the Agency recognizes that the formulation changes required by the addition of the indicator dye and bittering agent may take longer. The Agency will work with registrants to establish a timeframe for the incorporation of the dye and bittering agent into rodenticide products at a meeting or through other means, prior to the initial stakeholder meeting. At such time, deadlines and submittal procedures for additional efficacy testing, if required, will also be addressed.

Improved Labeling Requirements

EPA is requiring a number of label revisions to rodenticides used in and around the home. These requirements are set forth in Section V of this RED document and are in addition to those required by PR Notice 94-7 that have already been implemented. The Agency is monitoring the outcome of the requirements in PR Notice 94-7 along with the measures required in this RED document, to determine their effectiveness in reducing the number of incidents and exposures to these pesticides.

Annual Submission of American Association of Poison Control Centers Data

Under the authority of FIFRA section 3(c)(2)(B), the Agency is requiring registrants of zinc phosphide subject to this RED document, to submit to the Agency annual American Association of Poison Control Centers' (AAPCC) data. The Agency is requiring AAPCC data for the years 1999 through 2009. These data will enable the Agency to determine whether the imposed risk mitigation measures are reducing incidents/exposures to humans, particularly children. AAPCC data obtained by the Agency for 1995 and 1996 will serve as baseline data. Registrants are encouraged to share the cost of generating data, whenever appropriate.

Stakeholders Meeting

As mentioned above, EPA will initiate a stakeholder meeting to discuss long-term exposure reduction measures (Phase II) and to decide on specific timing and other issues associated with bait dyes, bittering agents, and the content of a special label warning to users of rodenticides that children are particularly vulnerable to ingestion of baits. One such warning could be a large, red stop sign symbol, followed by "Children at risk. Use product only as specified on label." in large, bold lettering. As noted earlier, the stakeholder group may include rodenticide registrants (with zinc phosphide, rodenticide cluster, and new active ingredient products as well as those that may have previously undergone reregistration), states, various poison control centers, rodent control experts, the medical community and other interested parties. The first stakeholders meeting is expected to be held 120 days from the date of the issuance of this RED in Washington, DC. It is the Agency's intent that, within nine months or less from the issuance of the RED, the stakeholder group will conclude with its recommendations.

b. Environmental/Ecological Effects

Zinc phosphide has a high to very high primary toxicity to birds and small mammals. Field, pen and laboratory studies indicate that some birds and mammals are likely to be poisoned when exposed directly to zinc phosphide. Because of the mode of action, secondary poisoning is expected to be minimal. There is concern for primary exposure to non-targets from the field uses as well as those uses in/around homes and buildings. In an attempt to minimize these exposures the Agency will be requiring that all field uses of zinc phosphide remain classified as Restricted Use. Since data are not available to assess potential risks to aquatic organisms, these data are now required.

The Agency is concerned about zinc phosphide's potential effects on non-target animals, especially from the broadcast use. The Agency has determined that the adverse effects associated with this use are not unreasonable due to the benefits of broadcast applications of zinc phosphide. Many of the tracts of land that are treated with zinc phosphide are vast, making hand baiting infeasible. The Agency also believes that limiting the broadcast uses may indirectly encourage the use of other pesticides that are more hazardous to non-target animals than zinc phosphide. In addition, the available data do not show that hand-baiting will necessarily result in reduced exposure to non-target animals. Rather than impose specific use restrictions at this time, the Agency will continue its evaluation of the risks associated with hand baiting versus broadcast applications and may impose additional data requirements or label amendments at a later date.

The major route of degradation of zinc phosphide is hydrolysis, which results in the formation of phosphine and zinc ions, common nutrients in soil. Zinc phosphide and its residues do not appear to be persistent or mobile under most environmental conditions. When applied to dry soil environments, zinc phosphide may be moderately persistent. Zinc phosphide and its degradation products appear to have a low potential for ground water and surface water contamination.

c. Restricted Use Classification

Based on its toxicity and use patterns, the Agency is maintaining Restricted Use classification for all zinc phosphide products that are currently so classified. This includes all agricultural use and tracking powder products.

d. Endangered Species Statement

The Agency has developed a program (the "Endangered Species Protection Program") to identify pesticides whose use may cause adverse impacts on endangered and threatened species, and to implement mitigation measures that will eliminate the adverse impacts. At present, the program is being implemented on an interim basis as described in a Federal Register notice (54 FR 27984-28008, July 3, l989), and is providing information to pesticide users to help them protect these species on a voluntary basis. As currently planned, the final program will call for label modifications referring to required limitations on pesticide uses, typically as depicted in county-specific bulletins or by other site-specific mechanisms as specified by state partners. A final program, which may be altered from the interim program, will be described in a future Federal Register notice. The Agency is not imposing label modifications through the RED. Rather, any requirements for product use modifications will occur in the future under the Endangered Species Protection Program.

Zinc phosphide has been subject to a formal consultation with the Fish and Wildlife Service, as noted in Section III. Additional consultation with the Fish and Wildlife Service and/or the National Marine Fisheries Service may be necessary to determine if steps need to be taken to protect newly listed species or from proposed new uses of these pesticides.

e. Occupational/Residential Labeling Rationale

At this time, some products containing zinc phosphide are intended primarily for residential use and some are intended primarily for occupational use. The Worker Protection Standard (WPS) does not cover pesticides applied for control of vertebrate pests such as rodents. Therefore, all of the uses of zinc phosphide are NOT within the scope of WPS.

1. Requirements for Handlers

For each end-use product, personal protective equipment (PPE) and engineering control requirements for pesticide handlers are set during reregistration as follows:

- Based on risks posed to handlers by the active ingredient, EPA may establish active-ingredient specific (a.i. specific) handler requirements for end-use products containing that active ingredient. If such risks are minimal, EPA may choose not to establish a.i. specific handler requirements.

- EPA establishes handler PPE requirements for most end-use products, based on each product's acute toxicity characteristics.

- If a.i. specific requirements have been established, they must be compared to the PPE specified for the end-use product. The more stringent choice for each type of PPE (i.e., bodywear, hand protection, footwear, eyewear, etc.) must be placed on the label of the end-use product. Engineering controls are considered more stringent than PPE requirements.

For zinc phosphide products, EPA has considered each distinct formulation and is establishing, in this document, formulation-specific personal protective equipment and engineering control requirements for pesticide handlers.

(a) Occupational-Use Products

The Agency has concerns about occupational handlers mixing/loading/applying zinc phosphide tracking powders, concentrates, wettable powders and bait formulations not sold in tamper-resistant bait stations. EPA is concerned that such handlers may inhale fine particles or dusts that may become airborne during the handling and that such handlers may ingest zinc phosphide as a result of hand to mouth transfer of dusts or residues or as a result of swallowing fine particles that may become airborne during handling activities. For specific labeling requirements refer to Section V.

(b) Homeowner-Use Products

EPA is not establishing PPE requirements for homeowner handlers for zinc phosphide. In general, the Agency does not consider PPE requirements for homeowners to be practical or reliable risk-mitigation measures.

2. Post-Application/Entry Restrictions

EPA is not establishing post-application entry restrictions for any zinc phosphide end-use products.

3. Other Labeling Requirements

All products intended for use at residential sites must have label restrictions limiting their use to either outdoor underground sites or in areas that are inaccessible to children and pets.

The Agency is not requiring the same restrictions for uses of zinc phosphide in agricultural settings as for residential settings. The Agency does not anticipate the same types of exposures to children and pets in the agricultural areas; therefore, the current label restrictions are adequate and will be maintained.

The Agency is also requiring other use and safety information to be placed on the labeling of all end-use products containing zinc phosphide. For the specific labeling statements, refer to Section V of this document.

V. ACTIONS REQUIRED OF REGISTRANTS

This section specifies the data requirements and responses necessary for the reregistration of both manufacturing-use and end-use products.

A. Manufacturing-Use Products

1. Additional Generic Data Requirements

The generic data base supporting the reregistration of zinc phosphide for the eligible uses has been reviewed and determined to be substantially complete. The following data gaps remain and data are still required:

61-, 62- and 63- series product chemistry data

72-1a	Acute Fish Toxicity (bluegill sunfish)[1]
72-1c	Acute Fish Toxicity (rainbow trout)[1]
72-2	Acute Aquatic Invertebrate Toxicity[1]
171-3	Directions for Use[2]
171-4e	Storage Stability[3]
171-4k	Crop Field Trials[4]

The Agency is also requiring zinc phosphide registrants, as well as registrants of other rodenticides, to submit annual American Association of Poison Control Centers (AAPCC) data. The Agency is requiring AAPCC data for the years 1999 through 2009, which must be submitted to the Agency within one-year after the end of the reporting year. For example, 1999 AAPCC data must be submitted to the Agency on or before December 31, 2000. The American Association of Poison Control Centers is located at 3201 New Mexico Avenue, Suite 310, Washington, D.C. 20016. They can be reached by telephone on (202) 362-7217 and by fax on (202) 362-8377. The Agency encourages registrants to share the costs associated with data generation, whenever possible.

2. Labeling Requirements for Manufacturing-Use Products

To remain in compliance with FIFRA, manufacturing use product (MP) labeling must be revised to comply with all current EPA regulations, PR Notices and applicable policies. The MP labeling must bear the labeling contained in the table at the end of this section.

B. End-Use Products

1. Formulation Changes

All registrants of rodenticides must incorporate an Agency-approved indicator dye and bittering agent into their formulations. The Agency recognizes that the formulation changes required by the addition of the indicator dye and bittering agent may take longer than the eight months usually provided by the RED. The Agency will work with registrants to establish a timeframe for the incorporation of the dye and bittering agent into rodenticide products at a meeting, or through other means, prior to the initial stakeholder meeting. At such time, deadlines and submittal procedures for additional efficacy testing, if required, will also be addressed.

2. Stakeholder Meetings

The Agency is planning to hold the initial stakeholders meeting within 120 days from the issuance of this RED in Washington, DC. As mentioned earlier, these meetings will provide an open forum to develop workable mitigation measures to adequately protect children from accidental rodenticide exposures. For these meetings to be most efficient and successful, all interested parties and viewpoints will be welcomed and considered. The outcomes of these meetings will effect all rodenticide products with residential uses, including those that were previously reregistered and those that have been registered more recently and, hence, not subject to reregistration.

3. Additional Product-Specific Data Requirements

Section 4(g)(2)(B) of FIFRA calls for the Agency to obtain any needed product-specific data regarding the pesticide after a determination of eligibility has been made. Registrants must review previous data submissions to ensure that they meet current EPA acceptance criteria and if not, commit to conduct new studies. If a registrant believes that previously submitted data meet current testing standards, then study MRID numbers should be cited according to the instructions in the Requirement Status and Registrants Response Form provided for each product.

4. Timeframes

Phase One mitigation requirements include: (a) incorporating bittering agents and dyes into all end-use formulations, (b) submitting revised labeling reflecting revisions as discussed below. The Agency recognizes that the formulation changes required by the addition of the indicator dye and bittering agent may take longer than the eight months usually provided by the RED. The Agency will work with registrants to establish a time frame for the incorporation of the dye and bittering agent into rodenticide products at a meeting or through other means. At the same time, deadlines and submittal procedures for additional efficacy testing, if required, will also be addressed. The Agency expects these issues to be resolved prior to the initial stakeholder's meeting. Revised labeling and other product-specific data is due to the Agency within the regular 8-month time frame.

5. Labeling Requirements for End-Use Products

All end-use products should have clear, concise and complete labeling instructions. Proper labels can improve reader understanding, thereby reducing misuse and the potential for incidents. Towards this end, the Agency is requiring the following:

<u>Directions for Use:</u>

Directions for Use must be stated in terms that can be easily read and understood by the average person likely to use or to supervise the use of the pesticide. It must be presented in a format that is easy to understand and follow. The Directions for Use section of a pesticide label must provide the necessary information to answer four major categories regarding the use of the pesticide. These four questions are:

1) Why is the pesticide being used? For what pest(s) or problem?
2) Where is the pesticide applied? (Where should it not be applied?)
3) How is the pesticide applied (what special precautions must the user take? how much should they use?)
4) When should the pesticide be applied?

In addition, the Agency encourages the use of graphic symbols whenever possible, to clarify the written label.

<u>National Pesticide Telecommunications (NPTN) Hotline Number</u>

All zinc phosphide labels must refer consumers to the NPTN number for additional information. This reference must bear the labeling contained in the table at the end of this section.

<u>First Aid (Statement of Practical Treatment)</u>

The Agency is requiring that all labels with Statement of Practical Treatment sections be amended so that these sections are entitled, "First Aid." First aid statements must be brief, clear, simple and in straightforward language (conforming to the labeling required by the Agency) so that the average person can easily and quickly understand the instructions. These statements should be appropriate for all ages or, when necessary, should include distinctions between the treatments for different ages.

PR Notice 94-7

All end-use products intended for use in residential settings must include the labeling language as outlined in PR Notice 94-7. When the label requirements imposed by this RED, or those imposed by PR Notice 94-7, are redundant or inconsistent with currently accepted labels those conflicts should be resolved in consultation with the Agency.

(1) Formulation Specific PPE Requirements for this Active Ingredient:

The Agency is establishing formulation-specific PPE for all occupational uses of zinc phosphide end-use products. Remove any conflicting PPE requirements on the current labeling by eliminating the less stringent requirement.

(2) Placement in Labeling

The personal protective equipment requirements must be placed on the end-use product labeling in the section titled: "Hazards to Humans (and domestic animals)" immediately following the precautionary statements. The exact language listed in the table at the end of this section must be used.

a. Products Intended for Use on Field Crops, Orchards or Vineyards

Products labeled for all crop uses regarded as non-food uses because of application methods and timing of applications must include all restrictions, rates, etc. as outlined in the labeling table below. All State and Local Needs products must contain specific information regarding use sites and use directions to help avoid inappropriate use of these products.

C. Required Labeling Changes Summary Table

The following table summarizes the labeling requirements being imposed by this RED for all zinc phosphide products. Any use instructions on current labels that conflict with the below should be removed.

Summary Table of Required Labeling Changes for Zinc Phosphide Products		
Description	**Required Labeling**	**Placement**
Manufacturing use		
	"Only for formulation into a rodenticide for the following use(s) [fill blank only with those uses that are being supported by MP registrant]."	Directions for Use
One of these statements may be added to a label to allow reformulation of the product for a specific use or all additional uses supported by a formulator or user group	"This product may be used to formulate products for specific use(s) not listed on the MP label if the formulator, user group, or grower has complied with U.S. EPA submission requirements regarding support of such use(s)." "This product may be used to formulate products for any additional use(s) not listed on the MP label if the formulator, user group, or grower has complied with U.S. EPA submission requirements regarding support of such use(s)."	
Products Intended Primarily for Homeowner/Residential Use (generally, not marketed for use by professional applicators)		
Indoor sites	"Do not contaminate human or pet food preparation items or areas. Do not place near or inside ventilation duct openings."	Use Restrictions section in Directions for Use
Products Intended Primarily for Occupational Use (generally, not marketed for use by homeowners)		
	"Do not apply this product in a way that will contact workers or other persons, either directly or through drift. Only protected handlers may be in the area during application. Keep all other persons out of the treated area during application."	Use Restrictions section in Directions for Use
	"Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions for washables, use detergent and hot water. Keep and wash PPE separately from other laundry." "Users should remove PPE immediately after handling this product. Wash the outside of gloves before removing. As soon as possible, wash thoroughly and change into clean clothing." "Any person who retrieves carcasses or unused bait following application of this product must wear gloves."	Hazards to Humans (and domestic animals)

Summary Table of Required Labeling Changes for Zinc Phosphide Products		
Description	**Required Labeling**	**Placement**
Concentrate formulations that must be diluted prior to use (includes wettable powders and dusts, but does not apply to tracking powders)	"All handlers (including mixers, loaders and applicators) must wear: -- long-sleeve shirt and long pants, -- shoes plus socks, -- gloves, and mixers and loaders must wear a dust/mist filtering respirator (MSHA/NIOSH approval number prefix TC-21C) and protective eyewear."	Hazards to Humans (and domestic animals)
Tracking powder formulations	"All handlers, including mixers/loaders and applicators, must wear: -- long sleeve shirt and long pants, -- shoes plus socks, -- gloves, -- a dust/mist filtering respirator (MSHA/NIOSH approval number prefix TC-21C), and -- protective eyewear."	Hazards to Humans (and domestic animals)
Tracking powder formulations	"Tracking powder must be placed in locations not accessible to children, pets, domestic animals or non-target wildlife. If using this product in agricultural buildings where livestock feeds are stored, or in commercial food service, food manufacturing or food processing establishments, limit treatments to concealed, inaccessible places such as spaces between floors and walls. Do not apply tracking powder along walls, in corners or in open floor areas of rooms in which food or feed is handled or stored. Do not place tracking powder in areas where there is a possibility of contaminating water, food, feedstuffs, food or feed handling equipment, or milk or meat handling equipment or surfaces that come in direct contact with food. Do not place near or inside ventilation duct openings."	Use Restrictions section in Directions for Use
Pellets or bait formulations	"All handlers, including loaders and applicators, must wear: -- long sleeve shirt and long pants, -- shoes plus socks, and -- gloves. In addition, persons loading the pellets or baits into aircraft or mechanical ground equipment and persons loading/applying with a hand-pushed or hand-held equipment, such as a push-type spreader or cyclone spreader, must wear a dust/mist filtering respirator (MSHA/NIOSH approval number prefix TC-21C) and protective eyewear."	Hazards to Humans (and domestic animals)

Summary Table of Required Labeling Changes for Zinc Phosphide Products		
Description	**Required Labeling**	**Placement**
Products mixed or applied via equipment	"Do not contaminate water when disposing of equipment wash water or rinsate."	Environmental Hazard Statement
For use in indoor commercial establishments (does not apply to tracking powders)	"Do not use in edible product areas of food or feed processing plants, restaurants or other areas where food or feed is commercially prepared or processed. Do not contaminate food/feed or food/feed handling equipment or place near or inside ventilation duct openings."	Use Restrictions section in Directions for Use
Products with Crop Uses (required to maintain non-food classification)		
State and Local Needs (SLN) products	Must contain specific information regarding use sites and use directions	Use Restrictions section in Directions for Use
Alfalfa (seed crop)	"Apply only underground or in burrow builder."	
Alfalfa	"Apply only underground, in bait stations, or in burrow builder."	
Barley, Oats, Wheat	"Apply only underground or in burrow builder. Dormant season use only."	
Berry Production Areas	"Apply only underground, in bait stations, or in burrow builder. Apply bait in fair weather after harvest only while crop is in a nonbearing phase."	
Bulbs	"Do not apply in gardens and areas where food or feed may be contaminated."	
Corn, no-till	"For pre-plant or at-plant application only. Do not apply to areas inhabited by livestock. Do not graze animals in treated areas."	
Macadamia nut orchards	"Apply only by broadcast or in burrow builder. Do not graze animals in treated areas. Bait must be removed from trees prior to harvest.Do not broadcast over growing crop when bait may lodge in plant."	
Maple, sugar	"Apply only in bait stations. Stations must be placed so that the bait will not come in contact with the harvested commodity or the tubing that harvests the commodity."	
Orchards/groves	"Apply after harvest or anytime during the dormant season, but before tree growth begins in the Spring. Do not broadcast over non-orchard/non-grove crops. Do not graze animals on treated areas."	

Summary Table of Required Labeling Changes for Zinc Phosphide Products		
Description	**Required Labeling**	**Placement**
Timothy	"Apply only during crop dormancy. Do not apply over growing crops. Do not graze animals in treated areas."	Use Restrictions section in Directions for Use
Products with Crop Uses that Require a Tolerance		
Grapes Broadcast, ground	Must be applied at a rate of 0.12 - 0.2 lb a.i./A "Do not apply by air. Do not apply over growing crop when bait may lodge in plant. Do not graze animals on treated areas. Do not broadcast over growing crops other than sugarcane or over bare ground."	
Grapes Broadcast aerial	Must be applied at a rate of 0.08 - 0.19 lb a.i./A "Apply during the non-bearing season. Do not apply over growing crop when bait may lodge in plant. Do not graze animals on treated areas. Do not broadcast over growing crops other than sugarcane."	
Grasses, rangeland Broadcast bait Hand bait	Must be applied at a rate of 0.06 - 0.12 lb a.i./treated swath acre or 1 tsp/burrow at a maximum of 1 application/year "Apply only to rangeland with <50% ground cover."	Use Restrictions section in Directions for Use
Grasses, rangeland Hand bait (edge of mound/burrow or adjacent feeding area)	Must be applied at a rate of 1 tsp (4 g)/mound or burrow at a maximum of 1 application/year "Do not use in areas inhabited by livestock. Do not graze animals in treated areas. Do not apply where plants are grown for food or feed."	
Grasses, pasture Hand bait (edge of mound or adjacent feeding area)	Must be applied at a rate of 1 tsp (4 g)/mound or burrow at a maximum of 1 application/year "Do not use in areas inhabited by livestock."	

Summary Table of Required Labeling Changes for Zinc Phosphide Products		
Description	**Required Labeling**	**Placement**
Grasses (reseeding of rangeland/reforestation) Broadcast/aerial /gnd 20' swaths Hand baiting Trail builder	Must be applied at a rate of 0.11 - 0.18 lb a.i./A "Do not apply in areas where plants are being grown for food or feed or areas inhabited by livestock."	Use Restrictions section in Directions for Use
Sugarcane Broadcast Aerial/ground	Must be applied at a rate of 0.1 lb a.i./A with a maximum number of applications of 4 in a 36-month period. A 30-day pre-harvest interval is required. "Do not graze animals in treated areas."	
Sugarcane Broadcast Aerial/ground	Must be applied at a rate of 0.1 lb a.i./A with a maximum number of applications of 4 per 2-year cycle and 2 per 1-year cycle. A 90-day pre-harvest and a 30-day retreatment intervals are required.	
All Products		
	"For information on this pesticide product (including health concerns, medical emergencies, or pesticide incidents), call the National Pesticide Telecommunications Network at 1-800-858-7378." "Do not apply this product by any method not specified on this label."	Directions For Use
	"Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet." "Users should remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing."	User Safety Recommendations (directly below Hazards to Humans)
	"Do not apply directly to water, or to areas where surface water is present or to intertidal areas below the mean high-water mark." "Dogs and other predatory and scavenging mammals might be poisoned if they feed upon animals that have eaten this bait."	Environmental Hazard Statements

D. Existing Stocks

Registrants may generally distribute and sell products bearing old labels/labeling for 26 months from the date of the issuance of this Reregistration Eligibility Decision (RED). Persons other than the registrant may generally distribute or sell such products for 50 months from the date of the issuance of this RED. However, existing stocks time frames will be established case-by-case, depending on the number of products involved, the number of label changes, and other factors. Refer to "Existing Stocks of Pesticide Products; Statement of Policy"; Federal Register, Volume 56, No. 123, June 26, 1991.

The Agency has determined that registrants may distribute and sell zinc phosphide products bearing old labels/labeling for 26 months from the date of issuance of this RED. Persons other than the registrant may distribute or sell such products for 50 months from the date of the issuance of this RED. Registrants and persons other than registrants remain obligated to meet pre-existing Agency imposed label changes and existing stocks requirements applicable to products they sell or distribute.

VI. APPENDICES

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PRD Report Date: 07/02/96
APPENDIX A REPORT

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
The uses listed in Appendix A were evaluated for reregistration. The following uses do not include any changes to use patterns, such as application rates or frequency, that may be mandated by this RED document.													
FOOD/FEED USES													
AGRICULTURAL CROPS/SOILS (UNSPECIFIED)			Use Group: TERRESTRIAL FOOD+FEED CROP										
Bait application, When needed, Spoon	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
AGRICULTURAL DRAINAGE SYSTEMS			Use Group: AQUATIC FOOD CROP										
Bait application, When needed, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Planter/seed box	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
AGRICULTURAL RIGHTS-OF-WAY/FENCEROWS/HEDGEROWS			Use Group: TERRESTRIAL FOOD+FEED CROP										
Bait application, When needed, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Planter/seed box	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, When needed, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
AGRICULTURAL UNCULTIVATED AREAS			Use Group: TERRESTRIAL FOOD+FEED CROP										
Bait application, When needed, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

USES ELIGIBLE FOR REREGISTRATION

FOOD/FEED USES (con't)

AGRICULTURAL UNCULTIVATED AREAS (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.02 tbsp station	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, By hand	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
Bait application, When needed, Hand probe	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, Not on label	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	MT		
Bait application, When needed, Planter/seed box	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

USES ELIGIBLE FOR REREGISTRATION

FOOD/FEED USES (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
AGRICULTURAL UNCULTIVATED AREAS (con't) — Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	B/S	NA	.01 tbsp burrow	*	NS	NS	NS	NS	NS	NS	CA		
	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS	MT		
	P/T	NA	.04 Tsp burrow	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.0025 Tsp ft interval	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spreader	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
AGRICULTURAL/FARM STRUCTURES/BUILDINGS AND EQUIPMENT — Use Group: INDOOR FOOD													
Bait application, When needed, Bait box	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
AGRICULTURAL/FARM STRUCTURES/BUILDINGS AND EQUIPMENT (con't) Use Group: INDOOR FOOD (con't)													
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.01 Tsp application	*	NS	NS	NS	NS	NS	NS	CA		
	D	NA	.04246 lb placement	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.005 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.005 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait station. Use code BAB, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
Tracking powder, When needed, Duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand bulb duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand held duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Spoon	D	NA	.2068 Tsp application	*	NS	NS	NS	NS	30	NS			CAC, CAL

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USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
ALFALFA — Use Group: TERRESTRIAL FEED CROP													
Bait application, Dormant, Bait box	G	NA	UC	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	UC	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Not on label, Hand probe	B/S	NA	7.055E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	7.055E-04 lb burrow	*	NS	NS	NS	NS	NS	NS	WA		C14, C20, GE9
Bait application, Not on label, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS	WA		C14, C20, GE9
Bait application, When needed, Hand probe	P/T	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, When needed, Mechanical burrow builder	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	P/T	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait station. Use code BAB, Dormant, Bait box	B/S	NA	.005 lb station	*	NS	NS	NS	NS	NS	NS	WA		C20

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USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
APPLE — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, Postharvest, Glove	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C92, CAL, G03
Bait application, Postharvest, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C92, CAL, G03
Bait application, Postharvest, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C92, CAL, G03
Bait application, Postharvest, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C92, CAL, G03
BARLEY — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
BLACKBERRY — Use Group: TERRESTRIAL FOOD CROP													
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
BLUEBERRY — Use Group: TERRESTRIAL FOOD CROP													
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
BOYSENBERRY — Use Group: TERRESTRIAL FOOD CROP													
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
CORN (UNSPECIFIED) — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, At planting, Planter/seed box	B/S	NA	.12 lb A	*	1	NS	NS	NS	NS	NS	OH		

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USES ELIGIBLE FOR REREGISTRATION

FOOD/FEED USES (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. @ Max. Dose	Max. # Apps /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
CORN (UNSPECIFIED) (con't)			Use Group: TERRESTRIAL FOOD+FEED CROP (con't)										
Bait application, Preplant, Aircraft	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	IN		
	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	OH		
Bait application, Preplant, Mechanical granule applicator	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	IN		
	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	OH		
Bait application, Preplant, Spreader	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	IN		
	B/S	NA	.2 lb A	*	2	NS	NS	NS	15	NS	OH		
FRUITS (UNSPECIFIED)			Use Group: TERRESTRIAL FOOD+FEED CROP										
Bait application, Nurserystock, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nurserystock, Spoon	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
GOOSEBERRY			Use Group: TERRESTRIAL FOOD CROP										
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
GRAPES			Use Group: TERRESTRIAL FOOD+FEED CROP										
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
GRAPES (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Foliar, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Foliar, Spreader	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03

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USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
GRAPES (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Postharvest, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Postharvest, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, CAC, CAL, G03
Bait application, When needed, Spreader	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C40, CAC, CAL, G03
GRASS FORAGE/FODDER/HAY Use Group: TERRESTRIAL FEED CROP													
Bait application, When needed, Spoon	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC

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USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
LAKES/PONDS/RESERVOIRS (WITH HUMAN OR WILDLIFE USE) Use Group: AQUATIC FOOD CROP													
Bait application, When needed, Ground	D	NA	UC	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
Bait application, When needed, Tray	D	NA	.06688 lb application	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
MACADAMIA NUT (BUSHNUT) Use Group: TERRESTRIAL FOOD CROP													
Bait application, Foliar, Aircraft	P/T	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAL, CAU, G03, H01(30)
Bait application, Foliar, Bait box	P/T	NA	.04 Tsp tree	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, G03, H01(30)
Bait application, Foliar, By hand	B/S	NA	.1 lb A	*	4	NS	NS	.4 lb	NS	NS			C20, C66, CAA, CAG, CAL, H01(30)
Bait application, Foliar, Glove	P/T	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAL, CAU, G03, H01(30)
Bait application, Foliar, Not on label	P/T	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, G03, H01(30)
Bait application, Foliar, Spoon	B/S	NA	3.527E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL, H01(0)
	P/T	NA	.04 Tsp tree	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, G03, H01(30)
	P/T	NA	.04 Tsp tree	*	NS	NS	NS	.4 lb	NS	NS			C20, CAL, CAU, G03, H01(30)
Bait application, Foliar, Spreader	B/S	NA	.1 lb A	*	4	NS	NS	.4 lb	NS	NS			C20, C66, CAA, CAG, CAL, H01(30)
	P/T	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAL, CAU, G03, H01(30)

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USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
MACADAMIA NUT (BUSHNUT) (con't) — Use Group: TERRESTRIAL FOOD CROP (con't)													
Bait application, Preharvest, Glove	G	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, C92, CAL, CCD(4), H01(30)
	G	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, CCD(4), G03, H01(30)
Bait application, Preharvest, Ground	G	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, C92, CAL, CCD(4), H01(30)
	G	NA	.1 lb A	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, CCD(4), G03, H01(30)
Bait application, When needed, Glove	D	NA	.1061 lb A	*	NS	NS	12.64 lb	NS	30	NS	HI		C20, C40, C92, CAL, CCD(4), H01(30)
Bait application, When needed, Ground	D	NA	.04246 lb burrow	*	NS	NS	12.64 lb	NS	30	NS	HI		C20, C40, C92, CAL, CCD(4), H01(30)
OATS — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
ORCHARDS (UNSPECIFIED) — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, Dormant, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
ORCHARDS (UNSPECIFIED) (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
Bait application, Dormant, Glove	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
ORCHARDS (UNSPECIFIED) (con't) — Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Dormant, Tray	P/T	NA	.00625 lb tree	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.003125 lb tree	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL, G03
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
Bait application, Postharvest, Glove	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS	AK, CA, MT, NM, PR, TX, UT		C20, CAG, CAL, CAU, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
ORCHARDS (UNSPECIFIED) (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	D	NA	UC	*	NS	NS	NS	NS	NS	NS			CAC, CAL, CDB, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, Helicopter	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Postharvest, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Postharvest, Planter/seed box	B/S	NA	.1092 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
Bait application, Postharvest, Spoon	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
ORCHARDS (UNSPECIFIED) (con't) — Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL, G03
	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Postharvest, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL, CAU, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, Tray	P/T	NA	.00625 lb tree	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.003125 lb tree	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
PASTURES — Use Group: TERRESTRIAL FEED CROP													
Bait application, Fall, Aircraft	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Fall, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Fall, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
RANGELAND — Use Group: TERRESTRIAL FEED CROP													
Bait application, Early fall, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20
Bait application, Early summer, Spoon	B/S	NA	.0188 Tsp burrow	*	NS	1/1 yr	NS	NS	NS	NS	CO, MT, AZ, NM, TX, OK, KS, NE, ND, SD		C20, CAC, CAL, G03
Bait application, Fall, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Fall, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Fall, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex.	Max. Dose	Max. # Apps @ Max. Rate /crop cycle /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
RANGELAND (con't) — Use Group: TERRESTRIAL FEED CROP (con't)													
	G	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, C92, CAL
	G	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAC, CAL, G03
Bait application, Fall, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Fall, Spoon	B/S	NA	.0752 lb A	*	NS	1/1 yr	NS	NS	NS	NS	CO, MT, AZ, NM, TX, OK, KS, NE, ND, SD		C20, CAC, CAL, G03
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	017, ND, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY		C20, C66, CAA, CAG, CAL
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	MT, ND, NE, SD, WY		C20, CAG, CAL
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	ND, SD, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY		C20, C92, CAL
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	P/T	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAC, CAL, G03

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
RANGELAND (con't) Use Group: TERRESTRIAL FEED CROP (con't)													
	P/T	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY, AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAL, CAU, G03
Bait application, Fall, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Late spring, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20
Bait application, Late spring, Spoon	B/S	NA	.0188 Tsp burrow	*	NS	1/1 yr	NS	NS	NS	NS	CO, MT, AZ, NM, TX, OK, KS, NE, ND, SD		C20, CAC, CAL, G03
Bait application, Late summer, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20
Bait application, Late summer, Spoon	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	017, ND, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY		C20, C66, CAA, CAG, CAL
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	MT, ND, NE, SD, WY		C20, CAG, CAL
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	ND, SD, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY		C20, C92, CAL

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USES ELIGIBLE FOR REREGISTRATION

FOOD/FEED USES (con't)

RANGELAND (con't) Use Group: TERRESTRIAL FEED CROP (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
	P/T	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAC, CAL, G03
	P/T	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY, AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAL, CAU, G03
Bait application, Spring, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Spring, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Spring, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Spring, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Summer, Glove	G	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, C92, CAL
	G	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAC, CAL, G03
Bait application, When needed, Glove	G	NA	1.764E-04 lb spot	*	NS	NS	NS	NS	NS	NS	MT		CAC, CAL, CCD(1)
Bait application, When needed, Mechanical burrow builder	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS	CO, MT, AZ, NM, TX, OK, KS, NE, ND, SD, 013, 017		C20, C66, CAC, CAL, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
RANGELAND (con't) Use Group: TERRESTRIAL FEED CROP (con't)													
Bait application, When needed, Not on label	B/S	NA	.12 lb A	*	1	NS	NS	NS	NS	NS	MT		
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
	B/S	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	017, ND, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY		C20, C66, CAA, CAG, CAL
	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS	CO, MT, AZ, NM, TX, OK, KS, NE, ND, SD, 013, 017		C20, C66, CAC, CAL, G03
	G	NA	1.764E-04 lb spot	*	NS	NS	NS	NS	NS	NS	MT		CAC, CAL, CCD(1)
	P/T	NA	.001058 lb mound	*	NS	NS	NS	NS	NS	NS	AZ, CO, KS, MT, NE, NM, ND, OK, SD, TX, UT, WY		C20, CAL, CAU, G03
RASPBERRY (BLACK, RED) Use Group: TERRESTRIAL FOOD CROP													
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
STORAGE AREAS-FULL — Use Group: INDOOR FOOD													
Bait application, When needed, Bait box	B/S	NA	.02 tbsp station	*	NS	NS	NS	NS	NS	NS			C20, CAG, CAL
STRAWBERRY — Use Group: TERRESTRIAL FOOD CROP													
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C40, C92, CAL
STREAMS/RIVERS/CHANNELED WATER — Use Group: AQUATIC FOOD CROP													
Bait application, When needed, Ground	D	NA	UC	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
Bait application, When needed, Tray	D	NA	.06688 lb application	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
SUGAR BEET — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, When needed, Aircraft	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS	CA		C20, C92, CAL, CCC(2), G03, H01(30)
Bait application, When needed, Spreader	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS	CA		C20, C92, CAL, CCC(2), G03, H01(30)
SUGAR MAPLE — Use Group: TERRESTRIAL FOOD CROP													
Bait station. Use code BAB, When needed, Bait box	B/S	NA	.03 lb A	*	NS	NS	NS	NS	NS	NS	VT		
SUGARCANE — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, Foliar, Aircraft	B/S	NA	.094 lb A	*	4	NS	.376 lb	NS	NS	NS	FL, HI		C20, CAC, CAL, G03, H01(30)
	B/S	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, C66, CAA, CAG, CAL, H01(30)

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
SUGARCANE (con't) Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	B/S	NA	.1 lb A	*	NS	2/1 yr	.4 lb	NS	30	NS			C92, CAL, H01(90)
	P/T	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, CAL, CAU, G03, H01(30)
	P/T	NA	.1 lb A	*	NS	NS	.4 lb	NS	NS	NS			C20, CAC, CAL, G03, H01(30)
Bait application, Foliar, By hand	B/S	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, C66, CAA, CAG, CAL, H01(30)
	B/S	NA	.1 lb A	*	NS	2/1 yr	.4 lb	NS	30	NS			C92, CAL, H01(90)
Bait application, Foliar, Glove	P/T	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, CAL, CAU, G03, H01(30)
	P/T	NA	.1 lb A	*	NS	NS	.4 lb	NS	NS	NS			C20, CAC, CAL, G03, H01(30)
Bait application, Foliar, Spreader	B/S	NA	.094 lb A	*	4	NS	.376 lb	NS	NS	NS	FL, HI		C20, CAC, CAL, G03, H01(30)
	B/S	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, C66, CAA, CAG, CAL, H01(30)
	B/S	NA	.1 lb A	*	NS	2/1 yr	.4 lb	NS	30	NS			C92, CAL, H01(90)
	P/T	NA	.1 lb A	*	4	NS	.4 lb	NS	NS	NS			C20, CAL, CAU, G03, H01(30)
	P/T	NA	.1 lb A	*	NS	NS	.4 lb	NS	NS	NS			C20, CAC, CAL, G03, H01(30)
Bait application, When needed, Aircraft	D	NA	.1061 lb A	*	NS	NS	12.64 lb	NS	30	NS			C20, C92, CAL, CCC(4), H01(30)

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
SUGARCANE (con't) — Use Group: TERRESTRIAL FOOD+FEED CROP (con't)													
	G	NA	UC	*	NS	NS	NS	.4 lb	NS	NS			C20, C92, CAL, CCC(4), H01(30)
	G	NA	UC	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, CCC(4), G03, H01(30)
Bait application, When needed, Glove	D	NA	.1061 lb A	*	NS	NS	12.64 lb	NS	30	NS			C20, C92, CAL, CCC(4), H01(30)
	G	NA	UC	*	NS	NS	NS	.4 lb	NS	NS			C20, C92, CAL, CCC(4), H01(30)
	G	NA	UC	*	NS	NS	NS	.4 lb	NS	NS			C20, CAC, CAL, CCC(4), G03, H01(30)
Bait application, When needed, Ground	D	NA	.1061 lb A	*	NS	NS	12.64 lb	NS	30	NS			C20, C92, CAL, CCC(4), H01(30)
TIMOTHY — Use Group: TERRESTRIAL FEED CROP													
Bait application, Dormant, Bait box	G	NA	UC	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	UC	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait station. Use code BAB, Dormant, Bait box	B/S	NA	.005 lb station	*	NS	NS	NS	NS	NS	NS	WA		C20
VEGETABLES (UNSPECIFIED) — Use Group: TERRESTRIAL FOOD+FEED CROP													
Bait application, When needed, Spoon	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
FOOD/FEED USES (con't)													
WHEAT	Use Group: TERRESTRIAL FOOD+FEED CROP												
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	1	NS	NS	NS	NS	NS	MT		
NON-FOOD/NON-FEED													
COMMERCIAL/INSTITUTIONAL/INDUSTRIAL PREMISES/EQUIP. (INDOOR)	Use Group: INDOOR NON-FOOD												
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	D	NA	.04246 lb placement	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.04 Tsp placement	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.04 Tsp placement	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Tracking powder, When needed, Duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
COMMERCIAL/INSTITUTIONAL/INDUSTRIAL PREMISES/EQUIP. (INDOOR) (con't) Use Group: INDOOR NON-FOOD (con't)													
Tracking powder, When needed, Hand bulb duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand held duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Spoon	D	NA	.2068 Tsp application	*	NS	NS	NS	NS	30	NS			CAC, CAL
COTTONWOOD (FOREST/SHELTERBELT) Use Group: FORESTRY													
Bait application, When needed, Aircraft	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Glove	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Spoon	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Spreader	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
DRAINAGE SYSTEMS Use Group: AQUATIC NON-FOOD INDUSTRIAL													
Bait application, Late spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Late spring, Glove	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Late spring, Spoon	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL

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USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
DRAINAGE SYSTEMS (con't) Use Group: AQUATIC NON-FOOD INDUSTRIAL (con't)													
Bait application, Late spring, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Spring, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, Glove	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, Spoon	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

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USES ELIGIBLE FOR REREGISTRATION

NON-FOOD/NON-FEED (con't)

DRAINAGE SYSTEMS (con't) Use Group: AQUATIC NON-FOOD INDUSTRIAL (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
Bait application, When needed, By hand	B/S	NA	.0752 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL, G03
Bait application, When needed, Spreader	B/S	NA	.0752 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL, G03

FOREST PLANTINGS (REFORESTATION PROGRAMS)(TREE FARMS, TREE PLANTATIONS Use Group: FORESTRY

SITE Application Type, Application Timing, Application Equipment	Form(s)	Min. Appl. Rate	Max. Appl. Rate	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
Bait application, Fall, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
	D	NA	.2123 lb A	*	NS	NS	NS		NS	30	NS		C20, C92, CAL
Bait application, Fall, By hand	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Fall, Glove	D	NA	.2123 lb A	*	NS	NS	NS		NS	30	NS		C20, C92, CAL
Bait application, Fall, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Fall, Spoon	D	NA	.2123 lb A	*	NS	NS	NS		NS	30	NS		C20, C92, CAL
Bait application, Fall, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Spring, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Spring, By hand	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Spring, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Spring, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Aircraft	G	NA	.2 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Glove	G	NA	.2 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Spoon	G	NA	.2 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Spreader	G	NA	.2 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL

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USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
FOREST TREES (ALL OR UNSPECIFIED) Use Group: FORESTRY													
Bait application, When needed, Aircraft	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS	013, 017		C20, C66, CAC, CAL, G03
Bait application, When needed, Spoon	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS	013, 017		C20, C66, CAC, CAL, G03
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Spreader	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
FRUITS (UNSPECIFIED) Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Nonbearing, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nonbearing, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Nonbearing, Glove	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nonbearing, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
FRUITS (UNSPECIFIED) (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nonbearing, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Nonbearing, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
GOLF COURSE TURF Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, When needed, Aircraft	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		CA	C20, CAC, CAL
Bait application, When needed, By hand	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		CA	C20, CAC, CAL
Bait application, When needed, Hand probe	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
GOLF COURSE TURF (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
Bait application, When needed, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Spoon	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.02 Tsp mound .091 lb A	* *	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAA, CAG
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAB
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAG
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
GOLF COURSE TURF (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		CA	C20, CAC, CAL
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, C92, CAL
Bait application, When needed, Spreader	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		CA	C20, CAC, CAL
HOUSEHOLD/DOMESTIC DWELLINGS Use Group: INDOOR RESIDENTIAL													
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	D	NA	.04246 lb placement	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.005 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

USES ELIGIBLE FOR REREGISTRATION

NON-FOOD/NON-FEED (con't)

HOUSEHOLD/DOMESTIC DWELLINGS (con't) Use Group: INDOOR RESIDENTIAL (con't)

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
	G	NA	.005 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Tracking powder, When needed, Duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand bulb duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand held duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Spoon	D	NA	.2068 Tsp application	*	NS	NS	NS	NS	30	NS			CAC, CAL
HOUSEHOLD/DOMESTIC DWELLINGS OUTDOOR PREMISES Use Group: OUTDOOR RESIDENTIAL													
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
HOUSEHOLD/DOMESTIC DWELLINGS OUTDOOR PREMISES (con't) Use Group: OUTDOOR RESIDENTIAL (con't)													
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	P/T	NA	.04 Tsp burrow	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.0025 Tsp ft interval	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
LAKES/PONDS/RESERVOIRS (WITHOUT HUMAN OR WILDLIFE USE) Use Group: AQUATIC NON-FOOD INDUSTRIAL													
Bait application, When needed, Ground	D	NA	UC	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
Bait application, When needed, Tray	D	NA	.06688 lb application	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
NONAGRICULTURAL OUTDOOR BUILDINGS/STRUCTURES Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spoon	B/S	NA	.04 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp burrow	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.0025 Tsp ft interval	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU

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USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
NONAGRICULTURAL RIGHTS-OF-WAY/FENCEROWS/HEDGEROWS — Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Late spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Late spring, Glove	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Late spring, Spoon	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Late spring, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	CA, NV, OR		C20, C92, CAL
Bait application, Spring, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	CA, NV, OR		C20, C92, CAL
Bait application, Summer, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	CA, NV, OR		C20, C92, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, Glove	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	CA, NV, OR		C20, C92, CAL

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USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
NONAGRICULTURAL RIGHTS-OF-WAY/FENCEROWS/HEDGEROWS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
Bait application, Summer, Spoon	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, By hand	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Spoon	B/S	NA	.02 Tsp mound .091 lb A	* *	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Spreader	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
NONAGRICULTURAL UNCULTIVATED AREAS/SOILS Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Dormant, Bait box	G	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Early fall, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
NONAGRICULTURAL UNCULTIVATED AREAS/SOILS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
Bait application, Fall, Glove	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Fall, Helicopter	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Fall, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Late spring, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20
Bait application, Late summer, Glove	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		
	B/S	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS	WY		C20
Bait application, Not on label, Spreader	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Spring, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, Summer, Ground	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
Bait application, When needed, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes

))USES ELIGIBLE FOR REREGISTRATION

NON-FOOD/NON-FEED (con't)
))NONAGRICULTURAL UNCULTIVATED AREAS/SOILS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)

SITE Application Type, Application Timing, Application Equipment	Form(s)	Min. Appl. Rate	Max. Appl. Rate	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Allowed	Disallowed	Use Limitations Codes
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, By hand	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAC, CAL, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
Bait application, When needed, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	D	NA	.06688 lb burrow	*	NS	NS	NS	NS	NS	NS	TX		C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	G	NA	.06688 lb burrow	*	NS	NS	NS	NS	NS	NS	ID, ID		C20, CAC, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Hand probe	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	7.055E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, When needed, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, C66, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

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USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
NONAGRICULTURAL UNCULTIVATED AREAS/SOILS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	P/T	NA	.06 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAL, CAU, G03
Bait application, When needed, Not on label	B/S	NA	.12 lb A	*	NS	NS	NS		NS	NS	NS	MT	
Bait application, When needed, Spoon	B/S	NA	.02 Tsp burrow	*	NS	NS	NS		NS	30	NS		C66, CAC, CAL
	B/S	NA	.02 Tsp mound	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS		NS	NS	NS		C66
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS		NS	NS	NS		C66, CAA, CAG
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS		NS	NS	NS		C66, CAB
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		C66, CAC
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS		NS	NS	NS		C66, CAG
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		CAC
	B/S	NA	.01 tbsp burrow	*	NS	NS	NS		NS	NS	NS	CA	
	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS		NS	NS	NS	MT	
	D	NA	.2123 lb A	*	NS	NS	NS		NS	30	NS		C20, C92, CAL

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USES ELIGIBLE FOR REREGISTRATION														
NON-FOOD/NON-FEED (con't)														
NONAGRICULTURAL UNCULTIVATED AREAS/SOILS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)														
	D	NA	.06688 lb burrow	*	NS	NS	NS	NS	NS	NS		TX		C20, C92, CAL
	G	NA	.06688 lb burrow	*	NS	NS	NS	NS	NS	NS		ID, ID		C20, CAC, CAL
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS				C66, CAL, CAU
	P/T	NA	1.764E-04 lb mound	*	NS	NS	NS	NS	NS	NS				C20, CAL, CAU, G03
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS				C66, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		WA		C20, C92, CAL
Bait application, When needed, Spreader	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS				C20, C66, CAC, CAL, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		CA		
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS				C20, CAC, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS		OR		C20, C92, CAL
ORNAMENTAL AND/OR SHADE TREES Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL														
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS				C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS				C20, CAC, CAL, G03
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS				C20, CAC, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL AND/OR SHADE TREES (con't) Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)													
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Nurserystock, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Nurserystock, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nurserystock, Spoon	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nurserystock, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL AND/OR SHADE TREES (con't)			Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)										
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
ORNAMENTAL HERBACEOUS PLANTS			Use Group: TERRESTRIAL NON-FOOD CROP										
Bait application, When needed, Spoon	B/S	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
			Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL										
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL HERBACEOUS PLANTS (con't) — Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)													
Bait application, Dormant, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Nurserystock, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nurserystock, Spoon	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	UC	*	NS	NS	NS	NS	NS	NS			C66, CAA, CAG
	B/S	NA	UC	*	NS	NS	NS	NS	NS	NS			C66, CAG
	P/T	NA	UC	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
	P/T	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
ORNAMENTAL LAWNS AND TURF — Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, When needed, Hand probe	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL LAWNS AND TURF (con't)			Use Group: TERRESTRIAL NON-FOOD CROP (con't)										
Bait application, When needed, Spoon	B/S	NA	.02 Tsp mound	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
			Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL										
Bait application, When needed, Aircraft	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, By hand	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Spoon	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAA, CAG
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAB
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL LAWNS AND TURF (con't) — Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)													
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAG
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, C92, CAL
Bait application, When needed, Spreader	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
ORNAMENTAL NONFLOWERING PLANTS — Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL													
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex.	Max. # Apps @ Max. Dose	Max. # Apps /crop cycle	Max. # Apps /year	Max. Dose [(AI Rate unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
))))))))))USES ELIGIBLE FOR REREGISTRATION														
NON-FOOD/NON-FEED (con't)														
))))))))))ORNAMENTAL NONFLOWERING PLANTS (con't) Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)														
Bait application, Dormant, Spreader	B/S	NA	.182 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	NS	NS		NS		NS	NS	NS		C20, C66, CAA, CAG, CAL
	P/T	NA	1.764E-04 lb burrow	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL, G03
	P/T	NA	.02 Tsp burrow	*	NS	NS		NS		NS	NS	NS		C20, CAL, CAU, G03
ORNAMENTAL WOODY SHRUBS AND VINES Use Group: TERRESTRIAL NON-FOOD CROP														
Bait application, When needed, Spoon	B/S	NA	.02 Tsp mound	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL														
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL, G03
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL, G03
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
	B/S	NA	.188 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL, G03
Bait application, Dormant, Spreader	B/S	NA	.182 lb A	*	NS	NS		NS		NS	NS	NS		C20, CAC, CAL
Bait application, Nurserystock, Glove	G	NA	.2 lb A	*	NS	NS		NS		NS	NS	NS		C20, C92, CAL

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
ORNAMENTAL WOODY SHRUBS AND VINES (con't) Use Group: TERRESTRIAL NON-FOOD+OUTDOOR RESIDENTIAL (con't)													
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Nurserystock, Spoon	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, C92, CAL
	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Postharvest, Glove	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, Postharvest, Spoon	D	NA	.2123 lb A	*	NS	NS	NS	NS	30	NS			C20, C92, CAL
Bait application, When needed, Spoon	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
POPLAR (FOREST/SHELTERBELT) Use Group: FORESTRY													
Bait application, When needed, Aircraft	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Glove	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Spoon	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	WA		C20, C92, CAL
Bait application, When needed, Spreader	P/T	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	OR		C20, C92, CAL
PUBLIC BUILDINGS/STRUCTURES (VERT. PEST CONTROL) Use Group: INDOOR NON-FOOD													
Bait application, When needed, Bait box	B/S	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03

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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
PUBLIC BUILDINGS/STRUCTURES (VERT. PEST CONTROL) (con't) Use Group: INDOOR NON-FOOD (con't)													
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, Spoon	B/S	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Tracking powder, When needed, Duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand bulb duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Hand held duster	D	NA	.001323 lb application	*	NS	NS	NS	NS	30	NS			CAC, CAL
Tracking powder, When needed, Spoon	D	NA	.2068 Tsp application	*	NS	NS	NS	NS	30	NS			CAC, CAL
RECREATIONAL AREAS Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Not on label, Spreader	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Aircraft	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, By hand	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Glove	G	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
RECREATIONAL AREAS (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
Bait application, When needed, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		CAC
Bait application, When needed, Spreader	B/S	NA	.091 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
	G	NA	.2 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
SITE TERM TOO GENERAL Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Dormant, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Dormant, By hand	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Dormant, Mechanical burrow builder	B/S	NA	.0546 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Dormant, Spoon	B/S	NA	.091 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Dormant, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, Postharvest, Aircraft	B/S	NA	.182 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, By hand	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		C20, C66, CAA, CAG, CAL
	B/S	NA	.091 lb A	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Mechanical burrow builder	B/S	NA	.00455 Tsp ft interval	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL
Bait application, When needed, Spoon	P/T	NA	1.764E-04 lb burrow	*	NS	NS	NS		NS	NS	NS		C20, CAC, CAL, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
SITE TERM TOO GENERAL (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C20, CAL, CAU, G03
Bait application, When needed, Spreader	B/S	NA	.091 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL
STREAMS/RIVERS/CHANNELED WATER Use Group: AQUATIC NON-FOOD OUTDOOR													
Bait application, Late spring, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Late spring, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, By hand	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, Summer, Spreader	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	.12 lb A	*	NS	1/1 yr	NS	NS	NS	NS			C20, CAL, CAU, G03
	P/T	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, Ground	D	NA	UC	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
STREAMS/RIVERS/CHANNELED WATER (con't) Use Group: AQUATIC NON-FOOD OUTDOOR (con't)													
Bait application, When needed, Tray	D	NA	.06688 lb application	*	NS	NS	NS	NS	30	NS			C20, CAC, CAL
WIDE AREA/GENERAL OUTDOOR TREATMENT (PUBLIC HEALTH USE) Use Group: TERRESTRIAL NON-FOOD CROP													
Bait application, Fall, Glove	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Fall, Helicopter	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, Fall, Spreader	B/S	NA	.182 lb A	*	NS	NS	NS	NS	30	NS		AK, CA, MT, NM, PR, TX, UT	C20, CAG, CAL, CAU, G03
Bait application, When needed, Aircraft	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
Bait application, When needed, Bait box	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.04 Tsp station	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
Bait application, When needed, By hand	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
Bait application, When needed, Hand probe	B/S	NA	7.055E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	P/T	NA	7.055E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, Mechanical burrow builder	B/S	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, C66, CAA, CAG, CAL
	B/S	NA	.00376 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]

SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
WIDE AREA/GENERAL OUTDOOR TREATMENT (PUBLIC HEALTH USE) (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	P/T	NA	.06 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03
Bait application, When needed, Not on label	B/S	NA	.12 lb A	*	NS	NS	NS	NS	NS	NS	MT		
Bait application, When needed, Spoon	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	30	NS			C66, CAC, CAL
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAA, CAG
	B/S	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, CAB
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			C66, CAC
	B/S	NA	3.307E-04 lb burrow	*	NS	NS	NS	NS	NS	NS			CAC
	B/S	NA	.01 tbsp burrow	*	NS	NS	NS	NS	NS	NS	CA		
	B/S	NA	1.764E-04 lb burrow	*	NS	NS	NS	NS	NS	NS	MT		
	P/T	NA	.04 Tsp burrow	*	NS	NS	NS	NS	30	NS			C20, CAL, CAU, G03
	P/T	NA	.02 Tsp application	*	NS	NS	NS	NS	30	NS			C66, CAL, CAU
	P/T	NA	.02 Tsp burrow	*	NS	NS	NS	NS	NS	NS			C66, C92, CAL
Bait application, When needed, Spreader	B/S	NA	.0752 lb A	*	NS	NS	NS	NS	NS	NS			C20, CAC, CAL, G03

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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SITE Application Type, Application Timing, Application Equipment) Surface Type (Antimicrobial only) & Efficacy Influencing Factor (Antimicrobial only)	Form(s)	Min. Appl. Rate (AI unless noted otherwise)	Max. Appl. Rate (AI unless noted otherwise)	Soil Tex. Max. Dose	Max. # Apps @ Max. Rate /crop cycle	Max. # Apps @ Max. Rate /year	Max. Dose [(AI unless noted otherwise)/A] /crop cycle	Max. Dose [(AI unless noted otherwise)/A] /year	Min. Interv (days)	Re-Entry Intv.	Geographic Limitations Allowed	Geographic Limitations Disallowed	Use Limitations Codes
))USES ELIGIBLE FOR REREGISTRATION													
NON-FOOD/NON-FEED (con't)													
))WIDE AREA/GENERAL OUTDOOR TREATMENT (PUBLIC HEALTH USE) (con't) Use Group: TERRESTRIAL NON-FOOD CROP (con't)													
	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS	CA		
NOT SPECIFIED													
))													
SITE NOT SPECIFIED Use Group: USE GROUP FOR SITE 00000													
Bait application, When needed, Bait box	B/S	NA	UC	*	NS	NS	NS	NS	NS	NS			C93, CAL
Bait application, When needed, By hand	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C93, CAL
Bait application, When needed, Spoon	B/S	NA	.0025 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			C93, CAL
	WP	NA	UC	*	NS	NS	NS	NS	NS	NS			
	WP/D	NA	.094 Tsp ft interval	*	NS	NS	NS	NS	NS	NS			
Bait application, When needed, Spreader	B/S	NA	.2 lb A	*	NS	NS	NS	NS	NS	NS			C93, CAL

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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LEGEND
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Sort: Uses Eligible or Ineligible for Re-registration, Food/Feed or Non-Food/Non-Feed Uses, Alpha Site Name, Use Group Name, Alpha Application Type/Timing/Equipment Description, Formulation, Maximum Application Rate Unit/Area Quantity, Minimum Application Rate

HEADER ABBREVIATIONS

Min. Appl. Rate (AI unless noted otherwise) : Minimum dose for a single application to a single site. System calculated. Antimicrobial claims only.
Max. Appl. Rate (AI unless noted otherwise) : Maximum dose for a single application to a single site. System calculated.
Soil Tex. Max. Dose : Maximum dose for a single application to a single site as related to soil texture (Herbicide claims only).
Max. # Apps @ Max. Rate : Maximum number of Applications at Maximum Dosage Rate. Example: "4 applications per year" is expressed as "4/1 yr"; "4 applications per 3 years" is expressed as "4/3 yr"
Max. Dose [(AI unless noted otherwise)/A] : Maximum dose applied to a site over a single crop cycle or year. System calculated.
Min. Interv (days) : Minimum Interval between Applications (days)
Re-Entry Intv. : Reentry Intervals
PRD Report Date : LUIS contains all products that were active or suspended (and that were available from OPP Document Center) as of this date. Some products registered after this date may have data included in this report, but LUIS does not guarantee that all products registered after this date have data that has been captured.

SOIL TEXTURE FOR MAX APP. RATE

* : Non-specific
C : Coarse
M : Medium
F : Fine
O : Others

FORMULATION CODES

B/S : BAIT/SOLID
D : DUST
G : GRANULAR
P/T : PELLETED/TABLETED
WP : WETTABLE POWDER
WP/D : WETTABLE POWDER/DUST

ABBREVIATIONS

AN : As Needed
NA : Not Applicable
NS : Not Specified (on label)
UC : Unconverted due to lack of data (on label), or with one of following units: bag, bait, bait block, bait pack, bait station, bait station(s), block, briquet, briquets, bursts, cake, can, canister, capsule, cartridges, coil, collar, container, dispenser, drop, eartag, grains, lure, pack, packet, packets, pad, part, parts, pellets, piece, pieces, pill, pumps, sec, sec burst, sheet, spike, stake, stick, strip, tab, tablet, tablets, tag, tape, towelette, tray, unit, --

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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APPLICATION RATE
DCNC : Dosage Can Not be Calculated
No Calc : No Calculation can be made
W : PPM calculated by weight
V : PPM Calculated by volume
U : Unknown whether PPM is given by weight or by volume
cwt : Hundred Weight
nnE-xx : nn times (10 power -xx); for instance, "1.234E-04" is equivalent to ".0001234"

USE LIMITATIONS CODES
C14 : Grown for seed only.
C20 : Endangered species restriction.
C40 : Do not apply by aircraft.
C66 : Underground application only.
C92 : For terrestrial uses, do not apply directly to water or to areas where surface water is present or to intertidal areas below the mean high water mark.
C93 : Do not apply directly to water.
CAA : Do not apply to any body of water.
CAB : Keep out of lakes, streams, ponds, tidal marshes, and estuaries.
CAC : Keep out of lakes, streams, and ponds.
CAG : Do not apply where runoff is likely to occur.
CAL : Do not contaminate water, food or feed.
CAU : Do not apply directly to water, or to areas where surface water is present or to intertidal areas below the mean high water mark.
CCC : Do not make more than _____ applications per crop cycle.
CCD : Do not make more than _____ applications per year.
CDB : Do not use in homes.
G03 : Do not graze livestock in treated areas.
GE9 : Do not graze for one year after treatment.
H01 : __ day(s) preharvest interval.
* NUMBER IN PARENTHESES REPRESENTS THE NUMBER OF TIME UNITS (HOURS,DAYS, ETC.) DESCRIBED IN THE LIMITATION.

GEOGRAPHIC CODES
013 : Other
017 : Western States-DO NOT USE
AK : Alaska
AZ : Arizona
CA : California
CO : Colorado
FL : Florida
HI : Hawaii
ID : Idaho
IN : Indiana
KS : Kansas
MT : Montana
ND : North Dakota
NE : Nebraska
NM : New Mexico
NV : Nevada
OH : Ohio
OK : Oklahoma
OR : Oregon
PR : Puerto Rico

Case 0026 [Zinc Phosphide] Chemical 088601 [Zinc phosphide]
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GEOGRAPHIC CODES (Cont.)
SD : South Dakota
TX : Texas
UT : Utah
VT : Vermont
WA : Washington
WY : Wyoming

UNIT DESCRIPTIONS
A : acre
Tsp : teaspoon
application :
burrow :
ft interval : Not in LUIS Unit Conversion Vocabulary File
lb : pound
mound :
placement :
spot :
station :
tbsp : tablespoon
tree :
→

GUIDE TO APPENDIX B

Appendix B contains listings of data requirements which support the reregistration for active ingredients within the case Zinc phosphide covered by this Reregistration Eligibility Decision Document. It contains generic data requirements that apply to Zinc phosphide in all products, including data requirements for which a "typical formulation" is the test substance.

The data table is organized in the following format:

1. Data Requirement (Column 1). The data requirements are listed in the order in which they appear in 40 CFR Part 158. the reference numbers accompanying each test refer to the test protocols set in the Pesticide Assessment Guidelines, which are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (703) 487-4650.

2. Use Pattern (Column 2). This column indicates the use patterns for which the data requirements apply. The following letter designations are used for the given use patterns:

A	Terrestrial food
B	Terrestrial feed
C	Terrestrial non-food
D	Aquatic food
E	Aquatic non-food outdoor
F	Aquatic non-food industrial
G	Aquatic non-food residential
H	Greenhouse food
I	Greenhouse non-food
J	Forestry
K	Residential
L	Indoor food
M	Indoor non-food
N	Indoor medical
O	Indoor residential

3. Bibliographic citation (Column 3). If the Agency has acceptable data in its files, this column lists the identifying number of each study. This normally is the Master Record Identification (MRID) number, but may be a "GS" number if no MRID number has been assigned. Refer to the Bibliography appendix for a complete citation of the study.

APPENDIX B

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN[*]	CITATION(S)
<u>PRODUCT CHEMISTRY for</u> HACCO 61282-13			
61-1	Chemical Identity	ALL	43452401, Data Gap
61-2A	Start. Mat. & Mnfg. Process	ALL	43452401
61-2B	Formation of Impurities	ALL	42986201
62-1	Preliminary Analysis	ALL	42986201, 43549801
62-2	Certification of limits	ALL	43549801
62-3	Analytical Method	ALL	42986201, 43549801
63-2	Color	ALL	42986202
63-3	Physical State	ALL	42986202
63-4	Odor	ALL	42986202
63-5	Melting Point	ALL	42986202
63-6	Boiling Point	ALL	N/A
63-7	Density	ALL	43452401
63-8	Solubility	ALL	42986202
63-9	Vapor Pressure	ALL	N/A

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
63-10	Dissociation Constant	ALL	N/A
63-11	Octanol/Water Partition	ALL	N/A
63-12	pH	ALL	N/A
63-13	Stability	ALL	43452402, Data Gap
63-14	Oxidizing/Reducing Action	ALL	N/A
63-15	Flammability	ALL	N/A
63-16	Explodability	ALL	42986202, Data Gap
63-17	Storage stability	ALL	42986202
63-18	Viscosity	ALL	N/A
63-19	Miscibility	ALL	N/A
63-20	Corrosion Characteristics	ALL	43452402
PRODUCT CHEMISTRY for Bell Laboratories 12455-24			
61-1	Chemical Identity	ALL	43125501, 44227301
61-2A	Start. Mat. & Mnfg. Process	ALL	43125501, 44227301
61-2B	Formation of Impurities	ALL	43125501
62-1	Preliminary Analysis	ALL	43125502, 44227301

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
62-2	Certification of limits	ALL	43125501, 44227301
62-3	Analytical Method	ALL	44227301
63-2	Color	ALL	41250602
63-3	Physical State	ALL	41250602
63-4	Odor	ALL	41250602
63-5	Melting Point	ALL	41280602
63-6	Boiling Point	ALL	N/A
63-7	Density	ALL	41250602, 43125503, 44227302
63-8	Solubility	ALL	41250602, 43125503, 44227302
63-9	Vapor Pressure	ALL	N/A
63-10	Dissociation Constant	ALL	N/A
63-11	Octanol/Water Partition	ALL	N/A
63-12	pH	ALL	N/A
63-13	Stability	ALL	41250602, 43787801, 44227302
63-14	Oxidizing/Reducing Action	ALL	N/A
63-15	Flammability	ALL	N/A
63-16	Explodability	ALL	41250602

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
63-17	Storage stability	ALL	41250602
63-18	Viscosity	ALL	N/A
63-19	Miscibility	ALL	N/A
63-20	Corrosion Characteristics	ALL	Data Gap
	ECOLOGICAL EFFECTS		
71-1A	Acute Avian Oral- Quail/Duck	A,B,C,J,K	00006031, 00006032
71-2A	Avian Dietary - Quail	A,B,C,J,K	00006025, 00006031
71-4B	Avian Reproduction - Duck		Not Required
72-1A	Fish Toxicity Bluegill	A,B,C,J (broadcast uses)	Data Gap
72-1C	Fish Toxicity Rainbow Trout	A,B,C,J (broadcast uses)	Data Gap
72-2A	Invertebrate Toxicity	A,B,C,J (broadcast uses)	Data Gap
72-4A	Early Life Stage Fish		Not Required
124-1	Terrestrial Field		Not Required
141-1	Honey Bee Acute Contact	A,B,C,J,K	Waived
141-2	Honey Bee Residue on Foliage	A,B,C,J,K	Waived

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
141-5	Field Test for Pollinators	A,B,C,J,K	WAIVED
TOXICOLOGY			
81-1	Acute Oral Toxicity - Rat	ALL	00085366
81-2	Acute Dermal Toxicity - Rabbit/Rat	ALL	00006030
81-3	Acute Inhalation Toxicity - Rat	ALL	Waived
81-4	Primary Eye Irritation - Rabbit	ALL	00029247
81-5	Primary Dermal Irritation - Rabbit	ALL	00006029
81-6	Dermal Sensitization - Guinea Pig	ALL	Waived
81-7	Acute Delayed Neurotoxicity - Hen		Not Required
82-1A	90-Day Feeding - Rodent	ALL	43436601
82-1B	90-Day Feeding - Non-rodent		Not Required
82-2	21-Day Dermal - Rabbit/Rat		Not Required
82-3	90-Day Dermal - Rodent		Not Required
82-4	90-Day Inhalation - Rat		Not Required
82-5A	90-Day Neurotoxicity - Hen		Not Required
82-5B	90-Day Neurotoxicity - Mammal	ALL	43903801, 43903802

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
83-1A	Chronic Feeding Toxicity - Rodent	ALL	Waived
83-1B	Chronic Feeding Toxicity - Non-Rodent	ALL	Waived
83-2A	Oncogenicity - Rat	ALL	Waived
83-2B	Oncogenicity - Mouse	ALL	Waived
83-3A	Developmental Toxicity - Rat	ALL	43083501
83-3B	Developmental Toxicity - Rabbit	ALL	Waived
83-4	2-Generation Reproduction - Rat	ALL	Waived
84-2A	Gene Mutation (Ames Test)	ALL	42987301
84-2B	Structural Chromosomal Aberration	ALL	42987303
84-4	Other Genotoxic Effects	ALL	42987302
85-1	General Metabolism	ALL	Waived
OCCUPATIONAL/RESIDENTIAL EXPOSURE			
132-1A	Foliar Residue Dissipation		Not Required
132-1B	Soil Residue Dissipation		Not Required
133-3	Dermal Passive Dosimetry Exposure		Not Required

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
133-4	Inhalation Passive Dosimetry Exposure		Not Required
ENVIRONMENTAL FATE			
161-1	Hydrolysis	A,B,C,J,K	00068028
161-2	Photodegradation - Water	A,B,J	43466302, 43466303
161-3	Photodegradation - Soil	A,B,J	43466302, 43466303
161-4	Photodegradation - Air		Not Required
162-1	Aerobic Soil Metabolism	A,B,C,J,K	43466302, 43466303
162-2	Anaerobic Soil Metabolism	A,B,C	43466302, 43466303
162-3	Anaerobic Aquatic Metabolism		Not Required
162-4	Aerobic Aquatic Metabolism	J	43466302, 43466303
163-1	Leaching/Adsorption/Desorption	A,B,C,J,K	43466302, 43466303
163-2	Volatility - Lab	A,B	43466302, 43466303
164-1	Terrestrial Field Dissipation	A,B,C,K	43466302, 43466303
164-2	Aquatic Field Dissipation		43466302, 43466303
165-1	Confined Rotational Crop	A,B,C	43466302, 43466303
165-2	Field Rotational Crop		Not Required

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
RESIDUE CHEMISTRY			
171-3	Directions for Use	ALL	Data gap
171-4A	Nature of Residue - Plants	A,B	00006047, 00005999, 05007787
171-4B	Nature of Residue - Livestock		Not Required
171-4C	Residue Analytical Method - Plants	A,B	00006044, 05007610
171-4D	Residue Analytical Method - Animal		Not Required
171-4E	Storage Stability	A,B	Data Gap, 41035001
171-4I	Magnitude of Residues - Food Handling		Not Required
171-4J	Magnitude of Residues - Meat/Milk/Poultry/Egg	B	Waived
171-4K	Crop Field Trials		
	Artichokes	A,B	40962501
	Sugarbeet roots and tops	A,B	41035001
	Grapes	A,B	00006044, 00006045

Data Supporting Guideline Requirements for the Reregistration of Zinc Phosphide

REQUIREMENT		USE PATTERN*	CITATION(S)
	Grasses	A,B	00005950, 00005951, 00005952, 00005962, 00005965, 00005968, 00005969, 00005970, 00082533, 00082535, 00082538, 00082540, 00082541, 00082542, 00082550, 00082553
	Sugarcane	A,B	00005921, 00005922, 00005923, 00005924, 00005925, 00005926, 00005927, 00005928, 00005929, 00005930, 00005931, 00005932, 00005933, 00005936, 00005938, 00005939, 00005940, 00005941, 00005947, 00005948, 00005949, 00006058, 00019919
	Corn (no-till)	A,B	43903802
171-4L	Processed Food		
	Beets, sugar	A,B	Waived
	Grapes	A,B	00006044
	Sugarcane	A,B	see studies under 171-4k

* Use patterns are based on the General Use Patterns as cited in 40 CFR part 158 for each guideline, except for the toxicity guidelines which are listed for all uses

GUIDE TO APPENDIX C

1. CONTENTS OF BIBLIOGRAPHY. This bibliography contains citations of all studies considered relevant by EPA in arriving at the positions and conclusions stated elsewhere in the Reregistration Eligibility Document. Primary sources for studies in this bibliography have been the body of data submitted to EPA and its predecessor agencies in support of past regulatory decisions. Selections from other sources including the published literature, in those instances where they have been considered, are included.

2. UNITS OF ENTRY. The unit of entry in this bibliography is called a "study". In the case of published materials, this corresponds closely to an article. In the case of unpublished materials submitted to the Agency, the Agency has sought to identify documents at a level parallel to the published article from within the typically larger volumes in which they were submitted. The resulting "studies" generally have a distinct title (or at least a single subject), can stand alone for purposes of review and can be described with a conventional bibliographic citation. The Agency has also attempted to unite basic documents and commentaries upon them, treating them as a single study.

3. IDENTIFICATION OF ENTRIES. The entries in this bibliography are sorted numerically by Master Record Identifier, or "MRID number". This number is unique to the citation, and should be used whenever a specific reference is required. It is not related to the six-digit "Accession Number" which has been used to identify volumes of submitted studies (see paragraph 4(d)(4) below for further explanation). In a few cases, entries added to the bibliography late in the review may be preceded by a nine character temporary identifier. These entries are listed after all MRID entries. This temporary identifying number is also to be used whenever specific reference is needed.

4. FORM OF ENTRY. In addition to the Master Record Identifier (MRID), each entry consists of a citation containing standard elements followed, in the case of material submitted to EPA, by a description of the earliest known submission. Bibliographic conventions used reflect the standard of the American National Standards Institute (ANSI), expanded to provide for certain special needs.

   a Author. Whenever the author could confidently be identified, the Agency has chosen to show a personal author. When no individual was identified, the Agency has shown an identifiable laboratory or testing facility as the author. When no author or laboratory could be identified, the Agency has shown the first submitter as the author.

   b. Document date. The date of the study is taken directly from the document. When the date is followed by a question mark, the bibliographer has deduced the date from the evidence contained in the document. When the date appears as (19??), the Agency was unable to determine or estimate the date of the document.

c. Title. In some cases, it has been necessary for the Agency bibliographers to create or enhance a document title. Any such editorial insertions are contained between square brackets.

d. Trailing parentheses. For studies submitted to the Agency in the past, the trailing parentheses include (in addition to any self-explanatory text) the following elements describing the earliest known submission:

(1) Submission date. The date of the earliest known submission appears immediately following the word "received."

(2) Administrative number. The next element immediately following the word "under" is the registration number, experimental use permit number, petition number, or other administrative number associated with the earliest known submission.

(3) Submitter. The third element is the submitter. When authorship is defaulted to the submitter, this element is omitted.

(4) Volume Identification (Accession Numbers). The final element in the trailing parentheses identifies the EPA accession number of the volume in which the original submission of the study appears. The six-digit accession number follows the symbol "CDL," which stands for "Company Data Library." This accession number is in turn followed by an alphabetic suffix which shows the relative position of the study within the volume.

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00005921	Hawaii. Department of Agriculture (1970?) Preparation of Pure Phosphine Gas and Notes on the Analysis of Phosphine in Closed Systems. Undated method. (Unpublished study received Mar 3, 1971 under 0F0890; CDL:093187-D)
00005922	Robinson, W.H.; Hilton, H.W.; Mee, J.; Uyehara, G. (1968) Methodology: Determination of Phosphine Residues in Sugarcane and Related Sugar Products from the Use of Zinc phosphide. Includes undated method. (Unpublished study received Sep 25, 1969 under 0F0890; prepared by U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Section of Chemical Research and Analytical Activities in cooperation with Hawaiian Sugar Planters' Association, Experiment Station, submitted by Hawaii, Dept. of Agriculture, Honolulu, Hawaii; CDL:093187-F)
00005923	Hawaii. Department of Agriculture (1969) Laboratory Evaluation of Zinc phosphide Toxicity and Bait Formulations. (Unpublished study received Sep 25, 1969 under 0F0890; CDL:093187-H)
00005924	Hawaii, Department of Agriculture (1966?) Physical and Chemical Properties of Technical Zinc phosphide. Summary of studies 093187-V and 093187-Z through 093187-AB. (Unpublished study received Sep 25, 1969 under 0F0890; CDL:093187-I)
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

OFFICE OF
PREVENTION, PESTICIDES
AND TOXIC SUBSTANCES

GENERIC AND PRODUCT SPECIFIC
DATA CALL-IN NOTICE

CERTIFIED MAIL

Dear Sir or Madam:

This Notice requires you and other registrants of pesticide products containing the active ingredient identified in Attachment A of this Notice, the Data Call-In Chemical Status Sheet, to submit certain data as noted herein to the U.S. Environmental Protection Agency (EPA, the Agency). These data are necessary to maintain the continued registration of your product(s) containing this active ingredient. Within 90 days after you receive this Notice you must respond as set forth in Section III below. Your response must state:

1. How you will comply with the requirements set forth in this Notice and its Attachments 1 through 6; or

2. Why you believe you are exempt from the requirements listed in this Notice and in Attachment 3 (for both generic and product specific data), the Requirements Status and Registrant's Response Form, (see section III-B); or

3. Why you believe EPA should not require your submission of data in the manner specified by this Notice (see section III-D).

If you do not respond to this Notice, or if you do not satisfy EPA that you will comply with its requirements or should be exempt or excused from doing so, then the registration of your product(s) subject to this Notice will be subject to suspension. We have provided a list of all of your products subject to this Notice in Attachment 2. All products are listed on both the generic and product specific Data Call-In Response Forms. Also included is a list of all registrants who were sent this Notice (Attachment 5).

The authority for this Notice is section 3(c)(2)(B) of the Federal Insecticide, Fungicide and Rodenticide Act as amended (FIFRA), 7 U.S.C. section 136a(c)(2)(B). Collection of this information is authorized under the Paperwork Reduction Act by OMB Approval No. 2070-0107 and 2070-0057 (expiration date 3-31-99).

This Notice is divided into six sections and six Attachments. The Notice itself contains information and instructions applicable to all Data Call-In Notices. The Attachments contain specific chemical information and instructions. The six sections of the Notice are:

Section I	-	Why You are Receiving this Notice
Section II	-	Data Required by this Notice
Section III	-	Compliance with Requirements of this Notice
Section IV	-	Consequences of Failure to Comply with this Notice
Section V	-	Registrants' Obligation to Report Possible Unreasonable Adverse Effects
Section VI	-	Inquiries and Responses to this Notice

The Attachments to this Notice are:

1 - Data Call-In Chemical Status Sheet
2 - Generic Data Call-In and Product Specific Data Call-In Response Forms with Instructions (Form A)
3 - Generic Data Call-In and Product Specific Data Call-In Requirements Status and Registrant's Response Forms with Instructions (Form B)
4 - EPA Batching of End-Use Products for Meeting Acute Toxicology Data Requirements for Reregistration
5 - List of Registrants Receiving This Notice
6 - Cost Share and Data Citation Forms

SECTION I. WHY YOU ARE RECEIVING THIS NOTICE

The Agency has reviewed existing data for this active ingredient(s) and reevaluated the data needed to support continued registration of the subject active ingredient(s). This reevaluation identified additional data necessary to assess the health and safety of the continued use of products containing this active ingredient(s). You have been sent this Notice because you have product(s) containing the subject active ingredient(s).

SECTION II. DATA REQUIRED BY THIS NOTICE

II-A. DATA REQUIRED

The data required by this Notice are specified in the Requirements Status and Registrant's Response Forms: Attachment 3 (for both generic and product specific data requirements). Depending on the results of the studies required in this Notice, additional studies/testing may be required.

II-B. SCHEDULE FOR SUBMISSION OF DATA

You are required to submit the data or otherwise satisfy the data requirements specified in the Requirements Status and Registrant's Response Forms (Attachment 3) within the timeframes provided.

II-C. TESTING PROTOCOL

All studies required under this Notice must be conducted in accordance with test standards outlined in the Pesticide Assessment Guidelines for those studies for which guidelines have been established.

These EPA Guidelines are available from the National Technical Information Service (NTIS), Attn: Order Desk, 5285 Port Royal Road, Springfield, VA 22161 (Telephone number: 703-605-6000).

Protocols approved by the Organization for Economic Cooperation and Development (OECD) are also acceptable if the OECD recommended test standards conform to those specified in the Pesticide Data Requirements regulation (40 CFR § 158.70). When using the OECD protocols, they should be modified as appropriate so that the data generated by the study will satisfy the requirements of 40 CFR § 158. Normally, the Agency will not extend deadlines for complying with data requirements when the studies were not conducted in accordance with acceptable standards. The OECD protocols are available from OECD, 2001 L Street, N.W., Washington, D.C. 20036 (Telephone number 202-785-6323; Fax telephone number 202-785-0350).

All new studies and proposed protocols submitted in response to this Data Call-In Notice must be in accordance with Good Laboratory Practices [40 CFR Part 160].

II-D. REGISTRANTS RECEIVING PREVIOUS SECTION 3(c)(2)(B) NOTICES ISSUED BY THE AGENCY

Unless otherwise noted herein, this Data Call-In does not in any way supersede or change the requirements of any previous Data Call-In(s), or any other agreements entered into with the Agency pertaining to such prior Notice. Registrants must comply with the requirements of all Notices to avoid issuance of a Notice of Intent to Suspend their affected products.

SECTION III. COMPLIANCE WITH REQUIREMENTS OF THIS NOTICE

You must use the correct forms and instructions when completing your response to this Notice. The type of Data Call-In you must comply with (Generic or Product Specific) is specified in item number 3 on the four Data Call-In forms (Attachments 2 and 3).

III-A. SCHEDULE FOR RESPONDING TO THE AGENCY

The appropriate responses initially required by this Notice for generic and product specific data must be submitted to the Agency within 90 days after your receipt of this Notice. Failure to adequately respond to this Notice within 90 days of your receipt will be a basis for issuing a Notice of Intent to Suspend (NOIS) affecting your products. This and other bases for issuance of NOIS due to failure to comply with this Notice are presented in Section IV-A and IV-B.

III-B. OPTIONS FOR RESPONDING TO THE AGENCY

1. Generic Data Requirements

The options for responding to this Notice for generic data requirements are: (a) voluntary cancellation, (b) delete use(s), (c) claim generic data exemption, (d) agree to satisfy the generic data requirements imposed by this Notice or (e) request a data waiver(s).

A discussion of how to respond if you choose the Voluntary Cancellation option, the Delete Use(s) option or the Generic Data Exemption option is presented below. A discussion of the various options available for satisfying the generic data requirements of this Notice is contained in Section III-C. A discussion of options relating to requests for data waivers is contained in Section III-D.

Two forms apply to generic data requirements, one or both of which must be used in responding to the Agency, depending upon your response. These two forms are the Data-Call-In Response Form, and the Requirements Status and Registrant's Response Form, (contained in Attachments 2 and 3, respectively).

The Data Call-In Response Forms must be submitted as part of every response to this Notice. The Requirements Status and Registrant's Response Forms also must be submitted if you do not qualify for a Generic Data Exemption or are not requesting voluntary cancellation of your registration(s). Please note that the company's authorized representative is required to sign the first page of both Data Call-In Response Forms and the Requirements Status and Registrant's Response Forms (if this form is required) and initial any subsequent pages. The forms contain separate detailed instructions on the response options. Do not alter the printed material. If you have questions or need assistance in preparing your response, call or write the contact person(s) identified in Attachment 1.

a. Voluntary Cancellation -

You may avoid the requirements of this Notice by requesting voluntary cancellation of your product(s) containing the active ingredient that is the subject of this Notice. If you wish to voluntarily cancel your product, you must submit completed Generic and Product Specific Data Call-In Response Forms (Attachment 2), indicating your election of this option.

Voluntary cancellation is item number 5 on both Data Call-In Response Form(s). If you choose this option, these are the only forms that you are required to complete.

If you choose to voluntarily cancel your product, further sale and distribution of your product after the effective date of cancellation must be in accordance with the Existing Stocks provisions of this Notice, which are contained in Section IV-C.

b. Use Deletion -

You may avoid the requirements of this Notice by eliminating the uses of your product to which the requirements apply. If you wish to amend your registration to delete uses, you must submit the Requirements Status and Registrant's Response Form (Attachment 3), a completed application for amendment, a copy of your proposed amended labeling, and all other information required for processing the application. Use deletion is option number 7 under item 9 in the instructions for the Requirements Status and Registrant's Response Forms. You must also complete a Data Call-In Response Form by signing the certification, item number 8. Application forms for amending registrations may be obtained from the Registration Support Branch, Registration Division, Office of Pesticide Programs, EPA, by calling (703) 308-8358.

If you choose to delete the use(s) subject to this Notice or uses subject to specific data requirements, further sale, distribution, or use of your product after one year from the due date of your 90 day response, is allowed only if the product bears an amended label.

c. Generic Data Exemption -

Under section 3(c)(2)(D) of FIFRA, an applicant for registration of a product is exempt from the requirement to submit or cite generic data concerning an active ingredient if the active ingredient in the product is derived exclusively from purchased, registered pesticide products containing the active ingredient. EPA has concluded, as an exercise of its discretion, that it normally will not suspend the registration of a product which would qualify and continue to qualify for the generic data exemption in section 3(c)(2)(D) of FIFRA. To qualify, all of the following requirements must be met:

(i). The active ingredient in your registered product must be present solely because of incorporation of another registered product which contains the subject active ingredient and is purchased from a source not connected with you;

(ii). Every registrant who is the ultimate source of the active ingredient in your product subject to this DCI must be in compliance with the requirements of this Notice and must remain in compliance; and

(iii). You must have provided to EPA an accurate and current "Confidential Statement of Formula" for each of your products to which this Notice applies.

To apply for the Generic Data Exemption you must submit a completed Data Call-In Response Form, Attachment 2 and all supporting documentation. The Generic Data Exemption is item number 6a on the Data Call-In Response Form. If you claim a generic data exemption you are not required to complete the Requirements Status and Registrant's Response Form. Generic Data Exemption cannot be selected as an option for responding to product specific data requirements.

If you are granted a Generic Data Exemption, you rely on the efforts of other persons to provide the Agency with the required data. If the registrant(s) who have committed to generate and submit the required data fail to take appropriate steps to meet requirements or are no longer in compliance with this Data Call-In Notice, the Agency will consider that both they and you are not compliance and will normally initiate proceedings to suspend the registrations of both your and their product(s), unless you commit to submit and do submit the required data within the specified time. In such cases the Agency generally will not grant a time extension for submitting the data.

d. Satisfying the Generic Data Requirements of this Notice

There are various options available to satisfy the generic data requirements of this Notice. These options are discussed in Section III-C.1. of this Notice and comprise options 1 through 6 of item 9 in the instructions for the Requirements Status and Registrant's Response Form and item 6b on the Data Call-In Response Form. If you choose item 6b (agree to satisfy the generic data requirements), you must submit the Data Call-In Response Form and the Requirements Status and Registrant's Response Form as well as any other information/data pertaining to the option chosen to address the data requirement. Your response must be on the forms marked "GENERIC" in item number 3.

e. Request for Generic Data Waivers.

Waivers for generic data are discussed in Section III-D.1. of this Notice and are covered by options 8 and 9 of item 9 in the instructions for the Requirements Status and Registrant's Response Form. If you choose one of these options, you must submit both forms as well as any other information/data pertaining to the option chosen to address the data requirement.

2. Product Specific Data Requirements

The options for responding to this Notice for product specific data are: (a) voluntary cancellation, (b) agree to satisfy the product specific data requirements imposed by this Notice or (c) request a data waiver(s).

A discussion of how to respond if you choose the Voluntary Cancellation option is presented below. A discussion of the various options available for satisfying the product specific data requirements of this Notice is contained in Section III-C.2. A discussion of options relating to requests for data waivers is contained in Section III-D.2.

Two forms apply to the product specific data requirements one or both of which must be used in responding to the Agency, depending upon your response. These forms are the Data-Call-In Response Form, and the Requirements Status and Registrant's Response Form, for product specific data (contained in Attachments 2 and 3, respectively). The Data Call-In Response Form must be submitted as part of every response to this Notice. In addition, one copy of the Requirements Status and Registrant's Response Form also must be submitted for each product listed on the Data Call-In Response Form unless the voluntary cancellation option is selected. Please note that the company's authorized representative is required to sign the first page of the Data Call-In Response Form and Requirements Status and Registrant's Response Form (if this form is required) and initial any subsequent pages. The forms contain separate detailed instructions on the response options. Do not alter the printed material. If you have questions or need assistance in preparing your response, call or write the contact person(s) identified in Attachment 1.

a. Voluntary Cancellation

You may avoid the requirements of this Notice by requesting voluntary cancellation of your product(s) containing the active ingredient that is the subject of this Notice. If you wish to voluntarily cancel your product, you must submit a completed Data Call-In Response Form, indicating your election of this option. Voluntary cancellation is item number 5 on both the Generic and Product Specific Data Call-In Response Forms. If you choose this option, you must complete both Data Call-In response forms. These are the only forms that you are required to complete.

If you choose to voluntarily cancel your product, further sale and distribution of your product after the effective date of cancellation must be in accordance with the Existing Stocks provisions of this Notice which are contained in Section IV-C.

b. Satisfying the Product Specific Data Requirements of this Notice.

There are various options available to satisfy the product specific data requirements of this Notice. These options are discussed in Section III-C. of this Notice and comprise options 1 through 6 of item 9 in the instructions for the product specific Requirements Status and Registrant's Response Form and item numbers 7a and 7b (agree to satisfy the product specific data requirements for an MUP or EUP as applicable) on the product specific Data Call-In Response Form. Note that the options available for addressing product specific data requirements differ slightly from those options for fulfilling generic data requirements. Deletion of a use(s) and the low volume/minor use option are not valid options for fulfilling product specific data requirements. It is important to ensure that you are using the correct forms and instructions when completing your response to the Reregistration Eligibility Decision document.

c. Request for Product Specific Data Waivers.

Waivers for product specific data are discussed in Section III-D.2. of this Notice and are covered by option 7 of item 9 in the instructions for the Requirements Status and Registrant's Response Form. If you choose this option, you must submit the Data Call-In Response Form and the Requirements Status and Registrant's Response Form as well as any other information/data pertaining to the option chosen to address the data requirement. Your response must be on the forms marked "PRODUCT SPECIFIC" in item number 3.

III-C SATISFYING THE DATA REQUIREMENTS OF THIS NOTICE

1. Generic Data

If you acknowledge on the Generic Data Call-In Response Form that you agree to satisfy the generic data requirements (i.e. you select item number 6b), then you must select one of the six options on the Generic Requirements Status and Registrant's Response Form related to data production for each data requirement. Your option selection should be entered under item number 9, "Registrant Response." The six options related to data production are the first six options discussed under item 9 in the instructions for completing the Requirements Status and Registrant's Response Form. These six options are listed immediately below with information in parentheses to guide you to additional instructions provided in this Section. The options are:

(1) I will generate and submit data within the specified timeframe (Developing Data)
(2) I have entered into an agreement with one or more registrants to develop data jointly (Cost Sharing)
(3) I have made offers to cost-share (Offers to Cost Share)
(4) I am submitting an existing study that has not been submitted previously to the Agency by anyone (Submitting an Existing Study)
(5) I am submitting or citing data to upgrade a study classified by EPA as partially acceptable and upgradeable (Upgrading a Study)
(6) I am citing an existing study that EPA has classified as acceptable or an existing study that has been submitted but not reviewed by the Agency (Citing an Existing Study)

Option 1. Developing Data

If you choose to develop the required data it must be in conformance with Agency guidelines and with other Agency requirements as referenced herein and in the attachments. All data generated and submitted must comply with the Good Laboratory Practice (GLP) rule (40 CFR Part 160), be conducted according to the Pesticide Assessment Guidelines (PAG) and be in conformance with the requirements of PR Notice 86-5. In addition, certain studies require Agency approval of test protocols in advance of study initiation. Those studies for which a protocol must be submitted have been identified in the Requirements Status and

Registrant's Response Form and/or footnotes to the form. If you wish to use a protocol which differs from the options discussed in Section II-C of this Notice, you must submit a detailed description of the proposed protocol and your reason for wishing to use it. The Agency may choose to reject a protocol not specified in Section II-C. If the Agency rejects your protocol you will be notified in writing, however, you should be aware that rejection of a proposed protocol will not be a basis for extending the deadline for submission of data.

A progress report must be submitted for each study within 90 days from the date you are required to commit to generate or undertake some other means to address that study requirement, such as making an offer to cost share or agreeing to share in the cost of developing that study. This 90-day progress report must include the date the study was or will be initiated and, for studies to be started within 12 months of commitment, the name and address of the laboratory(ies) or individuals who are or will be conducting the study.

In addition, if the time frame for submission of a final report is more than 1 year, interim reports must be submitted at 12 month intervals from the date you are required to commit to generate or otherwise address the requirement for the study. In addition to the other information specified in the preceding paragraph, at a minimum, a brief description of current activity on and the status of the study must be included as well as a full description of any problems encountered since the last progress report.

The time frames in the Requirements Status and Registrant's Response Form are the time frames that the Agency is allowing for the submission of completed study reports or protocols. The noted deadlines run from the date of the receipt of this Notice by the registrant. If the data are not submitted by the deadline, each registrant is subject to receipt of a Notice of Intent to Suspend the affected registration(s).

If you cannot submit the data/reports to the Agency in the time required by this Notice and intend to seek additional time to meet the requirements(s), you must submit a request to the Agency which includes: (1) a detailed description of the expected difficulty and (2) a proposed schedule including alternative dates for meeting such requirements on a step-by-step basis. You must explain any technical or laboratory difficulties and provide documentation from the laboratory performing the testing. While EPA is considering your request, the original deadline remains. The Agency will respond to your request in writing. If EPA does not grant your request, the original deadline remains. Normally, extensions can be requested only in cases of extraordinary testing problems beyond the expectation or control of the registrant. Extensions will not be given in submitting the 90-day responses. Extensions will not be considered if the request for extension is not made in a timely fashion; in no event shall an extension request be considered if it is submitted at or after the lapse of the subject deadline.

Option 2. Agreement to Share in Cost to Develop Data

If you choose to enter into an agreement to share in the cost of producing the required data but will not be submitting the data yourself, you must provide the name of the registrant who will be submitting the data. You must also provide EPA with documentary evidence that an agreement has been formed. Such evidence may be your letter offering to join in an agreement and the other registrant's acceptance of your offer, or a written statement by the parties that an agreement exists. The agreement to produce the data need not specify all of the terms of the final arrangement between the parties or the mechanism to resolve the terms. Section 3(c)(2)(B) provides that if the parties cannot resolve the terms of the agreement they may resolve their differences through binding arbitration.

Option 3. Offer to Share in the Cost of Data Development

If you have made an offer to pay in an attempt to enter into an agreement or amend an existing agreement to meet the requirements of this Notice and have been unsuccessful, you may request EPA (by selecting this option) to exercise its discretion not to suspend your registration(s), although you did not comply with the data submission requirements of this Notice. EPA has determined that as a general policy, absent other relevant considerations, it will not suspend the registration of a product of a registrant who has in good faith sought and continues to seek to enter into a joint data development/cost sharing program, but the other registrant(s) developing the data has refused to accept the offer. To qualify for this option, you must submit documentation to the Agency proving that you have made an offer to another registrant (who has an obligation to submit data) to share in the burden of developing that data. You must also submit to the Agency a completed EPA Form 8570-32, Certification of Offer to Cost Share in the Development of Data, Attachment 6. In addition, you must demonstrate that the other registrant to whom the offer was made has not accepted your offer to enter into a cost-sharing agreement by including a copy of your offer and proof of the other registrant's receipt of that offer (such as a certified mail receipt). Your offer must, in addition to anything else, offer to share in the burden of producing the data upon terms to be agreed to or, failing agreement, to be bound by binding arbitration as provided by FIFRA section 3(c)(2)(B)(iii) and must not qualify this offer. The other registrant must also inform EPA of its election of an option to develop and submit the data required by this Notice by submitting a Data Call-In Response Form and a Requirements Status and Registrant's Response Form committing to develop and submit the data required by this Notice.

In order for you to avoid suspension under this option, you may not withdraw your offer to share in the burden of developing the data. In addition, the other registrant must fulfill its commitment to develop and submit the data as required by this Notice. If the other registrant fails to develop the data or for some other reason is subject to suspension, your registration as well as that of the other registrant normally will be subject to initiation of suspension proceedings, unless you commit to submit, and do submit, the required data in the specified time frame. In such cases, the Agency generally will not grant a time extension for submitting the data.

Option 4. Submitting an Existing Study

If you choose to submit an existing study in response to this Notice, you must determine that the study satisfies the requirements imposed by this Notice. You may only submit a study that has not been previously submitted to the Agency or previously cited by anyone. Existing studies are studies which predate issuance of this Notice. Do not use this option if you are submitting data to upgrade a study. (See Option 5).

You should be aware that if the Agency determines that the study is not acceptable, the Agency will require you to comply with this Notice, normally without an extension of the required date of submission. The Agency may determine at any time that a study is not valid and needs to be repeated.

To meet the requirements of the DCI Notice for submitting an existing study, all of the following three criteria must be clearly met:

a. You must certify at the time that the existing study is submitted that the raw data and specimens from the study are available for audit and review and you must identify where they are available. This must be done in accordance with the requirements of the Good Laboratory Practice (GLP) regulation, 40 CFR Part 160. As stated in 40 CFR 160.3, *Raw data* means any laboratory worksheets, records, memoranda, notes, or exact copies thereof, that are the result of original observations and activities of a study and are necessary for the reconstruction and evaluation of the report of that study. In the event that exact transcripts of raw data have been prepared (e.g., tapes which have been transcribed verbatim, dated, and verified accurate by signature), the exact copy or exact transcript may be substituted for the original source as raw data. 'Raw data' may include photographs, microfilm or microfiche copies, computer printouts, magnetic media, including dictated observations, and recorded data from automated instruments." The term "specimens", according to 40 CFR 160.3, means "any material derived from a test system for examination or analysis."

b. Health and safety studies completed after May 1984 must also contain all GLP-required quality assurance and quality control information pursuant to the requirements of 40 CFR Part 160. Registrants also must certify at the time of submission of the existing study that such GLP information is available for post May 1984 studies by including an appropriate statement on or attached to the study signed by an authorized official or representative of the registrant.

c. You must certify that each study fulfills the acceptance criteria for the Guideline relevant to the study provided in the FIFRA Accelerated Reregistration Phase 3 Technical Guidance and that the study has been conducted according to the Pesticide Assessment Guidelines (PAG) or meets the purpose of the PAG (both documents available from NTIS). A study not conducted according to the PAG may be submitted to the Agency for consideration if the registrant believes that the study clearly meets the purpose of the PAG. The registrant is referred to 40 CFR 158.70 which states the Agency's policy regarding acceptable protocols. If you wish to submit the study, you must, in addition to certifying that the purposes of the PAG are met by the study, clearly articulate the rationale why you believe the study meets the purpose of the PAG, including copies of any supporting information or data. It has been the Agency's experience that studies completed prior to January 1970 rarely satisfied the purpose of the PAG and that necessary raw data usually are not available for such studies.

If you submit an existing study, you must certify that the study meets all requirements of the criteria outlined above.

If EPA has previously reviewed a protocol for a study you are submitting, you must identify any action taken by the Agency on the protocol and must indicate, as part of your certification, the manner in which all Agency comments, concerns, or issues were addressed in the final protocol and study.

If you know of a study pertaining to any requirement in this Notice which does not meet the criteria outlined above but does contain factual information regarding unreasonable adverse effects, you must notify the Agency of such a study. If such a study is in the Agency's files, you need only cite it along with the notification. If not in the Agency's files, you must submit a summary and copies as required by PR Notice 86-5.

Option 5. Upgrading a Study

If a study has been classified as partially acceptable and upgradeable, you may submit data to upgrade that study. The Agency will review the data submitted and determine if the requirement is satisfied. If the Agency decides the requirement is not satisfied, you may still be required to submit new data normally without any time extension. Deficient, but upgradeable studies will normally be classified as supplemental. However, it is important to note that not all studies classified as supplemental are upgradeable. If you have questions regarding the classification of a study or whether a study may be upgraded, call or write the contact person listed in Attachment 1. If you submit data to upgrade an existing study you must satisfy or supply information to correct all deficiencies in the study identified by EPA. You must provide a clearly articulated rationale of how the deficiencies have been remedied or corrected and why the study should be rated as acceptable to EPA. Your submission must also specify the MRID number(s) of the study which you are attempting to upgrade and must be in conformance with PR Notice 86-5.

Do not submit additional data for the purpose of upgrading a study classified as unacceptable and determined by the Agency as not capable of being upgraded.

This option also should be used to cite data that has been previously submitted to upgrade a study, but has not yet been reviewed by the Agency. You must provide the MRID number of the data submission as well as the MRID number of the study being upgraded.

The criteria for submitting an existing study, as specified in Option 4 above, apply to all data submissions intended to upgrade studies. Additionally, your submission of data intended to upgrade studies must be accompanied by a certification that you comply with each of those criteria, as well as a certification regarding protocol compliance with Agency requirements.

Option 6. Citing Existing Studies

If you choose to cite a study that has been previously submitted to EPA, that study must have been previously classified by EPA as acceptable, or it must be a study which has not yet been reviewed by the Agency. Acceptable toxicology studies generally will have been classified as "core-guideline" or "core-minimum." For ecological effects studies, the classification generally would be a rating of "core." For all other disciplines the classification would be "acceptable." With respect to any studies for which you wish to select this option, you must provide the MRID number of the study you are citing and, if the study has been reviewed by the Agency, you must provide the Agency's classification of the study.

If you are citing a study of which you are not the original data submitter, you must submit a completed copy of EPA Form 8570-34, Certification with Respect to Citation of Data and EPA Form 8570-35 Data Matrix.

2. Product Specific Data

If you acknowledge on the product specific Data Call-In Response Form that you agree to satisfy the product specific data requirements (i.e. you select option 7a or 7b), then you must select one of the six options on the Requirements Status and Registrant’s Response Form related to data production for each data requirement. Your option selection should be entered under item number 9, "Registrant Response." The six options related to data production are the first six options discussed under item 9 in the instructions for completing the Requirements Status and Registrant's Response Form. These six options are listed immediately below with information in parentheses to guide registrants to additional instructions provided in this Section. The options are:

(1) I will generate and submit data within the specified time-frame (Developing Data)
(2) I have entered into an agreement with one or more registrants to develop data jointly (Cost Sharing)
(3) I have made offers to cost-share (Offers to Cost Share)
(4) I am submitting an existing study that has not been submitted previously to the Agency by anyone (Submitting an Existing Study)

(5) I am submitting or citing data to upgrade a study classified by EPA as partially acceptable and upgradeable (Upgrading a Study)

(6) I am citing an existing study that EPA has classified as acceptable or an existing study that has been submitted but not reviewed by the Agency (Citing an Existing Study)

Option 1. Developing Data -- The requirements for developing product specific data are the same as those described for generic data (see Section III.C.1, Option 1) except that normally no protocols or progress reports are required.

Option 2. Agree to Share in Cost to Develop Data -- If you enter into an agreement to cost share, the same requirements apply to product specific data as to generic data (see Section III.C.1, Option 2). However, registrants may only choose this option for acute toxicity data and certain efficacy data and only if EPA has indicated in the attached data tables that your product and at least one other product are similar for purposes of depending on the same data. If this is the case, data may be generated for just one of the products in the group. The registration number of the product for which data will be submitted must be noted in the agreement to cost share by the registrant selecting this option.

Option 3. Offer to Share in the Cost of Data Development --The same requirements for generic data (Section III.C.I., Option 3) apply to this option. This option only applies to acute toxicity and certain efficacy data as described in option 2 above.

Option 4. Submitting an Existing Study -- The same requirements described for generic data (see Section III.C.1., Option 4) apply to this option for product specific data.

Option 5. Upgrading a Study -- The same requirements described for generic data (see Section III.C.1., Option 5) apply to this option for product specific data.

Option 6. Citing Existing Studies -- The same requirements described for generic data (see Section III.C.1., Option 6) apply to this option for product specific data.

Registrants who select one of the above 6 options must meet all of the requirements described in the instructions for completing the Data Call-In Response Form and the Requirements Status and Registrant's Response Form, and in the generic data requirements section (III.C.1.), as appropriate.

III-D REQUESTS FOR DATA WAIVERS

1. Generic Data

There are two types of data waiver responses to this Notice. The first is a request for a low volume/minor use waiver and the second is a waiver request based on your belief that the data requirement(s) are not appropriate for your product.

a. Low Volume/Minor Use Waiver

Option 8 under item 9 on the Requirements Status and Registrant's Response Form. Section 3(c)(2)(A) of FIFRA requires EPA to consider the appropriateness of requiring data for low volume/minor use pesticides. In implementing this provision, EPA considers low volume pesticides to be only those active ingredients whose total production volume for all pesticide registrants is small. In determining whether to grant a low volume, minor use waiver, the Agency will consider the extent, pattern and volume of use, the economic incentive to conduct the testing, the importance of the pesticide, and the exposure and risk from use of the pesticide. If an active ingredient is used for both high volume and low volume uses, a low volume exemption will not be approved. If all uses of an active ingredient are low volume and the combined volumes for all uses are also low, then an exemption may be granted, depending on review of other information outlined below. An exemption will not be granted if any registrant of the active ingredient elects to conduct the testing. Any registrant receiving a low volume/minor use waiver must remain within the sales figures in their forecast supporting the waiver request in order to remain qualified for such waiver. If granted a waiver, a registrant will be required, as a condition of the waiver, to submit annual sales reports. The Agency will respond to requests for waivers in writing.

To apply for a low volume/minor use waiver, you must submit the following information, as applicable to your product(s), as part of your 90-day response to this Notice:

(i). Total company sales (pounds and dollars) of all registered product(s) containing the active ingredient. If applicable to the active ingredient, include foreign sales for those products that are not registered in this country but are applied to sugar (cane or beet), coffee, bananas, cocoa, and other such crops. Present the above information by year for each of the past five years.

(ii) Provide an estimate of the sales (pounds and dollars) of the active ingredient for each major use site. Present the above information by year for each of the past five years.

(iii) Total direct production cost of product(s) containing the active ingredient by year for the past five years. Include information on raw material cost, direct labor cost, advertising, sales and marketing, and any other significant costs listed separately.

(iv) Total indirect production cost (e.g. plant overhead, amortized plant and equipment) charged to product(s) containing the active ingredient by year for the past five years. Exclude all non-recurring costs that were directly related to the active ingredient, such as costs of initial registration and any data development.

(v) A list of each data requirement for which you seek a waiver. Indicate the type of waiver sought and the estimated cost to you (listed separately for each data requirement and associated test) of conducting the testing needed to fulfill each of these data requirements.

(vi) A list of each data requirement for which you are not seeking any waiver and the estimated cost to you (listed separately for each data requirement and associated test) of conducting the testing needed to fulfill each of these data requirements.

(vii) For each of the next ten years, a year-by-year forecast of company sales (pounds and dollars) of the active ingredient, direct production costs of product(s) containing the active ingredient (following the parameters in item 2 above), indirect production costs of product(s) containing the active ingredient (following the parameters in item 3 above), and costs of data development pertaining to the active ingredient.

(viii) A description of the importance and unique benefits of the active ingredient to users. Discuss the use patterns and the effectiveness of the active ingredient relative to registered alternative chemicals and non-chemical control strategies. Focus on benefits unique to the active ingredient, providing information that is as quantitative as possible. If you do not have quantitative data upon which to base your estimates, then present the reasoning used to derive your estimates. To assist the Agency in determining the degree of importance of the active ingredient in terms of its benefits, you should provide information on any of the following factors, as applicable to your product(s): (a) documentation of the usefulness of the active ingredient in Integrated Pest Management, (b) description of the beneficial impacts on the environment of use of the active ingredient, as opposed to its registered alternatives, (c) information on the breakdown of the active ingredient after use and on its persistence in the environment, and (d) description of its usefulness against a pest(s) of public health significance.

Failure to submit sufficient information for the Agency to make a determination regarding a request for a low volume/minor use waiver will result in denial of the request for a waiver.

b. Request for Waiver of Data

Option 9, under Item 9, on the Requirements Status and Registrant's Response Form. This option may be used if you believe that a particular data requirement should not apply because the requirement is inappropriate. You must submit a rationale explaining why you believe the data requirements should not apply. You also must submit the current label(s) of your product(s) and, if a current copy of your Confidential Statement of Formula is not already on file you must submit a current copy.

You will be informed of the Agency's decision in writing. If the Agency determines that the data requirements of this Notice are not appropriate to your product(s), you will not be required to supply the data pursuant to section 3(c)(2)(B). If EPA determines that the data are required for your product(s), you must choose a method of meeting the requirements of this Notice within the time frame provided by this Notice. Within 30 days of your receipt of the Agency's written decision, you must submit a revised Requirements Status and Registrant's Response Form indicating the option chosen.

2. Product Specific Data

If you request a waiver for product specific data because you believe it is inappropriate, you must attach a complete justification for the request including technical reasons, data and references to relevant EPA regulations, guidelines or policies. (Note: any supplemental data must be submitted in the format required by PR Notice 86-5). This will be the only opportunity to state the reasons or provide information in support of your request. If the Agency approves your waiver request, you will not be required to supply the data pursuant to section 3(c)(2)(B) of FIFRA. If the Agency denies your waiver request, you must choose an option for meeting the data requirements of this Notice within 30 days of the receipt of the Agency's decision. You must indicate and submit the option chosen on the product specific Requirements Status and Registrant's Response Form. Product specific data requirements for product chemistry, acute toxicity and efficacy (where appropriate) are required for all products and the Agency would grant a waiver only under extraordinary circumstances. You should also be aware that submitting a waiver request will not automatically extend the due date for the study in question. Waiver requests submitted without adequate supporting rationale will be denied and the original due date will remain in force.

SECTION IV. CONSEQUENCES OF FAILURE TO COMPLY WITH THIS NOTICE

IV-A NOTICE OF INTENT TO SUSPEND

The Agency may issue a Notice of Intent to Suspend products subject to this Notice due to failure by a registrant to comply with the requirements of this Data Call-In Notice, pursuant to FIFRA section 3(c)(2)(B). Events which may be the basis for issuance of a Notice of Intent to Suspend include, but are not limited to, the following:

1. Failure to respond as required by this Notice within 90 days of your receipt of this Notice.

2. Failure to submit on the required schedule an acceptable proposed or final protocol when such is required to be submitted to the Agency for review.

3. Failure to submit on the required schedule an adequate progress report on a study as required by this Notice.

4. Failure to submit on the required schedule acceptable data as required by this Notice.

5. Failure to take a required action or submit adequate information pertaining to any option chosen to address the data requirements (e.g., any required action or information pertaining to submission or citation of existing studies or offers, arrangements, or arbitration on the sharing of costs or the formation of Task Forces, failure to comply with the terms of an agreement or arbitration concerning joint data development or failure to comply with any terms of a data waiver).

6. Failure to submit supportable certifications as to the conditions of submitted studies, as required by Section III-C of this Notice.

7. Withdrawal of an offer to share in the cost of developing required data.

8. Failure of the registrant to whom you have tendered an offer to share in the cost of developing data and provided proof of the registrant's receipt of such offer or failure of a registrant on whom you rely for a generic data exemption either to:

   a. Inform EPA of intent to develop and submit the data required by this Notice on a Data Call-In Response Form and a Requirements Status and Registrant's Response Form.

   b. Fulfill the commitment to develop and submit the data as required by this Notice; or

   c. Otherwise take appropriate steps to meet the requirements stated in this Notice, unless you commit to submit and do submit the required data in the specified time frame.

9. Failure to take any required or appropriate steps, not mentioned above, at any time following the issuance of this Notice.

IV-B. BASIS FOR DETERMINATION THAT SUBMITTED STUDY IS UNACCEPTABLE

The Agency may determine that a study (even if submitted within the required time) is unacceptable and constitutes a basis for issuance of a Notice of Intent to Suspend. The grounds for suspension include, but are not limited to, failure to meet any of the following:

1) EPA requirements specified in the Data Call-In Notice or other documents incorporated by reference (including, as applicable, EPA Pesticide Assessment Guidelines, Data Reporting Guidelines, and GeneTox Health Effects Test Guidelines) regarding the design, conduct, and reporting of required studies. Such requirements include, but are not limited to, those relating to test material, test procedures, selection of species, number of animals, sex and distribution of animals, dose and effect levels to be tested or attained, duration of test, and, as applicable, Good Laboratory Practices.

2) EPA requirements regarding the submission of protocols, including the incorporation of any changes required by the Agency following review.

3) EPA requirements regarding the reporting of data, including the manner of reporting, the completeness of results, and the adequacy of any required supporting (or raw) data, including, but not limited to, requirements referenced or included in this Notice or contained in PR 86-5. All studies must be submitted in the form of a final report; a preliminary report will not be considered to fulfill the submission requirement.

IV-C EXISTING STOCKS OF SUSPENDED OR CANCELLED PRODUCTS

EPA has statutory authority to permit continued sale, distribution and use of existing stocks of a pesticide product which has been suspended or cancelled if doing so would be consistent with the purposes of the Act.

The Agency has determined that such disposition by registrants of existing stocks for a suspended registration when a section 3(c)(2)(B) data request is outstanding generally would not be consistent with the Act's purposes. Accordingly, the Agency anticipates granting registrants permission to sell, distribute, or use existing stocks of suspended product(s) only in exceptional circumstances. If you believe such disposition of existing stocks of your product(s) which may be suspended for failure to comply with this Notice should be permitted, you have the burden of clearly demonstrating to EPA that granting such permission would be consistent with the Act. You also must explain why an "existing stocks" provision is necessary, including a statement of the quantity of existing stocks and your estimate of the time required for their sale, distribution, and use. Unless you meet this burden, the Agency will not consider any request pertaining to the continued sale, distribution, or use of your existing stocks after suspension.

If you request a voluntary cancellation of your product(s) as a response to this Notice and your product is in full compliance with all Agency requirements, you will have, under most circumstances, one year from the date your 90 day response to this Notice is due, to sell, distribute, or use existing stocks. Normally, the Agency will allow persons other than the registrant such as independent distributors, retailers and end users to sell, distribute or use such existing stocks until the stocks are exhausted. Any sale, distribution or use of stocks of voluntarily cancelled products containing an active ingredient for which the Agency has particular risk concerns will be determined on a case-by-case basis.

Requests for voluntary cancellation received after the 90 day response period required by this Notice will not result in the agency granting any additional time to sell, distribute, or use existing stocks beyond a year from the date the 90 day response was due, unless you demonstrate to the Agency that you are in full compliance with all Agency requirements, including the requirements of this Notice. For example, if you decide to voluntarily cancel your registration six months before a 3-year study is scheduled to be submitted, all progress reports and other information necessary to establish that you have been conducting the study in an acceptable and good faith manner must have been submitted to the Agency, before EPA will consider granting an existing stocks provision.

SECTION V. REGISTRANTS' OBLIGATION TO REPORT POSSIBLE UNREASONABLE ADVERSE EFFECTS

Registrants are reminded that FIFRA section 6(a)(2) states that if at any time after a pesticide is registered a registrant has additional factual information regarding unreasonable adverse effects on the environment by the pesticide, the registrant shall submit the information to the Agency. Registrants must notify the Agency of any factual information they have, from whatever source, including but not limited to interim or preliminary results of studies, regarding unreasonable adverse effects on man or the environment. This requirement continues as long as the products are registered by the Agency.

SECTION VI. INQUIRIES AND RESPONSES TO THIS NOTICE

If you have any questions regarding the requirements and procedures established by this Notice, call the contact person(s) listed in Attachment 1, the Data Call-In Chemical Status Sheet.

All responses to this Notice must include completed Data Call-In Response Forms (Attachment 2)and completed Requirements Status and Registrant's Response Forms (Attachment 3), for both (generic and product specific data) and any other documents required by this Notice, and should be submitted to the contact person(s) identified in Attachment 1. If the voluntary cancellation or generic data exemption option is chosen, only the Generic and Product Specific Data Call-In Response Forms need be submitted.

The Office of Compliance (OC) of the Office of Enforcement and Compliance Assurance (OECA), EPA, will be monitoring the data being generated in response to this Notice.

Sincerely yours,

Lois A. Rossi, Director
Special Review and
Reregistration Division

Attachments

The Attachments to this Notice are:

1 - Data Call-In Chemical Status Sheet
2 - Generic Data Call-In and Product Specific Data Call-In Response Forms with Instructions
3 - Generic Data Call-In and Product Specific Data Call-In Requirements Status and Registrant's Response Forms with Instructions
4 - EPA Batching of End-Use Products for Meeting Acute Toxicology Data Requirements for Reregistration
5 - List of Registrants Receiving This Notice
6 - Confidential Statement of Formula, Cost Share and Data Citation Forms

ZINC PHOSPHIDE DATA CALL-IN CHEMICAL STATUS SHEET

INTRODUCTION

You have been sent this Product Specific Data Call-In Notice because you have product(s) containing Zinc phosphide.

This Product Specific Data Call-In Chemical Status Sheet, contains an overview of data required by this notice, and point of contact for inquiries pertaining to the reregistration of Zinc phosphide. This attachment is to be used in conjunction with (1) the Product Specific Data Call-In Notice, (2) the Product Specific Data Call-In Response Form (Attachment 2), (3) the Requirements Status and Registrant's Form (Attachment 3), (4) EPA's Grouping of End-Use Products for Meeting Acute Toxicology Data Requirement (Attachment 4), (5) the EPA Acceptance Criteria (Attachment 5), (6) a list of registrants receiving this DCI (Attachment 6) and (7) the Cost Share and Data Citation Forms in replying to this Zinc phosphide Product Specific Data Call-In (Attachment 7). Instructions and guidance accompany each form.

DATA REQUIRED BY THIS NOTICE

The additional data requirements needed to complete the database for Zinc phosphide are contained in the Requirements Status and Registrant's Response, Attachment 3. The Agency has concluded that additional data on Zinc phosphide are needed for specific products. These data are required to be submitted to the Agency within the time frame listed. These data are needed to fully complete the reregistration of all eligible Zinc phosphide products.

INQUIRIES AND RESPONSES TO THIS NOTICE

If you have any questions regarding this product specific data requirements and procedures established by this Notice, please contact Frank Rubis at (703) 308-8184.

All responses to this Notice for the Product Specific data requirements should be submitted to:

Frank Rubis
Chemical Review Manager Team 81
Product Reregistration Branch
Special Review and Reregistration Branch 7508W
Office of Pesticide Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

RE: **Zinc phosphide**

ZINC PHOSPHIDE DATA CALL-IN CHEMICAL STATUS SHEET

INTRODUCTION

You have been sent this Generic Data Call-In Notice because you have product(s) containing Zinc phosphide.

This Generic Data Call-In Chemical Status Sheet, contains an overview of data required by this notice, and point of contact for inquiries pertaining to the reregistration of Zinc phosphide. This attachment is to be used in conjunction with (1) the Generic Data Call-In Notice, (2) the Generic Data Call-In Response Form (Attachment 2), (3) the Requirements Status and Registrant's Form (Attachment 2), (4) a list of registrants receiving this DCI (Attachment 4), (5) the EPA Acceptance Criteria (Attachment 5), and (6) the Cost Share and Data Citation Forms in replying to this Zinc phosphide Generic Data Call In (Attachment F). Instructions and guidance accompany each form.

DATA REQUIRED BY THIS NOTICE

The additional data requirements needed to complete the generic database for Zinc phosphide are contained in the Requirements Status and Registrant's Response, Attachment C. The Agency has concluded that additional product chemistry data on Zinc phosphide are needed. These data are needed to fully complete the reregistration of all eligible Zinc phosphide products.

INQUIRIES AND RESPONSES TO THIS NOTICE

If you have any questions regarding the generic data requirements and procedures established by this Notice, please contact Dana Lateulere at (703) 308-8044.

All responses to this Notice for the generic data requirements should be submitted to:

Susan Jennings, Chemical Review Manager
Reregistration Branch 3
Special Review and Registration Division (H7508W)
Office of Pesticiafde Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460
RE: Zinc phosphide

Instructions For Completing The "Data Call-In Response Forms" For The Generic And Product Specific Data Call-In

INTRODUCTION

These instructions apply to the Generic and Product Specific "Data Call-In Response Forms" and are to be used by registrants to respond to generic and product specific Data Call-Ins as part of EPA's Reregistration Program under the Federal Insecticide, Fungicide, and Rodenticide Act. If you are an end-use product registrant only and have been sent this DCI letter as part of a RED document you have been sent just the product specific "Data Call-In Response Forms." Only registrants responsible for generic data have been sent the generic data response form. **The type of Data Call-In (generic or product specific) is indicated in item number 3 ("Date and Type of DCI") on each form.**

Although the form is the same for both generic and product specific data, instructions for completing these forms are different. Please read these instructions carefully before filling out the forms.

EPA has developed these forms individually for each registrant, and has preprinted these forms with a number of items. DO NOT use these forms for any other active ingredient.

Items 1 through 4 have been preprinted on the form. Items 5 through 7 must be completed by the registrant as appropriate. Items 8 through 11 must be completed by the registrant before submitting a response to the Agency.

The public reporting burden for this collection of information is estimated to average 15 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Chief, Information Policy Branch, Mail Code 2137, U.S. Environmental Protection Agency, 401 M St., S.W., Washington, D.C. 20460; and to the Office of Management and Budget, Paperwork Reduction Project 2070-0107, Washington, D.C. 20503.

INSTRUCTIONS FOR COMPLETING THE DATA CALL-IN RESPONSE FORMS
Generic and Product Specific Data Call-In

Item 1. **ON BOTH FORMS**: This item identifies your company name, number and address.

Item 2. **ON BOTH FORMS:** This item identifies the case number, case name, EPA chemical number and chemical name.

Item 3. **ON BOTH FORMS:** This item identifies the type of Data Call-In. The date of issuance is date stamped.

Item 4. **ON BOTH FORMS:** This item identifies the EPA product registrations relevant to the data call-in. Please note that you are also responsible for informing the Agency of your response regarding any product that you believe may be covered by this Data Call-In but that is not listed by the Agency in Item 4. You must bring any such apparent omission to the Agency's attention within the period required for submission of this response form.

Item 5. **ON BOTH FORMS:** Check this item for each product registration you wish to cancel voluntarily. If a registration number is listed for a product for which you previously requested voluntary cancellation, indicate in Item 5 the date of that request. Since this Data Call-In requires both generic and product specific data, you must complete item 5 on both Data Call-In response forms. You do not need to complete any item on the Requirements Status and Registrant's Response Forms.

Item 6a. **ON THE GENERIC DATA FORM:** Check this Item if the Data Call-In is for generic data as indicated in Item 3 and you are eligible for a Generic Data Exemption for the chemical listed in Item 2 and used in the subject product. By electing this exemption, you agree to the terms and conditions of a Generic Data Exemption as explained in the Data Call-In Notice.

If you are eligible for or claim a Generic Data Exemption, enter the EPA registration Number of each registered source of that active ingredient that you use in your product.

Typically, if you purchase an EPA-registered product from one or more other producers (who, with respect to the incorporated product, are in compliance with this and any other outstanding Data Call-In Notice), and incorporate that product into all your products, you may complete this item for all products listed on this form. If, however, you produce the active ingredient yourself, or use any unregistered product (regardless of the fact that some of your sources are registered), you may not claim a Generic Data Exemption and you may not select this item.

INSTRUCTIONS FOR COMPLETING THE DATA CALL-IN RESPONSE FORMS
Generic and Product Specific Data Call-In

Item 6b. **ON THE GENERIC DATA FORM:** Check this Item if the Data Call-In is for generic data as indicated in Item 3 and if you are agreeing to satisfy the generic data requirements of this Data Call-In. Attach the Requirements Status and Registrant's Response Form that indicates how you will satisfy those requirements.

NOTE: **Item 6a and 6b are not applicable for Product Specific Data.**

Item 7a. **ON THE PRODUCT SPECIFIC DATA FORM:** For each manufacturing use product (MUP) for which you wish to maintain registration, you must agree to satisfy the data requirements by responding "yes."

Item 7b. For each end use product (EUP) for which you wish to maintain registration, you must agree to satisfy the data requirements by responding "yes."

FOR BOTH MUP and EUP products

You should also respond "yes" to this item (7a for MUP's and 7b for EUP's) if your product is identical to another product and you qualify for a data exemption. You must provide the EPA registration numbers of your source(s); do not complete the Requirements Status and Registrant's Response form. Examples of such products include repackaged products and Special Local Needs (Section 24c) products which are identical to federally registered products.

If you are requesting a data waiver, answer "yes" here; in addition, on the "Requirements Status and Registrant's Response" form under Item 9, you must respond with option 7 (Waiver Request) for each study for which you are requesting a waiver.

NOTE: **Item 7a and 7b are not applicable for Generic Data.**

Item 8. **ON BOTH FORMS:** This certification statement must be signed by an authorized representative of your company and the person signing must include his/her title. Additional pages used in your response must be initialled and dated in the space provided for the certification.

Item 9. **ON BOTH FORMS:** Enter the date of signature.

Item 10. **ON BOTH FORMS:** Enter the name of the person EPA should contact with questions regarding your response.

Item 11. **ON BOTH FORMS:** Enter the phone number of your company contact.

Note: You may provide additional information that does not fit on this form in a signed letter that accompanies your response. For example, you may wish to report that your product has already been transferred to another company or that you have already voluntarily cancelled this product. For these cases, please supply all relevant details so that EPA can ensure that its records are correct.

Instructions For Completing The "Requirements Status and Registrant's Response Forms" For The Generic and Product Specific Data Call-In

INTRODUCTION

These instructions apply to the Generic and Product Specific "Requirements Status and Registrant's Response Forms" and are to be used by registrants to respond to generic and product specific Data Call-In's as part of EPA's reregistration program under the Federal Insecticide, Fungicide, and Rodenticide Act. If you are an end-use product registrant only and have been sent this DCI letter as part of a RED document you have been sent just the product specific "Requirements Status and Registrant's Response Forms." Only registrants responsible for generic data have been sent the generic data response forms. **The type of Data Call-In (generic or product specific) is indicated in item number 3 ("Date and Type of DCI") on each form.**

Although the form is the same for both product specific and generic data, instructions for completing the forms differ slightly. Specifically, options for satisfying product specific data requirements do not include (1) deletion of uses or (2) request for a low volume/minor use waiver. Please read these instructions carefully before filling out the forms.

EPA has developed these forms individually for each registrant, and has preprinted these forms to include certain information unique to this chemical. DO NOT use these forms for any other active ingredient.

Items 1 through 8 have been preprinted on the form. Item 9 must be completed by the registrant as appropriate. Items 10 through 13 must be completed by the registrant before submitting a response to the Agency.

The public reporting burden for this collection of information is estimated to average 30 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Chief, Information Policy Branch, Mail Code 2136, U.S. Environmental Protection Agency, 401 M St., S.W., Washington, D.C. 20460; and to the Office of Management and Budget, Paperwork Reduction Project 2070-0107, Washington, D.C. 20503.

INSTRUCTIONS FOR COMPLETING THE "REQUIREMENTS STATUS AND REGISTRANT'S RESPONSE FORMS"

Generic and Product Specific Data Call-In

Item 1. **ON BOTH FORMS:** This item identifies your company name, number and address.

Item 2. **ON THE GENERIC DATA FORM:** This item identifies the case number, case name, EPA chemical number and chemical name.

ON THE PRODUCT SPECIFIC DATA FORM: This item identifies the case number, case name, and the EPA Registration Number of the product for which the Agency is requesting product specific data.

Item 3. **ON THE GENERIC DATA FORM:** This item identifies the type of Data Call-In. The date of issuance is date stamped.

ON THE PRODUCT SPECIFIC DATA FORM: This item identifies the type of Data Call-In. The date of issuance is also date stamped. Note the unique identifier number (ID#) assigned by the Agency. This ID number must be used in the transmittal document for any data submissions in response to this Data Call-In Notice.

Item 4. **ON BOTH FORMS:** This item identifies the guideline reference number of studies required. These guidelines, in addition to the requirements specified in the Data Call-In Notice, govern the conduct of the required studies. Note that series 61 and 62 in product chemistry are now listed under 40 CFR 158.155 through 158.180, Subpart c.

Item 5. **ON BOTH FORMS:** This item identifies the study title associated with the guideline reference number and whether protocols and 1, 2, or 3-year progress reports are required to be submitted in connection with the study. As noted in Section III of the Data Call-In Notice, 90-day progress reports are required for all studies.

If an asterisk appears in Item 5, EPA has attached information relevant to this guideline reference number to the Requirements Status and Registrant's Response Form.

INSTRUCTIONS FOR COMPLETING THE "REQUIREMENTS STATUS AND REGISTRANT'S RESPONSE FORMS"

Generic and Product Specific Data Call-In

Item 6. **ON BOTH FORMS:** This item identifies the code associated with the use pattern of the pesticide. In the case of efficacy data (product specific requirement), the required study only pertains to products which have the use sites and/or pests indicated. A brief description of each code follows:

A	Terrestrial food
B	Terrestrial feed
C	Terrestrial non-food
D	Aquatic food
E	Aquatic non-food outdoor
F	Aquatic non-food industrial
G	Aquatic non-food residential
H	Greenhouse food
I	Greenhouse non-food crop
J	Forestry
K	Residential
L	Indoor food
M	Indoor non-food
N	Indoor medical
O	Indoor residential

Item 7. **ON BOTH FORMS:** This item identifies the code assigned to the substance that must be used for testing. A brief description of each code follows:

EUP	End-Use Product
MP	Manufacturing-Use Product
MP/TGAI	Manufacturing-Use Product and Technical Grade Active Ingredient
PAI	Pure Active Ingredient
PAI/M	Pure Active Ingredient and Metabolites
PAI/PAIRA	Pure Active Indredient or Pute Active Ingredient Radiolabelled
PAIRA	Pure Active Ingredient Radiolabelled
PAIRA/M	Pure Active Ingredient Radiolabelled and Metabolites
PAIRA/PM	Pure Active Ingredient Radiolabelled and Plant Metabolites
TEP	Typical End-Use Product
TEP ___%	Typical End-Use Product, Percent Active Ingredient Specified
TEP/MET	Typical End-Use Product and Metabolites

TEP/PAI/M	Typical End-Use Product or Pure Active Ingredient and Metabolites
TGAI	Technical Grade Active Ingredient
TGAI/PAI	Technical Grade Active Ingredient or Pure Active Ingredient
TGAI/PAIRA	Technical Grade Active Ingredient or Pure Active Ingredient Radiolabelled
TGAI/TEP	Technical Grade Active Ingredient or Typical End-Use Product
MET	Metabolites
IMP	Impurities
DEGR	Degradates
*	See: guideline comment

Item 8. This item completed by the Agency identifies the time frame allowed for submission of the study or protocol identified in item 5.

ON THE GENERIC DATA FORM: The time frame runs from the date of your receipt of the Data Call-In notice.

ON THE PRODUCT SPECIFIC DATA FORM: The due date for submission of product specific studies begins from the date stamped on the letter transmitting the Reregistration Eligibility Decision document, and not from the date of receipt. However, your response to the Data Call-In itself is due 90 days from the date of receipt.

Item 9. **ON BOTH FORMS:** Enter the appropriate Response Code or Codes to show how you intend to comply with each data requirement. Brief descriptions of each code follow. The Data Call-In Notice contains a fuller description of each of these options.

Option 1. **ON BOTH FORMS:** (Developing Data) I will conduct a new study and submit it within the time frames specified in item 8 above. By indicating that I have chosen this option, I certify that I will comply with all the requirements pertaining to the conditions for submittal of this study as outlined in the Data Call-In Notice and that I will provide the protocols and progress reports required in item 5 above.

Option 2. **ON BOTH FORMS:** (Agreement to Cost Share) I have entered into an agreement with one or more registrants to develop data jointly. By indicating that I have chosen this option, I certify that I will comply with all the requirements pertaining to sharing in the cost of developing data as outlined in the Data Call-In Notice.

However, for Product Specific Data, I understand that this option is available for acute toxicity or certain efficacy data **ONLY** if the Agency indicates in an attachment to this notice that my product is similar enough to another product to qualify for this option. I certify that another party in the agreement is committing to submit or provide the required data; if the required study is not submitted on time, my product may be subject to suspension.

Option 3. **ON BOTH FORMS:** (Offer to Cost Share) I have made an offer to enter into an agreement with one or more registrants to develop data jointly. I am also submitting a completed "Certification of offer to Cost Share in the Development of Data" form. I am submitting evidence that I have made an offer to another registrant (who has an obligation to submit data) to share in the cost of that data. I am including a copy of my offer and proof of the other registrant's receipt of that offer. I am identifying the party which is committing to submit or provide the required data; if the required study is not submitted on time, my product may be subject to suspension. I understand that other terms under Option 3 in the Data Call-In Notice apply as well.

However, for Product Specific Data, I understand that this option is available only for acute toxicity or certain efficacy data and only if the Agency indicates in an attachment to this Data Call-In Notice that my product is similar enough to another product to qualify for this option.

Option 4. **ON BOTH FORMS:** (Submitting Existing Data) I will submit an existing study by the specified due date that has never before been submitted to EPA. By indicating that I have chosen this option, I certify that this study meets all the requirements pertaining to the conditions for submittal of existing data outlined in the Data Call-In Notice and I have attached the needed supporting information along with this response.

Option 5. **ON BOTH FORMS:** (Upgrading a Study) I will submit by the specified due date, or will cite data to upgrade a study that EPA has classified as partially acceptable and potentially upgradeable. By indicating that I have chosen this option, I certify that I have met all the requirements pertaining to the conditions for submitting or citing existing data to upgrade a study described in the Data Call-In Notice. I am indicating on attached correspondence the Master Record Identification Number (MRID) that EPA has assigned to the data that I am citing as well as the MRID of the study I am attempting to upgrade.

Option 6. **ON BOTH FORMS:** (Citing a Study) I am citing an existing study that has been previously classified by EPA as acceptable, core, core minimum, or a study that has not yet been reviewed by the Agency. If reviewed, I am providing the Agency's classification of the study.

However, for Product Specific Data, I am citing another registrant's study. I understand that this option is available **ONLY** for acute toxicity or certain efficacy data and **ONLY** if the cited study was conducted on my product, an identical product or a product which the Agency has "grouped" with one or more other products for purposes of depending on the same data. I may also choose this option if I am citing my own data. In either case, I will provide the MRID or Accession number (s). If I cite another registrant's data, I will submit a completed "Certification With Respect To Data Citation Requirements" form.

FOR THE GENERIC DATA FORM ONLY: The following three options (Numbers 7, 8, and 9) are responses that apply only to the "Requirements Status and Registrant's Response Form" for generic data.

Option 7. (Deleting Uses) I am attaching an application for amendment to my registration deleting the uses for which the data are required.

Option 8. (Low Volume/Minor Use Waiver Request) I have read the statements concerning low volume-minor use data waivers in the Data Call-In Notice and I request a low-volume minor use waiver of the data requirement. I am attaching a detailed justification to support this waiver request including, among other things, all information required to support the request. I understand that, unless modified by the Agency in writing, the data requirement as stated in the Notice governs.

Option 9. (Request for Waiver of Data) I have read the statements concerning data waivers other than lowvolume minor-use data waivers in the Data Call-In Notice and I request a waiver of the data requirement. I am attaching a rationale explaining why I believe the data requirements do not apply. I am also submitting a copy of my current labels. (You must also submit a copy of your Confidential Statement of Formula if not already on file with EPA). I understand that, unless modified by the Agency in writing, the data requirement as stated in the Notice governs.

FOR PRODUCT SPECIFIC DATA: The following option (number 7) is a response that applies to the "Requirements Status and Registrant's Response Form" for product specific data.

Option 7. (Waiver Request) I request a waiver for this study because it is inappropriate for my product. I am attaching a complete justification for this request, including technical reasons, data and references to relevant EPA regulations, guidelines or policies. [Note: any supplemental data must be submitted in the format required by P.R. Notice 86-5]. I understand that this is my only opportunity to state the reasons or provide information in support of my request. If the Agency approves my waiver request, I will not be required to supply the data pursuant to Section 3(c) (2) (B) of FIFRA. If the Agency denies my waiver request, I must choose a method of meeting the data requirements of this Notice by the due date stated by this Notice. In this case, I must, within 30 days-of my receipt of the Agency's written decision, submit a revised "Requirements Status" form specifying the option chosen. I also understand that the deadline for submission of data as specified by the original Data Call-In notice will not change.

Item 10. **ON BOTH FORMS:** This item must be signed by an authorized representative of your company. The person signing must include his/her title, and must initial and date all other pages of this form.

Item 11. **ON BOTH FORMS:** Enter the date of signature.

Item 12. **ON BOTH FORMS:** Enter the name of the person EPA should contact with questions regarding your response.

Item 13. **ON BOTH FORMS:** Enter the phone number of your company contact.

NOTE: You may provide additional information that does not fit on this form in a signed letter that accompanies this your response. For example, you may wish to report that your product has already been transferred to another company or that you have already voluntarily cancelled this product. For these

EPA'S BATCHING OF PRODUCTS CONTAINING ZINC PHOSPHIDE AS THE ACTIVE INGREDIENT FOR MEETING ACUTE TOXICITY DATA REQUIREMENTS FOR REREGISTRATION

In an effort to reduce the time, resources and number of animals needed to fulfill the acute toxicity data requirements for reregistration of products containing the active ingredient zinc phosphide, the Agency has batched products which can be considered similar in terms of acute toxicity. Factors considered in the sorting process include each product's active and inert ingredients (identity, percent composition and biological activity), product form (liquid, paste, solid, etc.), and labeling (e.g., signal word, precautionary labeling, etc.).

Using available information, batching has been accomplished by the process described in the preceding paragraph. Notwithstanding the batching process, the Agency reserves the right to require, at any time, acute toxicity data for an individual product should the need arise.

Registrants of products within a batch may choose to cooperatively generate, submit or cite a single battery of six acute toxicological studies to represent all the products within that batch. It is the registrants' option to participate in the process with all other registrants, only some of the other registrants, or only their own products within a batch, or to generate all the required acute toxicological studies for each of their own products. If a registrant chooses to generate the data for a batch, he/she must use one of the products within the batch as the test material. If a registrant chooses to rely upon previously submitted acute toxicity data, he/she may do so provided that the data base is complete and valid by today's standards (see acceptance criteria attached), the formulation tested is considered by EPA to be similar for acute toxicity, and the formulation has not been significantly altered since submission and acceptance of the acute toxicity data. TRB must approve any new formulations (that were presented to the Agency after the publication of the RED) before data derived from them can be used to cover other products in a batch. Regardless of whether new data is generated or existing data is referenced, registrants must clearly identify the test material by EPA Registration Number. If more than one confidential statement of formula (CSF) exists for a product, the registrant must indicate the formulation actually tested by identifying the corresponding CSF.

In deciding how to meet the product specific data requirements, registrants must follow the directions given in the Data Call-In Notice and its attachments appended to the RED. The DCI Notice contains two response forms which are to be completed and submitted to the Agency within 90 days of receipt. The first form, "Data Call-In Response," asks whether the registrant will meet the data requirements for each product. The second form, "Requirements Status and Registrant's Response," lists the product specific data required for each product, including the standard six acute toxicity tests. A registrant who wishes to participate in a batch must decide whether he/she will provide the data or depend on someone else to do so. If a registrant supplies the data to support a batch of products, he/she must select one of the following options: Developing Data (Option 1), Submitting an Existing Study (Option 4), Upgrading an Existing Study (Option 5) or Citing an Existing Study (Option 6). If a registrant depends on another's data, he/she must choose among: Cost Sharing (Option 2), Offers to Cost Share (Option 3) or Citing an Existing Study (Option 6). If a registrant does not want to participate in a batch, the choices are Options 1, 4, 5 or 6. However, a registrant should know that choosing not to participate in a batch does not preclude other registrants in the batch from citing his/her studies and offering to cost share (Option 3) those studies.

Table 1 displays the batches for the active ingredient zinc phosphide.

Table 1.

Batch	Registration Number	Percent Active Ingredient	Form
1	769-741	zinc phosphide ... 94%	powder
	61282-3	zinc phosphide ... 93%	powder
2	769-656	zinc phosphide ... 80%	solid
	769-743	zinc phosphide ... 80%	solid
	4221-11	zinc phosphide ... 80%	solid
	12455-24	zinc phosphide ... 80%	solid
	61282-13	zinc phosphide ... 82%	solid
3	769-756	zinc phosphide ... 62%	solid
	56228-6	zinc phosphide ... 63.2%	solid
	56228-9	zinc phosphide ... 63.2%	solid
	ID91001800	zinc phosphide ... 63.2%	solid
	TX95000200	zinc phosphide ... 63.2%	solid
4	7173-197	zinc phosphide ... 10.3%	solid
	12455-16	zinc phosphide ... 10.0%	solid
5	4-152	zinc phosphide ... 2%	solid

	4-285	zinc phosphide ... 2%	solid
	30-25	zinc phosphide ... 2%	solid
	192-204	zinc phosphide ... 2%	solid
	192-205	zinc phosphide ... 2%	solid
	322-8	zinc phosphide ... 2%	solid
	358-165	zinc phosphide ... 2%	solid
	814-9	zinc phosphide ... 2%	solid
	2393-185	zinc phosphide ... 2%	solid
	2393-521	zinc phosphide ... 2%	solid
	2393-522	zinc phosphide ... 2%	solid
	4271-16	zinc phosphide ... 1.82%	solid
	5887-179	zinc phosphide ... 2%	solid
	7122-124	zinc phosphide ... 2%	solid
	7173-195	zinc phosphide ... 1.88%	solid
	12455-17	zinc phosphide ... 2%	solid
	12455-18	zinc phosphide ... 2%	solid
	12455-30	zinc phosphide ... 2%	solid
	12455-59	zinc phosphide ... 2%	solid
	12455-85	zinc phosphide ... 2%	solid
	13808-6	zinc phosphide ... 2%	solid
	36029-10	zinc phosphide ... 2%	solid
	36029-12	zinc phosphide ... 2%	solid

36029-13	zinc phosphide	... 2%	solid
56228-3	zinc phosphide	... 1.82%	solid
56228-14	zinc phosphide	... 2%	solid
61282-14	zinc phosphide	... 2%	solid
61282-20	zinc phosphide	... 2%	solid
CA89002600	zinc phosphide	... 1%	solid
CA89002700	zinc phosphide	... 2%	solid
HI96000700	zinc phosphide	... 2%	solid
IL97000100	zinc phosphide	... 2%	solid
IN83000300	zinc phosphide	... 2%	solid
KS97000100	zinc phosphide	... 2%	solid
KY96000500	zinc phosphide	... 2%	solid
MO96001400	zinc phosphide	... 2%	solid
MT89000900	zinc phosphide	... 2%	solid
MT95000300	zinc phosphide	... 2%	solid
NE97000100	zinc phosphide	... 2%	solid
OH85000100	zinc phosphide	... 2%	solid
OR95002100	zinc phosphide	... 2%	solid
TX95000200	zinc phosphide	... 2%	solid
VT90000200	zinc phosphide	... 2%	solid
WA91000300	zinc phosphide	... 2%	solid
WA91001800	zinc phosphide	... 2%	solid

	WA95002200	zinc phosphide ... 2%	solid
	WY92000200	zinc phosphide ... 2%	solid
	WY92000300	zinc phosphide ... 2%	solid

There was no “No Batch” group for this RED.

The following is a list of available documents for Zinc phosphide that my further assist you in responding to this Reregistration Eligibility Decision document. These documents may be obtained by the following methods:

Electronic
File format: Portable Document Format (.PDF) Requires Adobe® Acrobat or compatible reader. Electronic copies can be downloaded from the internet using WWW (World Wide Web) at www.epa.gov/REDs.

1. PR Notice 86-5.

2. PR Notice 91-2 (pertains to the Label Ingredient Statement).

3. A full copy of this RED document.

4. A copy of the fact sheet for zinc phosphide.

The following documents are part of the Administrative Record for Zinc phosphide and may included in the EPA's Office of Pesticide Programs Public Docket. Copies of these documents are not available electronically, but may be obtained by contacting the person listed on the Chemical Status Sheet.

1. Health and Environmental Effects Science Chapters.

2. Detailed Label Usage Information System (LUIS) Report.

The following Agency reference documents are not available electronically, but may be obtained by contacting the person listed on the Chemical Status Sheet of this RED document.

1. The Label Review Manual.

2. EPA Acceptance Criteria

Instructions for Completing the Confidential Statement of Formula

The Confidential Statement of Formula (CSF) Form 8570-4 must be used. Two legible, signed copies of the form are required. Following are basic instructions:

a. All the blocks on the form must be filled in and answered completely.

b. If any block is not applicable, mark it N/A.

c. The CSF must be signed, dated and the telephone number of the responsible party must be provided.

d. All applicable information which is on the product specific data submission must also be reported on the CSF.

e. All weights reported under item 7 must be in pounds per gallon for liquids and pounds per cubic feet for solids.

f. Flashpoint must be in degrees Fahrenheit and flame extension in inches.

g. For all active ingredients, the EPA Registration Numbers for the currently registered source products must be reported under column 12.

h. The Chemical Abstracts Service (CAS) Numbers for all actives and inerts and all common names for the trade names must be reported.

i. For the active ingredients, the percent purity of the source products must be reported under column 10 and must be exactly the same as on the source product's label.

j. All the weights in columns 13.a. and 13.b. must be in pounds, kilograms, or grams. In no case will volumes be accepted. Do not mix English and metric system units (i.e., pounds and kilograms).

k. All the items under column 13.b. must total 100 percent.

1. All items under columns 14.a. and 14.b. for the active ingredients must represent pure active form.

m. The upper and lower certified limits for ail active and inert ingredients must follow the 40 CFR 158.175 instructions. An explanation must be provided if the proposed limits are different than standard certified limits.

n. When new CSFs are submitted and approved, all previously submitted CSFs become obsolete for that specific formulation.

Attachment 1. List of All Registrants Sent This Data Call-In (insert) Notice

Instructions for Completing the Confidential Statement of Formula

The Confidential Statement of Formula (CSF) Form 8570-4 must be used. Two legible, signed copies of the form are required. Following are basic instructions:

a. All the blocks on the form must be filled in and answered completely.

b. If any block is not applicable, mark it N/A.

c. The CSF must be signed, dated and the telephone number of the responsible party must be provided.

d. All applicable information which is on the product specific data submission must also be reported on the CSF.

e. All weights reported under item 7 must be in pounds per gallon for liquids and pounds per cubic feet for solids.

f. Flashpoint must be in degrees Fahrenheit and flame extension in inches.

g. For all active ingredients, the EPA Registration Numbers for the currently registered source products must be reported under column 12.

h. The Chemical Abstracts Service (CAS) Numbers for all actives and inerts and all common names for the trade names must be reported.

i. For the active ingredients, the percent purity of the source products must be reported under column 10 and must be exactly the same as on the source product's label.

j. All the weights in columns 13.a. and 13.b. must be in pounds, kilograms, or grams. In no case will volumes be accepted. Do not mix English and metric system units (i.e., pounds and kilograms).

k. All the items under column 13.b. must total 100 percent.

1. All items under columns 14.a. and 14.b. for the active ingredients must represent pure active form.

m. The upper and lower certified limits for ail active and inert ingredients must follow the 40 CFR 158.175 instructions. An explanation must be provided if the proposed limits are different than standard certified limits.

n. When new CSFs are submitted and approved, all previously submitted CSFs become obsolete for that specific formulation.

Confidential Business Information: Does Not Contain National Security Information (E.O. 12065)

Form Approved. OMB No. 2070-0060. Approval Expires 2/28/94

EPA

United States Environmental Protection Agency
Office of Pesticide Programs (TS-767)
Washington, DC 20460

Confidential Statement of Formula

A. ☐ Basic Formulation ☐ Alternate Formulation

B. Page of

See Instructions on Back

1. Name and Address of Applicant/Registrant *(Include ZIP Code)*	2. Name and Address of Producer *(Include ZIP Code)*

3. Product Name	4. Registration No./File Symbol	5. EPA Product Mgr/Team No.	6. Country Where Formulated
	7. Pounds/Gal or Bulk Density	8. pH	9. Flash Point/Flame Extension

EPA USE ONLY	10. Components in Formulation *(List as actually introduced into the formulation. Give commonly accepted chemical name, trade name, and CAS number.)*	11. Supplier Name & Address	12. EPA Reg. No.	13. Each Component in Formulation a. Amount	13. b. % by Weight	14. Certified Limits % by Weight a. Upper Limit	14. b. Lower Limit	15. Purpose in Formulation

16. Typed Name of Approving Official		17. Total Weight	100%
18. Signature of Approving Official	19. Title	20. Phone No. *(Include Area Code)*	21. Date

EPA Form 8570-4 (Rev. 12-90) **Previous editions are obsolete.** If you can photocopy this, please submit an additional copy. White - EPA File Copy (original) Yellow - Applicant copy

United States Environmental Protection Agency Washington, D.C. 20460 **Certification of Offer to Cost Share in the Development of Data**	**Form Approved OMB No. 2070-0106, 2070-0057 Approval Expires 3-31-99**

Public reporting burden for this collection of information is estimated to average 15 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to, Chief Information Policy Branch, PM-233, U.S. Environmental Protection Agency, 401 M St., S.W., Washington, DC 20460; and to the Office of Management and Budget, Paperwork Reduction Project (2070-0106), Washington, DC 20503.

Please fill in blanks below:

Company Name	**Company Number**
Product Name	**EPA Reg. No.**

I Certify that:

My company is willing to develop and submit the data required by EPA under the authority of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), if necessary. However my company would prefer to enter into an agreement with one or more registrants to develop jointly or share in the cost of developing data.

My firm has offered in writing to enter into such an agreement. That offer was irrevocable and included an an offer to be bound by arbitration decision under section 3(c)(2)(B)(iii) of FIFRA if final agreement on all terms could not be reached otherwise. This offer was made to the following firms on the following date(s):

Name of Firm(s)	**Date of Offer**

Certification:

I certify that I am duly authorized to represent the company named above, and that the statements that I have made on this form and all attachments therein are true, accurate, and complete. I acknowledge that any knowingly false or misleading statement may be punishable by fine or imprisonment or both under applicable law.

Signature of Company's Authorized Representative	**Date**
Name and Title (Please Type or Print)	

EPA Form 8570-32 (5/91) Replaces EPA form 8580 which is obselete

Form Approved OMB No. 2070-0060

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
401 M Street, S.W.
WASHINGTON, D.C. 20460

Paperwork Reduction Act Notice: The public reporting burden for this collection of information is estimated to average 1.25 hours per response for registration and 0.25 hours per response for reregistration and special review activities, including time for reading the instructions and completing the necessary forms. Send comments regarding burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to: Director, OPPE Information Management Division (2137), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460.
Do not send the completed form to this address.

Certification with Respect to Citation of Data

Applicant's/Registrant's Name, Address, and Telephone Number	EPA Registration Number/File Symbol
Active Ingredient(s) and/or representative test compound(s)	Date
General Use Pattern(s) (list all those claimed for this product using 40 CFR Part 158)	Product Name

NOTE: If your product is a 100% repackaging of another purchased EPA-registered product labeled for all the same uses on your label, you do not need to submit this form. You must submit the Formulator's Exemption Statement (EPA Form 8570-27).

☐ I am responding to a Data-Call-In Notice, and have included with this form a list of companies sent offers of compensation (the Data Matrix form should be used for this purpose).

SECTION I: METHOD OF DATA SUPPORT (Check one method only)

☐ I am using the cite-all method of support, and have included with this form a list of companies sent offers of compensation (the Data Matrix form should be used for this purpose).

☐ I am using the selective method of support (or cite-all option under the selective method), and have included with this form a completed list of data requirements (the Data Matrix form must be used).

SECTION II: GENERAL OFFER TO PAY

[Required if using the cite-all method or when using the cite-all option under the selective method to satisfy one or more data requirements]

☐ I hereby offer and agree to pay compensation, to other persons, with regard to the approval of this application, to the extent required by FIFRA.

SECTION III: CERTIFICATION

I certify that this application for registration, this form for reregistration, or this Data-Call-In response is supported by all data submitted or cited in the application for registration, the form for reregistration, or the Data-Call-In response. In addition, if the cite-all option or cite-all option under the selective method is indicated in Section I, this application is supported by all data in the Agency's files that (1) concern the properties or effects of this product or an identical or substantially similar product, or one or more of the ingredients in this product; and (2) is a type of data that would be required to be submitted under the data requirements in effect on the date of approval of this application if the application sought the initial registration of a product of identical or similar composition and uses .

I certify that for each exclusive use study cited in support of this registration or reregistration, that I am the original data submitter or that I have obtained the written permission of the original data submitter to cite that study.

I certify that for each study cited in support of this registration or reregistration that is not an exclusive use study, either: (a) I am the original data submitter; (b) I have obtained the permission of the original data submitter to use the study in support of this application; (c) all periods of eligibility for compensation have expired for the study; (d) the study is in the public literature; or (e) I have notified in writing the company that submitted the study and have offered (I) to pay compensation to the extent required by sections 3(c)(1)(F) and/or 3(c)(2)(B) of FIFRA; and (ii) to commence negotiations to determine the amount and terms of compensation, if any, to be paid for the use of the study.

I certify that in all instances where an offer of compensation is required, copies of all offers to pay compensation and evidence of their delivery in accordance with sections 3(c)(1)(F) and/or 3(c)(2)(B) of FIFRA are available and will be submitted to the Agency upon request. Should I fail to produce such evidence to the Agency upon request, I understand that the Agency may initiate action to deny, cancel or suspend the registration of my product in conformity with FIFRA.

I certify that the statements I have made on this form and all attachments to it are true, accurate, and complete. I acknowledge that any knowingly false or misleading statement may be punishable by fine or imprisonment or both under applicable law.

Signature	Date	Typed or Printed Name and Title

EPA Form 8570-34 (9-97) Electronic and Paper versions available. Submit only Paper version.

Form Approved OMB No. 2070-0060

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
401 M Street, S.W.
WASHINGTON, D.C. 20460

Paperwork Reduction Act Notice: The public reporting burden for this collection of information is estimated to average 0.25 hours per response for registration activities and 0.25 hours per response for reregistration and special review activities, including time for reading the instructions and completing the necessary forms. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to: Director, OPPE Information Management Division (2137), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460. Do not send the form to this address.

DATA MATRIX

Date			EPA Reg No./File Symbol		Page of
Applicant's/Registrant's Name & Address			Product		
Ingredient					
Guideline Reference Number	Guideline Study Name	MRID Number	Submitter	Status	Note
[redacted]					
Signature			Name and Title		Date

EPA Form 8570-35 (9-97) Electronic and Paper versions available. Submit only Paper version. **Public File Copy**

Form Approved OMB No. 2070-0060

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
401 M Street, S.W.
WASHINGTON, D.C. 20460

Paperwork Reduction Act Notice: The public reporting burden for this collection of information is estimated to average 0.25 hours per response for registration activities and 0.25 hours per response for reregistration and special review activities, including time for reading the instructions and completing the necessary forms. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to: Director, OPPE Information Management Division (2137), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460. Do not send the form to this address.

DATA MATRIX

Date	EPA Reg No./File Symbol	Page of
Applicant's/Registrant's Name & Address	Product	
Ingredient		

Guideline Reference Number	Guideline Study Name	MRID Number	Submitter	Status	Note

Signature	Name and Title	Date

EPA Form 8570-35 (9-97) Electronic and Paper versions available. Submit only Paper version. **Agency Internal Use Copy**

INSTRUCTIONS FOR DATA MATRIX

INSTRUCTIONS: Identify all data submitted or cited and all submitters from whom permission has been received or to whom offers to pay have been sent by entering sufficient information in the attached matrix (photocopy and attach additional pages as necessary). Complete all columns; omission of essential information will delay approval of the registration/reregistration. On each page enter the date, Applicant's/Registrant's name, EPA Registration Number or application file symbol of the product, ingredient, page number, and total number of pages.

The Data Compensation Form entitled "Certification with Respect to Citation of Data" and the Data Matrix will be publicly available, except for the Guideline Reference Number, Guideline Study Name, and MRID Number columns after the registration/reregistration of this product has been granted or once this form is received in response to a Data-Call-In Notice. However, the information in the Guideline Reference Number, Guideline Study Name, and MRID Number columns is available through the Freedom of Information Act in association with the EPA Registration Number.

Ingredient: Identify the active ingredient(s) in this product for which data are cited. The active ingredient(s) are to be identified by entering the chemical name and the CAS registry number. Begin a new page for each separate active ingredient for which data are cited. If bridging data from a related chemical or representative test compound are cited, enter the identity of that chemical/representative test compound including the EPA Registration Number/File Symbol if appropriate.

If the cite-all method is used for all data supporting this particular ingredient, enter "CITE-ALL" in the Guideline Reference Number column and leave the Guideline Study Name column blank. If the cite-all method is used for a particular Guideline Reference Number enter "CITE-ALL" in the MRID Number column on the line for that Guideline Reference Number. In either case, enter all submitters to whom offers to pay have been sent on subsequent lines. [Note: if the selective method of support is used and written authorization (letter of permission) is provided, the individual Guideline Reference Number, Guideline Study Name, and MRID Number columns must still be completed.] Otherwise:

Guideline Reference Number: Enter on separate lines in numerical order the Guideline Reference Numbers from 40 CFR Part 158 for all studies cited to support the registration/reregistration for this ingredient.

Guideline Study Name: For each Guideline Reference Number cited, enter the corresponding Guideline Study Name.

MRID Number: For each individual study cited in support of a Guideline Reference Number and Guideline Study Name, enter the Master Record Identification (MRID) Number listed in the Pesticide Document Management System (PDMS). Enter only one MRID Number on each line. Note that more than one MRID Number may be required per Guideline Reference Number. Note: Occasionally a study required to maintain a registration/reregistration is not associated with a Guideline Reference Number and Guideline Study Name. In such case, enter the MRID Number(s) for the study(ies).

Submitter: Using the most recent Data Submitters List, identify the Original Data Submitter with their current address for each study cited. The EPA assigned company number or other abbreviation may be used. Clearly explain any variations (alternate addresses, data owners not on the Data Submitters List, etc.) in footnotes to this table.

Status: Enter one of the following codes for each study cited, as appropriate:

OWN: I am the Original Data Submitter for this study.

EXC: I have obtained written permission of the Original Data Submitter to cite this exclusive-use study in support of this application.

PER: I have obtained the permission of the Original Data Submitter to use this study in support of this application.

OLD: The study was submitted more than 15 years ago and all periods of compensation have expired.

PL: The study is in the public literature.

PAY: I have notified in writing the Original Data Submitter or, if the cite-all method is used, all companies listed in the most current Data Submitters List for this ingredient, and have offered (a) to pay compensation in accordance with FIFRA sections 3(c)(1)(F) and/or 3(c)(2)(B), and (b) to commence negotiations to determine the amount and terms of compensation, if any, to be paid for the use of the study(ies).

GAP: This Guideline data requirement is a data gap as defined in 40 CFR sections 152.83(a) and 152.96.

FOR: I am taking the formulator's exemption for this ingredient only. Other columns of this line should be marked "NA". However, if this product is to be registered/reregistered for additional uses for which the purchased EPA registered ingredient is not supported, additional data must be submitted or cited here to support those uses.

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[0] Required to support the broadcast applications. The consortium must consult with EPA prior to initiating studies to ensure agreement on the appropriate test material and test protocols.

[0] Required to retain artichoke (globe), sugar beet tops, and sugar beet roots uses. Proposed use directions must reflect the use patterns contained in the adequate residue data from the original tolerance petitions.

[0] Data are required concerning the length and conditions of sample storage for grapes, rangeland grass forage and sugarcane. Dates of harvest and analysis are also required for sugarcane.

[0] Required for grapes, grass forage and sugarcane if samples in field trial studies were stored for longer than 30 days (grapes) or 6 months (grass forage and sugarcane) prior to analysis.

4

Genetics and landscape connectivity

RICHARD FRANKHAM

INTRODUCTION

Most threatened species on the planet are being affected by habitat fragmentation (WCMC 1992). Habitat fragmentation involves two processes, a reduction in total habitat area and creation of separate isolated patches from a large continuous distribution, i.e., reduced connectivity among populations. This chapter deals with the genetic impacts of the latter of these effects.

Fragmentation and reduced connectivity are of major importance in conservation biology, as they affect extinction risk. Genetic factors affecting extinction risk in small fragmented populations are inbreeding depression, loss of genetic diversity, reduced ability to adapt to environmental change, loss of self-incompatibility alleles, mutation accumulation, and outbreeding depression (Frankham *et al.* 2002).

This chapter discusses the genetic effects of small population size and fragmentation, the impacts of different population structures, assessments of connectivity and measurement of gene flow, and concludes with consideration of the effects of fragmentation in species with diverse breeding systems and the evolutionary consequences of long-term fragmentation. Readers are referred to Frankham *et al.* (2002 and 2004) for more details on these topics and additional references, the former textbook having detailed referenced reviews and the latter a shorter simpler treatment.

GENETIC IMPACTS OF SMALL POPULATION SIZES AND FRAGMENTATION

Inbreeding and loss of genetic diversity are unavoidable in small isolated populations. For example, random mating populations lose neutral

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genetic diversity and become inbred over generations at greater rates in small than large populations, as described by the following equation (Frankham *et al.* 2002):

$$H_t/H_0 = [1 - 1/(2N_e)]^t = 1 - F \quad (4.1)$$

where H_t is heterozygosity at generation t, H_0 initial heterozygosity, N_e the effective population size, and F the inbreeding coefficient. The effective population size of a population is the number of individuals that would result in the same inbreeding or loss of genetic diversity or genetic drift (see below) if they behaved in the manner of an idealized population with random mating, Poisson variation in family sizes, and equal number per generation. Most natural populations violate these assumptions and have effective sizes much less than their census sizes; N_e is often only about 10% of the census population size (Frankham 1995). Inbreeding increases at a greater rate than above in species that habitually self-fertilize.

Inbreeding increases homozygosity, exposes deleterious alleles, and thus reduces survival and reproduction (inbreeding depression) in essentially all well-studied naturally outbreeding species (Frankham *et al.* 2002). In spite of early scepticism about its effects, inbreeding depression has been documented in many species, both in captivity (Ralls *et al.* 1988) and in the wild (Crnokrak and Roff 1999). It is a well-established cause of extinctions in captive populations and has been implicated in extinction in two species in the wild (Newman and Pilson 1997; Saccheri *et al.* 1998). Computer projections indicate that it is likely to increase extinction risk in most naturally outbreeding threatened species (Brook *et al.* 2002; O'Grady *et al.* 2006). Inbreeding depression also occurs in species that naturally inbreed, but usually at a lower level than for natural outbreeding species, as natural selection is usually more effective at removing (purging) deleterious recessive alleles in inbred populations (Husband and Schemske 1996).

Species face recurring environmental changes from climate change, changes in disease organisms, predators and competitors, etc. To cope with this they may either physiologically adapt, move, or evolve. When environmental changes are large, usually the only options are to evolve or become extinct. As genetic diversity is required for species to evolve, loss of genetic diversity reduces the ability of species and populations to evolve to cope with environmental change and thus increases extinction risk (Frankham *et al.* 2002).

Self-incompatible species suffer from an additional deleterious impact of loss of genetic diversity (Frankham *et al.* 2002). Self-incompatibility occurs in perhaps one-half of all flowering plant species where it prevents or greatly reduces self-fertilization. It is controlled by one or more genetic loci that have many alleles in large populations. In its simplest form, a plant of genotype S_1S_2 at a self-incompatibility locus cannot be fertilized by pollen bearing S_1 or S_2 alleles, but can be fertilized by S_3, S_4, . . . pollen. In small isolated populations, self-incompatibility alleles are lost, reducing mate availability and population fitness and potentially resulting in extinction. For example, the Lakeside daisy (*Hymenoxys acaulis* var. *glabra*) population in Illinois became so small and lost so many self-incompatibility alleles that it did not reproduce for 15 years, in spite of known pollen flow (Demauro 1993). It was only recovered following gene flow from populations elsewhere that had not suffered similarly. Young *et al.* (2000) provided a detailed analysis of the effects of loss of self-incompatibility alleles in an endangered grassland daisy (*Rutidosis leptorrhynchoides*) in southeastern Australia. While this effect has only been described in a handful of species, it will occur in most threatened self-incompatible species.

In small populations, selection is less effective than in large populations, so mildly deleterious alleles become effectively neutral and their fate is determined by random sampling (genetic drift). Some drift to fixation and thus reduce population fitness (Lande 1995; Lynch *et al.* 1995). Mutational accumulation clearly has a role in the long-term decline of asexual species with low population sizes (Zeyl *et al.* 2001). However, its role in extinctions of sexual species is controversial and likely to be less than that of inbreeding (Gilligan *et al.* 1997; Frankham *et al.* 2002; Garcia-Dorado 2003). The risk of mutation accumulation increases with population fragmentation and reduced connectivity (Higgins and Lynch 2001).

Crossing between genetically differentiated populations may reduce reproduction and/or survival (outbreeding depression), as occurs between northern and southern populations of the corroboree frog (*Pseudophryne corroboree*) in the mountains of southeastern Australia (Osborne and Norman 1991). While gene flow is usually genetically beneficial as described above, in this case it is deleterious. The importance of outbreeding depression is controversial and its impacts are likely to be species and population specific (Frankham *et al.* 2002). It is more likely when populations adapted to different environments come into contact. In this case, individuals from hybrid populations may be less adapted to local conditions in either environment and suffer reduced fitness. Outbreeding depression is especially likely when different subspecies or species hybridize. Connecting isolated populations that are strongly genetically

differentiated increases the risks of outbreeding depression. As outbreeding depression is known in only a minority of species, it should be much less of a problem than inbreeding depression and loss of genetic diversity, but the possibility should be evaluated when habitat corridors are being contemplated.

EFFECTS OF POPULATION STRUCTURE

The genetic impacts of population fragmentation and loss of connectivity may range from insignificant to severe, depending upon the details of the resulting population structures and gene flow patterns among fragments. Several different population structures can be distinguished (Fig. 4.1):

- Source–sink (or mainland–island) structure
- Island structure where gene flow is equal among all equally sized population fragments

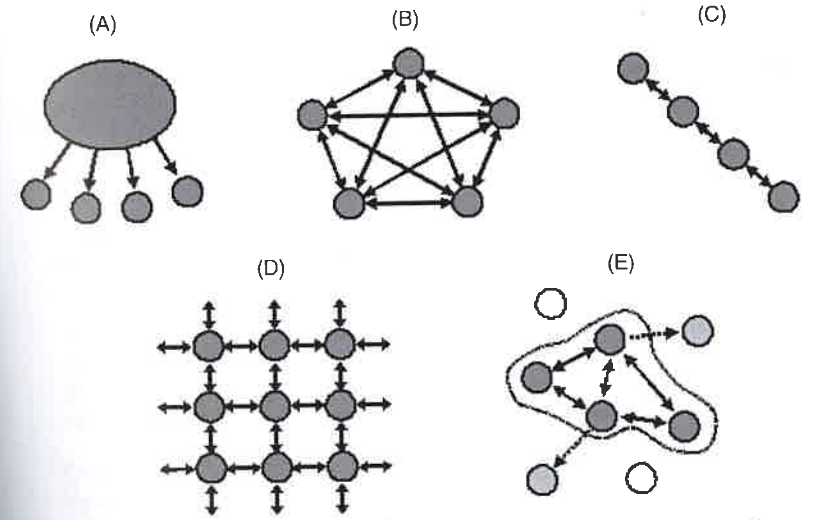

Fig. 4.1. Different fragmented population structures: (A) a source–sink (or mainland–island) structure where the source provides all the input to the sink populations; (B) an island structure where gene flow is equal among equal sized islands; (C) a linear stepping-stone structure where only neighboring populations engage in direct gene flow; (D) a two-dimensional stepping-stone structure where neighboring populations exchange migrants; and (E) a metapopulation (all from Frankham *et al.* 2002). In addition, there are totally isolated island structures and single large population structures.

- Linear stepping-stone structure where only neighboring populations engage in direct gene flow, as in riparian habitat along rivers
- Two-dimensional stepping stone structure where only surrounding populations engage in direct gene flow
- Metapopulations
- Islands: totally isolated fragments with no connectivity and gene flow, and
- Single large population where connectivity is sufficient for adequate gene flow.

Metapopulations differ from the other structures in having regular extinction and recolonization events, while no extinction is assumed in the other structures. These structures have different genetic consequences, with the totally isolated islands and the metapopulations typically having the worst genetic impacts (inbreeding and loss of genetic diversity) for the same total population sizes, especially in the long term (see below). The endangered Glanville fritillary butterfly (*Melitaea cinxia*) metapopulation in Finland (Case Study 4.1) provides a classic example where inbreeding has been shown to contribute to extinction risk.

In evaluating the impacts of isolation and lack of connectivity, I first consider completely isolated fragments with no gene flow and then review partially connected fragments. I then discuss population recovery

CASE STUDY 4.1 Inbreeding and extinction risk in butterfly metapopulations in Finland (Saccheri *et al.* 1998)

The endangered Glanville fritillary butterfly population in Finland exists in many fragmented populations with regular extinctions and recolonization. There are about 1600 suitable meadows for the butterfly, 320–524 being occupied in 1993–96. The population turnover rate is high, with an average of 200 extinctions and 114 colonizations per year.

As many of the populations are very small, inbreeding may contribute to extinction risks. Forty-two butterfly populations in Finland were typed for genetic markers in 1995, and their extinction or survival recorded in the following year. Of these, 35 survived to fall 1996 and seven went extinct. Extinction rates were higher for populations with lower heterozygosity, an indication of inbreeding (Eq. 4.1), even after accounting for the effects of demographic and environmental variables (population size, time trend in population size and area) known to affect extinction risk. Overall, inbreeding accounted for 26% of the variation in extinction risk.

following outcrossing of previously isolated populations, and the level of gene flow necessary to connect population fragments. I conclude the section with a summary of the impacts of different population structures on reproductive fitness.

Completely isolated fragments

The most severe effects of fragmentation are expected in isolated fragments with no connectivity or gene flow. Since fragmentation creates "islands" from once-continuous habitat, its effects parallel those in oceanic island populations. Island populations often have reduced genetic diversity, are inbred and have elevated extinction risks compared to mainland populations (Frankham 1997, 1998). Case Study 4.2 provides an

CASE STUDY 4.2 Impact of fragmentation in island populations of rock wallabies in Australia

Black-footed rock wallabies (*Petrogale lateralis*) in Australia illustrate many of the genetic effects of population fragmentation (Eldridge *et al.* 2001). Rock wallabies are small macropod marsupials (about 1 m tall) that live on rocky outcrops on the Australian mainland and on islands off Western Australia. The Barrow Island population of black-footed rock wallabies has been isolated from the mainland for 8000 years (about 1600 generations) and has a relatively small population size.

The Barrow Island population has very low genetic diversity, as assessed by microsatellites, compared to that for two mainland populations, as shown below. Other island populations also have low genetic diversity, as indicated below.

Population (location)	Proportion of loci polymorphic	Mean number of alleles/locus	Average heterozygosity
Barrow Island	0.1	1.2	0.05
Mainland			
Exmouth	1.0	3.4	0.62
Wheatbelt	1.0	4.4	0.56

The Barrow Island population has an inbreeding coefficient of 0.91. Further, it displays inbreeding depression compared to the mainland

Continued

CASE STUDY 4.2 *(cont.)*

population. The frequency of lactating females is 92% in mainland rock wallabies, but only 52% on Barrow Island. These rock wallaby populations demonstrate that genetics can have an impact before demographic and environmental stochasticity or catastrophes cause extinctions. They have clearly survived stochastic fluctuations and catastrophes, but they are suffering genetic problems that increase their risk of extinction.

The different island populations have all lost genetic diversity, but have become genetically differentiated since they were isolated by post-glacial sea level rises 8000–15 000 years ago. Alleles present (+) and absent (−) at four microsatellite loci in populations of black-footed rock wallabies on the mainland of Australia and on six offshore islands are shown below. Island populations contain many fewer alleles than mainland populations, but they are usually a subset of alleles found on the mainland. Different island populations often contain different alleles, as expected due to genetic drift.

Locus	Allele	Mainland	Islands					
			BI	SI	PI	MI	Wil	Wel
Pa297	102	+	−	−	−	−	−	−
	106	+	−	−	−	−	−	−
	118	+	−	−	−	−	−	−
	120	−	−	−	+	−	−	−
	124	+	−	−	−	+	−	−
	128	+	−	+	−	−	+	+
	130	+	−	−	−	−	−	−
	136	+	+	−	−	−	−	−
Pa385	157	+	−	−	−	−	−	−
	159	+	−	−	+	−	+	+
	161	+	−	+	−	−	−	−
	163	+	−	−	−	+	−	−
	165	+	−	−	−	−	−	−
	173	−	+	−	−	−	−	−
Pa593	105	+	+	−	−	−	+	+
	113	−	+	−	−	−	−	−
	123	+	−	−	−	−	−	−
	125	+	−	−	+	−	−	−
	127	+	−	−	−	−	−	−
	129	+	−	−	−	−	−	−
	131	+	−	+	−	−	−	−
	133	+	−	−	−	−	−	−
	135	+	−	−	−	−	−	−
	137	−	−	−	−	+	−	−
Me2	216	+	−	−	−	−	−	−
	218	+	−	−	−	+	+	−
	220	+	+	−	−	−	−	+
	222	+	−	+	−	−	−	−
	224	+	−	−	−	−	−	−
	230	−	−	−	+	−	−	−

Island populations have been viewed as ideal sources for restocking depleted or extinct mainland populations, especially in Australasian species. However, as they often have low genetic diversity and are inbred, they may not be good candidates for translocations, if alternative mainland populations still exist. However, the totality of all island populations contains most of the genetic diversity found in the mainland population, so it could provide individuals for reintroduction, following crossing of island populations.

example of the impacts of complete isolation in island populations of rock wallabies in Western Australia.

Replicate population fragments become genetically differentiated with generations at a rate that depends on the inbreeding coefficient (Wright 1969). Observed heterozygosity, measured across the totality of isolated populations, is reduced compared to Hardy–Weinberg expectations, the reduction being proportional to the inbreeding coefficient (the Wahlund effect). These effects depend critically on the effective population size of each isolated fragment, and the duration of isolation in generations. Isolated populations of outbreeding species not only lose genetic diversity, but also suffer inbreeding depression, have reduced ability to evolve to cope with environmental change, and consequently have elevated extinction risk (Frankham *et al.* 2002; Reed and Frankham 2003; Reed *et al.* 2003). As inbreeding depression is typically more extreme under stressful environments (Frankham *et al.* 2002), the genetic effects in isolated fragments are likely to become worse in the future with global climate change, reductions in the ozone layer, accelerated movements of disease organisms across the planet due to human activities, and the increasing degradation of natural areas in general.

The impacts of reduced connectivity in fragmented populations are illustrated by comparing a single large (SL) population with several small (SS) completely isolated populations of the same total population size: the SLOSS comparison, as shown in Fig. 4.2. In the short term when there are no extinctions of SS populations, the SS populations retain greater overall allelic diversity than the SL population (Frankham *et al.* 2002). This expectation has been verified in experiments with fruit flies (Margan *et al.* 1998). In the long term, however, extinction rates will be greater in smaller than in larger population fragments due to environmental and demographic stochasticity, catastrophes, and genetic factors. With extinction of some SS populations (4), the SL population retains more genetic diversity and has higher reproductive fitness than all the SS populations combined (now only two populations).

The genetic impacts of fragmentation are expected to become increasingly deleterious as the degree of fragmentation increases. For a population of total size N_e separated into f totally isolated, equal-sized fragments, the size of each fragment is N_e/f. Each of the fragments will become inbred and lose genetic diversity at a rate dependent upon N_e/f, compared to N_e in a single population of the same total size. The proportion of initial heterozygosity retained after t generations in each of the f small SS fragments, compared to that in the single large population, is

$$\ln(H_t/H_0)_{SS/SL} = (1-f)t/2N_e. \qquad (4.2)$$

Thus, the proportional retention of heterozygosity in several small population fragments, compared to a single large population, declines with the number of fragments and increases with generations. The rate of decline is greater with smaller than larger total effective population size. The effects on inbreeding are similar and can be illustrated with examples all with a total constant effective size of 500 individuals per generation. Following Eq. (4.1), a single population of size 500 loses 5% of its initial heterozygosity over 50 generations, while two populations of effective size 250 each lose 10%, five populations of size 100 each lose 22%, ten populations of size 50 each lose 39% and twenty populations of size 25 each lose 64% of their initial genetic diversity. As expected, reproductive fitness drops at a greater rate in smaller populations than in larger ones (Bryant *et al.* 1999; Woodworth *et al.* 2002).

Loss of genetic diversity has been documented in many small isolated population fragments, including black-footed rock wallabies, greater

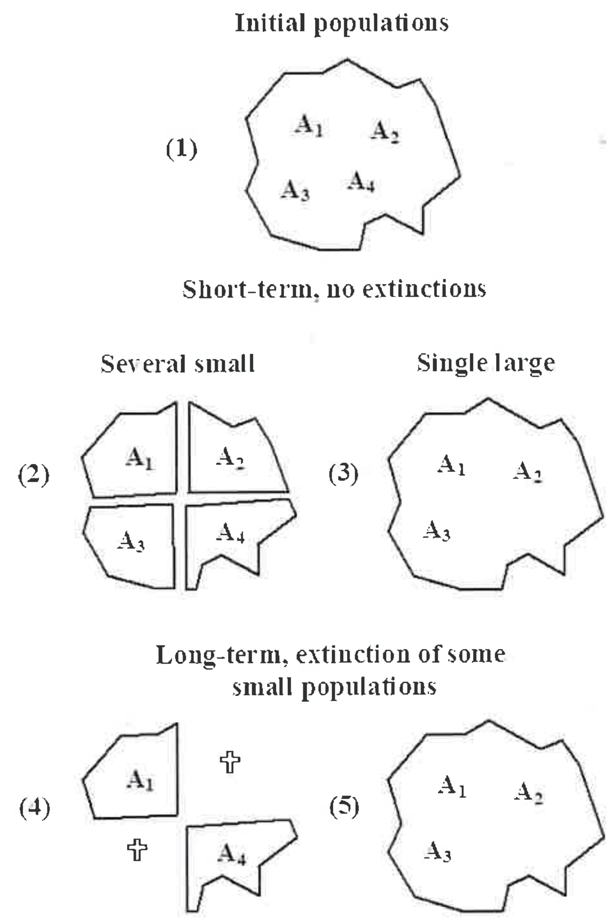

Fig. 4.2. The genetic consequences of a single large population (SL) versus several small (SS) completely isolated population fragments of initially the same total size (SLOSS) over different time frames (from Frankham *et al.* 2002). (1) A_1–A_4 represent four alleles initially present in the population. In the short-term, without extinctions, the several small populations (2) are expected to go to fixation more rapidly, but to retain greater overall genetic diversity than the single large population (3). The chances are greater that an allele will be totally lost from the large population than from all small populations combined. However, the SS populations will each be more inbred than the SL population. In the longer term, when extinctions of small, but not large populations occur, the sum of the small surviving populations (4) will retain less genetic diversity than the single large population (5). A metapopulation with extinctions and recolonizations is similar to (4).

prairie chickens (*Tymphanuchus cupido pinnatus*), adders (*Vipera berus*), Glanville fritillary butterflies, and grassland daisies (Frankham *et al.* 2002). Inbreeding depression has also been documented in these cases and in isolated populations of royal catchfly (*Sabatia angularis*) and scarlet gilia (*Ipomopsis aggregata*) plants.

Partially connected fragments

The impacts of population fragmentation on genetic diversity, inbreeding, differentiation, and extinction risk depend on the connectivity and level of gene flow among fragments. These in turn depend on:

- Number of population fragments
- Distribution of population sizes in the fragments
- Geographic distribution of populations
- Distance between fragments
- Dispersal ability of the species
- Migration rates between fragments
- Survival and reproductive success of migrants in new locations
- Environment of the matrix among the fragments and its impact on dispersal
- Time since fragmentation in generations
- Susceptibility of the species to inbreeding depression.

The genetic impacts in partially connected fragments depends upon rate of gene flow and ranges from that of totally isolated fragments to that of a single large population with complete connectivity. The endangered red-cockaded woodpecker (*Picoides borealis*) in the eastern USA illustrates many of the features and genetic problems associated with habitat fragmentation for a species with reduced gene flow between fragments (Case Study 4.3).

The large number of variables affecting fragmented populations and the stochastic nature of many effects makes them difficult to study in the field or with mathematical models. Consequently, computer simulations seem likely to be the tool that will provide the major insights on the genetic and ecological impacts of different connectivity in fragmented populations. Realistic stochastic computer simulations for real species have been done for several species. Such models predict population size trajectories without significant bias for well-studied species (Brook *et al.* 2000; McCarthy *et al.* 2003). Dobson *et al.* (1992) predicted that there would be substantial benefits of migration on the viability of black rhinoceros (*Diceros bicornis*) populations, especially in very small populations. McCullough *et al.* (1996) predicted benefits from gene flow in tule elk populations (*Cervus elaphus nannodes*). Young *et al.* (2000) showed that small isolated populations of the endangered Australian grassland daisy *Rutidosis leptorrhynchoides* were expected to lose self-incompatibility alleles and suffer reductions in population fitness, in line with observed effects.

Reed (2004) investigated the impact of population fragmentation with different dispersal rates in 30 real species using models that included all relevant variables (including demographic, environmental, and genetic stochasticity and catastrophes). The models included modest inbreeding depression (including purging effects), different values of environmental correlations among fragments, and two different total population sizes (250 and 1000). Dispersal rate was the most important explanatory

CASE STUDY 4.3 Impact of habitat fragmentation on the endangered red-cockaded woodpecker population in southeastern USA

The red-cockaded woodpecker was once common in the mature pine forests of the southeast USA (Kulhavy *et al.* 1995). It declined in numbers, primarily due to habitat loss, and was placed on the US endangered species list in 1970. It now survives in scattered and isolated sites within the US southeast. There is little connectivity and gene flow among isolated sites. As expected, populations have diverged genetically from each other, and lost genetic diversity, with smaller populations showing the greatest loss of genetic diversity and the most divergence (Stangel *et al.* 1992). Moderate divergences in allele frequencies exist among woodpecker populations. Differentiation, measured as F_{ST} (see pp. 86–87), is 0.14 based on allozyme data, and 0.19 based on randomly amplified polymorphic DNA(RAPD) data, and both show a general tendency for closer genetic similarity among geographically proximate populations (Haig and Avise 1996).

Computer simulations indicate that the smallest woodpecker populations are likely to suffer from inbreeding depression in the near future (Daniels *et al.* 2000). In response to the threats posed by fragmentation, management of the woodpeckers involves habitat protection, improvement of habitat suitability by constructing artificial nest holes, reintroductions into suitable habitat where populations become extinct, and augmentation of small populations to minimize inbreeding and loss of genetic diversity. This is one of the most extensive management programs for a fragmented population anywhere in the world.

variable affecting extinction differences between the fragmented and single large populations, with higher dispersal reducing extinction risk in the metapopulations. The correlation between subpopulations in environmental variation was the second most important variable, with higher correlations increasing the risk of extinction of metapopulations. Population growth rate was the third most important variable, species with low population growth rates being more sensitive to fragmentation than were populations with higher initial fitness. There was also a significant interaction between population growth rate and dispersal. Extinction risk was highly dependent upon the total carrying capacity and the time-frame in generations, decreasing with the former and increasing with the latter. The effects of dispersal, carrying capacity, and time-frame are all predicted from genetic considerations, but are also expected from ecological effects.

Population recovery following outcrossing

The above section presumes that when previously isolated populations are connected and gene flow re-established, inbred populations of naturally outbreeding species recover in fitness. This has been shown in many species, including wolves (*Canis lupus*), greater prairie chickens, snakes, water fleas (*Daphnia*), fruit flies (*Drosophila*), flour beetles (*Tribolium*), houseflies (*Musca domestica*) and plants (Richards 2000; Newman and Tallmon 2001; Ebert *et al.* 2002; Frankham *et al.* 2002; Vilà *et al.* 2003). Even a single immigrant can produce substantial effects and the immigrants can be themselves inbred, provided they are from a different population fragment (Spielman and Frankham 1992; Vilà *et al.* 2003). Migrant alleles are likely to be at a selective advantage, so that they contribute more genetically than expected based on their initial proportion (Ebert *et al.* 2002; Saccheri and Brakefield 2002).

How much gene flow is required to connect population fragments?

Migration reduces the impact of fragmentation by an extent dependent on the rate of gene flow. With sufficient migration, a fragmented population will have the same genetic consequences as a single large population of the same total size.

Sewall Wright obtained the surprising result that a single migrant per generation among idealized populations with an island model (Fig. 4.1B) was sufficient to prevent complete differentiation (and fixation of alleles) (Wright 1969). These results are independent of population size. The deleterious effects of inbreeding on reproductive fitness and extinction

risk are also expected to be largely alleviated in populations with one or more migrants per generation. Experimental studies support this prediction (Bryant *et al.* 1999; Newman and Tallmon 2001).

The conclusions above assume that migrants and residents are equally likely to survive and produce offspring, and that all population fragments have idealized structures, apart from the occurrence of migration. In real wild populations where these assumptions are unrealistic, 5–10 migrants per generation may therefore be required to achieve these effects (Frankham *et al.* 2002).

Impacts of different population structures on reproductive fitness

In summary, the overall consequences of different population structures on reproductive fitness will depend primarily on the inbreeding coefficient in each fragment. The single large unfragmented population becomes the standard for comparison. Consequences of different population structures are (Frankham *et al.* 2002):

- In source–sink (or mainland–island) structures, the effective population size will depend on N_e in the source population, rather than that for the total population. Thus, inbreeding and loss of fitness are likely to be much higher with this structure than for SL.
- In the island and stepping-stone models, inbreeding and fitness will depend critically upon the gene flow rates and upon the variation in population sizes on different islands. When there is no gene flow, inbreeding will depend upon the effective population sizes of the individual populations, and will be greater than for SL. Conversely, when there is ample gene flow among populations, inbreeding will depend upon the effective size of the total population, and be similar to SL.
- Metapopulations typically have effective sizes that are markedly less than the number of breeding adults, due to cycles of extinction and recolonization that eliminate ancestors and their alleles (Fig. 4.3). Typically, inbreeding will be greater and fitness lower than for other fragmented and non-fragmented structures. The effective size will approximate the sum of the effective sizes of fragments following extinctions, rather than the sum of all effective sizes. Bottlenecks during recolonization will subsequently reduce N_e still further.

If there are frequent extinctions and recolonization mainly from a few large fragments, the metapopulation structure approaches that of a source–sink, and less genetic diversity is retained than in a single large

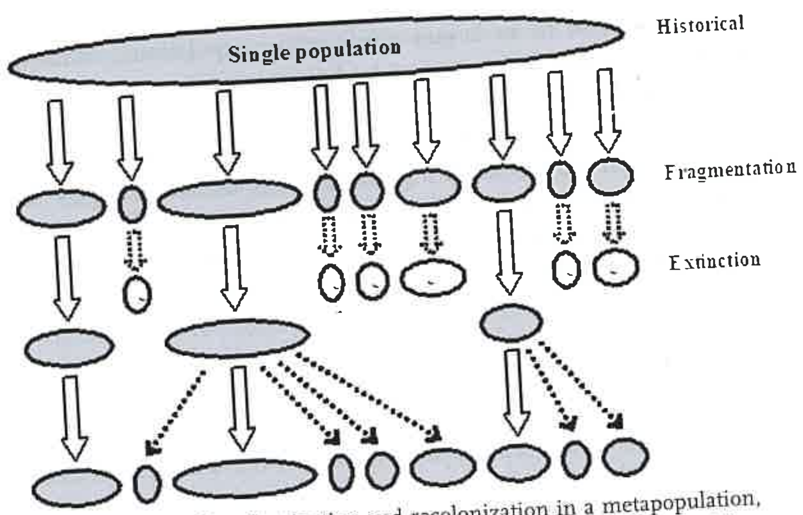

Fig. 4.3. Cycles of extinction and recolonization in a metapopulation, leading to reductions in the effective size of a species (from Frankham *et al.* 2002). The dotted lines indicate bottlenecks during recolonization.

population of the same total size. Conversely, a metapopulation with sufficient migration and low rates of local extinctions approaches the characteristics of a single large population. In general, the higher the rate of extinction and recolonization, the more jeopardized is the metapopulation.

ASSESSING CONNECTIVITY AND MEASURING GENE FLOW

Genetic methods are widely used to assess population connectivity. Migration rates are notoriously difficult to measure by direct tracking of individuals or gametes, and immigrants may not breed in their new habitat. Consequently, gene flow, rather than migration rate, is the critical variable to estimate.

Sewall Wright (1969) partitioned inbreeding of individuals (I) in the total (T) population (F_{IT}) into that due to inbreeding of individuals relative to their subpopulation (S) or fragment, F_{IS}, and inbreeding due to differentiation among subpopulations, relative to the total population, F_{ST} (*F* statistics). With high rates of gene flow among fragments, F_{ST} is low. With low rates of gene flow among fragments, populations diverge and become inbred, and F_{ST} increases.

The *F* statistics can be calculated from the relationship between heterozygosity for genetic markers such as allozymes or microsatellites and inbreeding (Eq. 4.1) using the following equations (Nei 1987):

$$F_{IS} = 1 - (H_I/H_S) \quad (4.3)$$

$$F_{ST} = 1 - (H_S/H_T) \quad (4.4)$$

$$F_{IT} = 1 - (H_I/H_T) \quad (4.5)$$

where H_I is the observed heterozygosity averaged across all population fragments, H_S is the Hardy–Weinberg expected heterozygosity averaged across all population fragments, and H_T is the expected heterozygosity for the total population. F_{ST} ranges from 0 (no differentiation between fragments) to 1 (fixation of different alleles in fragments). Reservations have been expressed about using F_{ST} with microsatellite data, as they have a different mutational process, so the related measure R_{ST} is often considered more suitable (Slatkin 1995). However, simulation studies indicate that neither statistic has consistently superior performance for microsatellites (Balloux and Goudet 2002). Case Study 4.4 illustrates the calculation of the *F* statistics based on heterozygosities for the endangered Pacific yew (*Taxus brevifolia*) in western North America. This species exhibits inbreeding within populations ($F_{IS} > 0$) and differentiation among populations ($F_{ST} > 0$).

Equilibrium between migration and inbreeding

With constant population sizes and migration rates, inbreeding and gene flow reach an equilibrium where the reduction in divergence due to migration balances the increase due to drift. The equilibrium inbreeding (F_{ST}) is related to the effective population size and the migration rate (m) in such a population (Wright 1969) as follows:

$$F_{ST} = 1/(4N_e m + 1). \quad (4.6)$$

This equation applies when the migration rate is small. Gene flow can be inferred from patterns of differentiation among populations using this equation. For example, for the Pacific yew, the effective number of migrants per generation $N_e\, m = [(1/F_{ST}) - 1]/4 = [(1/0.078) - 1]/4 = 2.96$. On average about three migrants per generation are entering Pacific yew populations. This value reflects historical evolutionary rates of gene flow in equilibrium circumstances, so it may not reflect current gene flow. This is an approximation based on the island model (Fig. 4.1B), but related expressions have been derived for other models of migration

CASE STUDY 4.4 Computation of *F* statistics for the rare Pacific yew

The endangered Pacific yew, a conifer found on the Pacific northwest of North America, is the source of the anticancer substance Taxol.

El-Kassaby and Yanchuk (1994) reported genotype frequencies and heterozygosities for 21 allozyme loci in nine Canadian populations. Average observed heterozygosity (H_I) across the nine populations was 0.085, while the average expected heterozygosity for these populations (H_S) was 0.166. Consequently, inbreeding within populations F_{IS} is:

$$F_{IS} = 1 - (H_I/H_S) = 1 - (0.085/0.166) = 0.49$$

The high level of inbreeding is not due to selfing, as the species is dioecious. It is probably due to offspring establishing close to parents and clumping of individuals founded from bird and rodent seed caches. The expected heterozygosity across the nine populations (H_T) was 0.18, so inbreeding due to population differentiation (F_{ST}) is

$$F_{ST} = 1 - (H_S/H_T) = 1 - (0.166/0.180) = 0.078$$

This indicates only a modest degree of population differentiation.

The total inbreeding due to both inbreeding within populations and differentiation among them (F_{IT}) is

$$F_{IT} = 1 - (H_I/H_T) = 1 - (0.085/0.18) = 0.53$$

(Neigel 1996). The exact estimates of migration rates obtained from this equation are not necessarily reliable or current, but they do indicate the relative rates of gene flow that populations would have if they adhered to the island population structure. In this way, they have a role that is analogous to that of effective population sizes.

Assignment tests using multiple genetic loci (e.g., microsatellites) provide a direct means for detecting recent immigrants (Paetkau *et al.* 1995; Neville *et al.* Chapter 13). In brief, analyses are used to ask if each individual originated in the geographic location where it was found or in another population at a different location. Eldridge *et al.* (2001) used an assignment test based on data from 11 polymorphic microsatellite loci to infer that a population of rock wallabies at Gardener's Outcrop in the Wheatbelt on the mainland of Western Australia was re-established by immigrants from the nearest extant population (see Case Study 4.2). Assignment tests can be highly powerful for detecting current movement even when little population differentiation exists. For example, the threatened geometric tortoise (*Psammobates geometricus*) in South Africa

shows little genetic differentiation (F_{ST} = 0.018–0.048) and retains appreciable genetic variation despite suffering extreme habitat fragmentation, having lost 97% of its habitat and declining from over 15 000 to 3500–5000 individuals. Interestingly, it appears to display some current migration, as indicated by assignment tests using data from eight microsatellite loci (Cunningham *et al.* 2002).

Like F_{ST}, coalescence approaches, based on the genealogies of alleles, can be used to infer historical gene flow and population structure, as illustrated by the work of Tero *et al.* (2003) on the endangered plant *Silene tatarica* in riparian zones in northern Finland. Analyses of amplified fragment-length polymorphism (AFLP) data based on coalescence, plus assignment tests, F_{ST}, and other approaches, revealed a classical metapopulation structure with a high subpopulation turnover rate and low gene flow among subpopulations, consistent with information from ecological surveys. Compared to traditional F_{ST} measures, coalescent methods make fewer assumptions about population dynamics and can provide additional information, such as estimates of asymmetrical dispersal rates among populations with different effective population sizes (Neville *et al.* Chapter 13).

Templeton's (1998) nested clade analysis, based on mapping haplotype networks onto geographic locations, provides a hypothesis-testing framework for delineating the historical processes that led to given patterns of genetic differentiation. He applied this analysis to buffalo (*Syncerus caffer*) and impala (*Aepyceros melampus*) and found different patterns and causes for population differentiation in the two species, in spite of similar F_{ST} values. Genetic distances, such as that of Nei, provide another means for describing genetic differentiation and are used to build phenograms or "trees" to visualize genetic similarity among populations (Nei 1987). Neville *et al.* (Chapter 13) provide further details on several of these methods and several examples from salmonid fish.

Dispersal and gene flow

Since differentiation among populations is dependent on levels of gene flow, we would expect this to be related to the dispersal abilities of species and the degree of isolation among populations. Thus, the degree of genetic differentiation among populations (F_{ST}) is expected to be greater for populations:

- in species with lower versus higher dispersal rates
- in subdivided vs. continuous habitat

- in distant vs. closer fragments
- in smaller vs. larger population fragments
- in species with longer vs. shorter divergence times (in generations)
- with adaptive differences vs. those without.

Observations generally confirm these predictions (Frankham *et al.* 2002).

There is a strong negative correlation between F_{ST} and the dispersal ability of species, as predicted; the average rank correlation was −0.73 in a meta-analysis involving 333 species across 20 animal groups (Bohonak 1999). Examples of mean F_{ST} values for major groups of organisms are given in Table 4.1. Taxa that can fly, such as birds and insects, have lower F_{ST} values than those that do not. Further, F_{ST} is higher in plants that self-fertilize (low pollen dispersal) than in outcrossing plants.

Dispersal rates typically reduce with distance. Consequently, distant fragments are expected to receive fewer migrants than nearby ones. Allozyme variability for island populations generally declines with distance from the mainland in lizards and several species of mammals (Frankham 1997). For mainland population fragments, distant habitat patches are expected to receive fewer migrants than nearby habitat patches, but this effect depends upon the nature of the surrounding matrix and its influence on dispersal rates (e.g., see Taylor *et al.* Chapter 2).

Table 4.1. *Fixation index (F_{ST}) in a range of taxa*

Species	F_{ST}
Mammals (57 species)	0.24
Birds (23 species)	0.05
Reptiles (22 species)	0.26
Amphibians (33 species)	0.32
Fish (79 species)	0.14
Insects (46 species)	0.10
Plants	
Selfing	0.51
Mixed selfing and outcrossing	
animal pollination	0.22
wind pollination	0.10
Outbreeding	
animal pollination	0.20
wind pollination	0.10

Source: After Frankham *et al.* (2002).

Genetic differentiation and gene flow are associated with geographic distance ("isolation by distance") in red-cockaded woodpeckers, bighorn sheep (*Ovis canadensis*), gray wolves, and brown bears (*Ursus arctos*) in North America (Haig and Avise 1996; Forbes and Hogg 1999), and in many other species. However, species with high dispersal rates may not show isolation by distance (e.g., Canada lynx: Schwartz *et al.* 2002), while completely isolated populations are likely to show random patterns of genetic differentiation.

EFFECTS OF FRAGMENTATION AND REDUCED CONNECTIVITY IN SPECIES WITH DIVERSE BREEDING SYSTEMS

The above discussion has concentrated on species that are naturally outbreeding diploids. The effects of fragmentation and reduced gene flow are different for species that are asexual, highly self-fertilizing, haploid, or polyploid (Frankham *et al.* 2002).

Asexual species, such as the critically endangered Meelup mallee tree (*Eucalyptus phylacis*) in Western Australia (Rossetto *et al.* 1999), and haploid species do not suffer from inbreeding depression, but they do suffer from loss of genetic diversity in small populations. Thus, highly isolated fragments with small population sizes are likely to have reduced ability to evolve to cope with environmental change. Selfing species, such as the endangered Malheur wirelettuce (*Stephanomeria malheurensis*: Falk *et al.* 1999), suffer from inbreeding depression, but typically at a lesser level than outbreeding species (Husband and Schemske 1996). They typically have genetic diversity distributed more among than within population, as compared to outbreeders. Consequently, they suffer serious losses of genetic diversity and evolutionary potential in metapopulations with high turnover rates. The taxonomic distribution of asexual and selfing species suggest that they are evolutionary dead-ends due to limited ability to evolve to cope with environmental change (White 1973).

Polyploids, such as the California redwoods (*Sequoia sempervirens*), are less sensitive to loss of genetic diversity than diploids with similar population sizes, seem to be less sensitive to inbreeding depression, and are generally less affected by genetic factors contributing to extinction risk in small populations (Frankham *et al.* 2002).

EVOLUTIONARY CONSEQUENCES OF FRAGMENTATION AND LACK OF CONNECTIVITY

Habitat fragmentation may have long-term evolutionary consequences. If a previously continuous population is fragmented and completely isolated it may change its evolutionary strategy from that of a habitat generalist to become habitat specialists adapted differentially to the conditions of the isolated fragments, provided it persists in the long term. Over even longer time-spans, this could lead to speciation, as habitat isolation is associated with most speciation (Frankham *et al.* 2002).

Fragmented populations without connectivity and gene flow may undergo evolutionary changes in breeding systems or dispersal rates. Small populations of naturally outbreeding plants may become selfers, as in the plant *Isotoma petraea* (James 1970), and some even evolve chromosomal systems that promote permanent heterozygosity. Self-incompatible species may evolve self-compatibility in small populations. Some isolated founder populations of insects, such as Orthoptera, have become parthenogenetic (White 1978). Populations of plants migrating to islands have been initiated by genotypes with high dispersal rates, but then evolved towards low dispersal rates within a few generations (Cody and Overton 1996). In birds, migration rates and patterns are heritable (Berthold and Pulido 1994) and evolutionary changes in migratory patterns have been documented (Berthold *et al.* 1992). Possibly, species with limited connectivity could evolve increased migration rates, but I know of no example of this.

CONCLUSIONS

Habitat fragmentation/connectivity is a fundamental concern in conservation biology as it affects extinction risk. The genetic impacts of population fragmentation depend critically upon connectivity and gene flow among fragments. Lack of gene flow among fragmented populations results in inbreeding and loss of genetic diversity and elevated extinction risk. Population fragmentation usually has deleterious genetic consequences in the long term, compared to a similar-sized unfragmented population. Further, lack of connectivity between populations precludes immigrants re-establishing extinct populations. The genetic impacts of fragmentation and connectivity depend on knowledge of many parameters (gene flows, inbreeding depression, and extinction rates) and so are difficult to investigate in the field, or with mathematical models. Consequently, realistic stochastic computer projections have a major role to play in understanding these effects. Metapopulation structures, with extinctions and recolonization of population fragments, are likely to be particularly deleterious. Genetic methods, such as F_{ST}, assignment tests, and coalescence can define the extent of connectivity and infer rates of gene flow between populations. This allows rational scientific management of threatened species in the wild.

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Conservation of Pattern and Process: Developing an Alternative Paradigm of Rangeland Management

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Abstract

This article examines the question of how well the rangeland management profession has served conservation of patterns and processes that support multiple ecosystem services. We examine the paradigms under which rangeland management operates and argue that our profession developed under the utilitarian paradigm with the primary goals of sustainable forage for livestock production. While optimization of multiple rangeland products and services has always been a consideration, a comprehensive set of principles have not be been developed to advance this concept. We argue that fire and grazing, often viewed as mere tools used for production goals, should rather be viewed as essential ecosystem processes. Rangeland management continues to operate under the utilitarian paradigm appropriate to societal values of the 20th century and by and large has failed to provide management guidance to reverse degradation of several highly valued ecosystem services. We support this argument with evidence that biodiversity has declined on rangelands in the past half century and that much of this decline is due to management goals that favor a narrow suite of species. The full suite of ecosystem services valued by society will only benefit by management for heterogeneity, which implies that there is no one goal for management and that landscape-level planning is crucial. Explicitly incorporating heterogeneity into state-and-transition models is an important advancement not yet achieved by our profession. We present new principles for rangeland management formed on the basis of conservation of pattern and process. While recognizing that many rangelands have significant deviations from historic plant communities and disturbance regimes, we suggest that management for conservation of pattern and process should focus on fire and grazing to the extent possible to promote a shifting mosaic across large landscapes that include patches that are highly variable in the amount of disturbance rather than the current goal of uniform moderate disturbance.

Resumen

Este artículo examina la pregunta de que tan bien los profesionales en manejo de pastizales han aplicado los patrones y procesos en la conservación de los servicios multiples que proveen los ecosistemas. Examinamos los paradigmas bajo los cuales opera el manejo de pastizales y discutimos el desarrollo de nuestra profesión bajo el paradigma utilitario con el principal objetivo de sustentabilidad forrajera para la producción de ganado. Mientras que la optimización de los múltiples productos y servicios de los pastizales han sido consideradas un paquete completo de principios no ha sido desarrollado para avanzar en este concepto. Discutimos que el fuego y el pastoreo a veces son vistos como simples herramientas usadas para objetivos de producción cuando deberían ser vistas como partes esenciales de los procesos del ecosistema. El manejo de pastizales continúa operando bajo el paradigma utilitario típico de los valores sociales del siglo XX y por mucho ha fallado en proveer directrices de manejo para revertir la degradación de varios servicios valiosos de los ecosistemas. Apoyamos este argumento con evidencia de que la biodiversidad ha decaído en los pastizales en la mitad del siglo pasado y mucho de esta disminución se debe a los objetivos de manejo que favorecen a un reducido número de especies. El juego completo de servicios valuados por la sociedad solo beneficiara con el manejo por heterogeneidad el cual implica que no hay un objetivo para el manejo y que la planeación a nivel paisaje es crucial. Incorporando de manera explícita modelos de estado y transición es un avance importante que no ha sido logrado por nuestra profesión. Presentamos nuevos principios para el manejo de pastizales desarrollados en base a procesos y patrones de conservación. Mientras reconozcamos que muchos pastizales tienen desviaciones significativas de históricas comunidades de plantas y regímenes de disturbio, sugerimos que el manejo por conservación de patrones y procesos deberá enfocarse en fuego y pastoreo en medida de lo posible para promover el cambio en un mosaico a través de grandes paisajes que incluyen parches que son altamente variables en la magnitud de disturbio en lugar de objetivos actuales de disturbio uniforme y moderado.

Key Words: biodiversity, fire, grazing, landscape ecology, pyric herbivory, shifting mosaic

INTRODUCTION

Conservation of natural resources has been described as progressing through three sequential paradigms (Callicott 1990; Weddell 2002). The first was the utilitarian paradigm, which was based largely on conservation to maintain long-term and sustainable production with the objective of providing the

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most benefit for the many (Pinchot 1947). Gifford Pinchot is considered the dominant influence for this perspective, which is based on conservation to maintain economic stability. Motivated by the spirituality of conservation and emerging from ideas of Ralph Waldo Emerson, Henry David Thoreau, and John Muir, the protectionist paradigm aims to protect nature from humans by setting aside or reserving lands, national parks, and wilderness areas from human influence. Utilitarianism and protectionism were often viewed as dichotomous perspectives. The third paradigm, ecosystem management, emphasizes conservation of processes and interrelatedness of parts by maintaining processes (grazing, fire, water cycling, nutrient cycling, and so on) with the objective of ultimately maintaining the full suite of biodiversity (Leopold 1949). Many attribute the ecosystem management paradigm to Aldo Leopold, who developed it to counter a land management system that he viewed as exploitive and without science at its core. While rangelands have benefited from conservation based on all three of the paradigms, the rangeland management profession developed largely under the utilitarian paradigm with the primary long-term goals of sustainable forage for livestock production and conserving production potential by minimizing soil erosion. Optimizing for all ecosystem services, while mentioned even early in the range profession history, has had limited application on large landscapes.

Because of these goals, conservation strategies in rangeland management have focused largely on minimizing irreversible soil degradation and loss of dominant forage species (Holechek et al. 2004). Traditional rangeland management consequently promoted late successional plant communities capable of sustaining livestock production. When the management goal is light or moderate disturbance and late successional plant communities, many native species of fauna and flora dependent on disturbance and earlier successional plant communities are neglected.

Under the utilitarian paradigm, livestock grazing and wildlife have often been viewed as competing rather than complementary (Stoddart et al. 1975), and grazing has been viewed more as a land use than as a process that promotes a pattern that is essential to ecosystem structure and function. In a similar way, the essential role of fire as an ecosystem process with importance equal to climate and soil (Axelrod 1985; Pyne 1991; Bond and van Wilgen 1996; Bond and Keeley 2005) has been replaced with the view that fire is merely a vegetation management tool (one among many other tools) applied primarily to benefit livestock production. This difference in how grazing and fire are viewed is not trivial if ecosystem services are important rangeland management goals. Viewing fire or grazing as tools interchangeable with herbicides and mechanical methods (e.g., Riggs et al. 1996; Scifres 2004) ignores the historical and ecological significance of these processes to biodiversity and patterns inherent to rangelands. In this article, we use biodiversity to present evidence of the essential role of pattern of process to ecosystem services. We discuss biodiversity as encompassing ecological patterns and processes according to the definition by West (1993, p. 2): "biodiversity is a multifaceted phenomenon involving the variety of organisms present, the genetic differences among them, and the communities, ecosystems, and landscape patterns in which they occur."

Concomitant to development of the conservation paradigm, the science of ecology has progressed from studies that rely on many replications of small plots to studies that emphasize pattern and process at multiple temporal and spatial scales. Watt (1947) and later Turner (1989) connected pattern to process, which led to *landscape ecology* as a discipline that has increased scientific attention to heterogeneity. In spite of these developments, rangeland management and research have failed generally to recognize the importance of scale and heterogeneity to biodiversity and ecological processes (Fuhlendorf and Smeins 1996, 1999; Briske et al. 2003). Increased interest in biodiversity conservation and the role of scale and heterogeneity are indications that traditional approaches to the science and management of rangelands may be inadequate to effectively embrace multiple uses at sufficient scales to meet society's expectations.

In this article, we argue that a *conservation of pattern and process* paradigm is a rational alternative to the utilitarian paradigm for the rangeland profession. While a conservation-based paradigm is neither novel nor entirely counter to the historical underpinnings of the profession (see Rumburg 1996), we argue that if rangelands are to fully meet the expectations of society, it will require fundamental and substantial change in the principles of our discipline and ultimately to the application of management at the landscape level. We also argue that focusing on soil protection and plant species composition as the primary indicators of rangeland condition to the exclusion of processes and life forms other than vascular plants impedes our profession's development and the profession's ability to meet society's values placed on rangeland ecosystem services. The paradigm of conservation of pattern and process broadly includes conservation of all species and life forms, habitat structures, and processes across complex landscapes. We examine rangeland conservation under the utilitarian paradigm followed by describing the conservation of pattern and process paradigm as it could be applied to rangeland management. We conclude by providing a framework for the conservation paradigm through a modified set of rangeland management principles that concomitantly address the current status of North American rangeland and societal values. Throughout, we supplement our focus on North American rangelands with citations from rangelands from other continents (e.g., Australia and Africa). We focus on rangelands that developed with a strong influence of grazing and/or frequent fire, but we broaden this to include rangelands that developed with infrequent fire.

BASIS AND LIMITATIONS TO THE UTILITARIAN PARADIGM

We rightly take pride in our profession's contributions to management that grew out of concern over destructive grazing practices and unregulated livestock use of private and public rangelands after the Civil War (Sampson 1952; Pieper 1994; Holechek et al. 2004). Driven largely by society's concern about reduced potential of these lands to produce forage for livestock resulting from an increase of undesirable species (i.e., species with low productivity and low livestock forage value) and eroded soil, pioneers of our profession discovered and successfully implemented practices that conserved rangeland production potential (i.e., desirable forage species and soil) for future utilitarian purposes. The first unified theory of rangeland conservation was based on the seminal paper by E. J. Dyksterhuis (1949) in which he proposed that condition of rangelands be based on the proportions of *increaser*, *decreaser*, and *invader* species in the plant community. Species were classified on the basis of their response to grazing such that increased grazing pressure would promote *increaser* and *invader* species and cause a decline in *decreaser* species. The species most preferred by livestock were classified as *decreasers*, and management was intended to promote *decreaser* dominance. The highest-quality rangeland vegetation from a livestock production context (excellent or good condition) was most similar to the climax plant community and thus not recently disturbed by grazing or fire (Pendleton 1989).

The definition of rangelands as ecosystems capable of supporting grazing animals led to management focused largely on manipulating domestic livestock grazing (Holechek et al. 2004). Some 60 yr after Sampson's (1952) early book on rangeland management, sustainable livestock grazing and economic returns continue to drive rangeland management decisions (Dunn et al. 2010), and conservation continues to focus primarily on maintaining or enhancing livestock production (Toombs and Roberts 2009). The utilitarian roots of range management that promoted protecting the soil and vegetation from disturbance and maintaining the output of products (Holechek et al. 2004) led to four foundational principles of rangeland management that focused on manipulating livestock grazing. These principles of rangeland (grazing) management are to 1) maintain proper stocking rate (number of animals per unit area per unit time), 2) achieve proper distribution of animals in space (generally considered to be spatially uniform grazing use), 3) achieve proper forage utilization in time, and 4) use the proper kind and class of grazing animals to match or obtain the desired plant community. These strategic principles, accompanied by many tactical rules of thumb, formed the basis for rangeland management as practiced today.

Ranchers do not normally manage with the goal of achieving excellent range condition across their ranch, but they have succeeded in managing for uniform grazing and increasing the proportion of desirable forage grasses while reducing bare ground—managing for the middle (Fuhlendorf et al. 2009). Applying the utilitarian paradigm has therefore achieved a measure of success reflected by improved range condition in the United States over the past century (Fig. 1; Holechek et al. 2004). The distribution of range condition (highest percentage in good and fair condition and lowest of excellent and poor) reflects meaningful achievement toward the management goal of obtaining uniform, moderate utilization necessary to minimize soil loss and rangeland area in poor condition. Goals of increasing dominance of important forage species and reducing bare ground have been achieved through cross fencing, water development, and other practices that promote uniform, moderate utilization while minimizing ungrazed and heavily grazed areas.

This is not to say that the scientific underpinnings of rangeland management have not advanced since Stoddard. The theoretical framework of rangeland management recently shifted focus from equilibrial to nonequilibrial dynamics, state-and-transition models, and rangeland health (Briske et al. 2003, 2005). Although an important advance in rangeland science and management, the shift largely refined the utilitarian model because single plant communities remain the primary management goal rather than embracing spatial and temporal heterogeneity. Policies of federal agencies have advanced the utilitarian model. For example, the US Department of Agriculture Natural Resource Conservation Service, through its Environmental Quality Incentive Program, invested primarily in improving and maintaining livestock production with most of the practices promoting uniform distribution of grazing animals and limiting the dominance of species of minimal forage value for livestock (Toombs and Roberts 2009). While management that achieves uniform grazing distribution and moderate forage utilization can benefit soil protection, water quality, and habitat for some wildlife species, the practices often fail to provide for habitat requirements and ecological processes that may be dependent on the extremes of a disturbance gradient (Knopf 1996; Fuhlendorf et al. 2006). Highly palatable and rare species ("ice cream plants") that are expected to be sacrificed under grazing practices designed to achieve uniform grazing use of abundant forage plants is yet another example of inattention to pattern and process under traditional rangeland management (Stoddart and Smith 1943; Vallentine 2001).

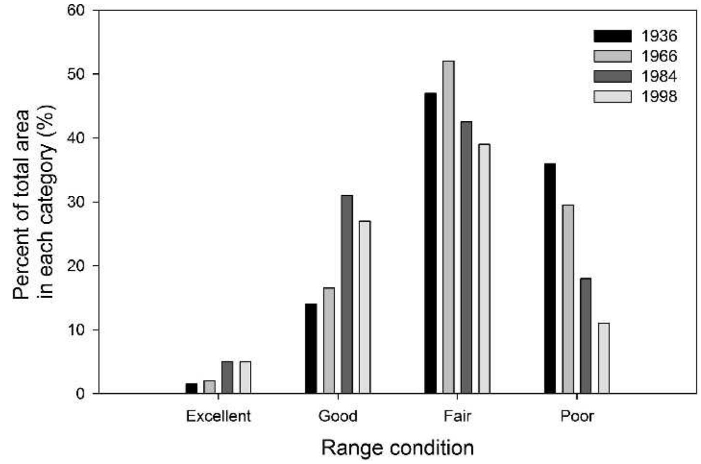

Figure 1. Proportion of US privately owned rangelands in each of four range condition classes from 1936 to 1998 (modified from Holechek et al. 2004).

Rangeland monitoring has focused recently on rangeland health, leading to conservation management based on reducing bare ground, stabilizing soil (Pellant et al. 2005), and anticipating threshold changes (Bestelmeyer et al. 2003). Rather than focusing on climax plant communities, the current plant community and soil conditions are compared to a potential natural community and desirable plant communities—a single reference community phase (Pellant et al. 2005). Therefore, monitoring continues to focus largely on maintaining desirable forage species and minimizing bare ground with a single state, phase, or condition considered the most appropriate for any ecological site (Bestelmeyer et al. 2003, 2009). This ignores the role of pattern and process of disturbance and enhancement of ecosystem services other than livestock production, and it reinforces the notion that a single plant community and homogeneity of the landscape are the

Table 1. Requirements to ensure processes and habitat for imperiled species on rangelands. These examples demonstrate that managing complex landscapes to achieve homogeneous accumulations of litter and minimizing bare ground will lead to undesirable biotic and abiotic changes on many rangelands.

Species/process	Location	Requirement	Citations
Biological diversity	Globally	Landscape heterogeneity	Christensen (1997), Wiens (1997), Fuhlendorf and Engle (2001), Fuhlendorf et al. (2006, 2009), Tews et al. (2004)
Diversity of insects	Grassland/steppe	Heterogeneity	Bestelmeyer and Wiens (2001), Dennis et al. (1998), Engle et al. (2008)
Diversity of mammals	Rangeland	Heterogeneity	Ceballos et al. (1999), Dean et al. (1999)
Diversity of birds	Rangelands	Heterogeneity	Knopf (1994), Fuhlendorf et al. (2006), Gregory et al. (2010), Reinkensmeyer et al. (2007)
Ecosystem stability	General	Heterogeneity	Holling and Meffe (1996), van de Koppel and Rietkerk (2004)
Soil aggregate stability and nutrient cycling	General	Heterogeneity	Herrick et al. (2002), Augustine and Frank (2001), Anderson et al. (2006)
Grazing patterns	General	Heterogeneity	Senft et al. (1987), Stuth (1991), Fuhlendorf and Engle (2004), Fryxell et al. (2005), Fuhlendorf et al. (2009)
Fire behavior	General	Heterogeneity	Fuhlendorf and Engle (2001), Archibald et al. (2005), Kerby et al. (2007), Fuhlendorf et al. (2009)
Hydrology	General	Heterogeneity	Belnap et al. (2005), Ludwig et al. (2000), Eldridge et al. (2002)
Blowout penstemon (*Penstemon haydenii*)	Central Great Plains	Bare ground	Stubbendieck et al. (1993)
Western juniper (*Juniperus occidentalis*)	Intermountain West	Low frequency of fire	Miller and Rose (1999)
Black-tailed prairie dog (*Cynomys ludovicianus*)	Shortgrass prairie	Low vegetation structure	Milne-Laux and Sweitzer (2006), Augustine et al. (2007), Northcott et al. (2008)
Mountain plover (*Charadrius montanus*)	Shortgrass prairie	Bare ground or heavy grazing	Derner et al. (2009), Knopf and Rupert (1995)
Aspen (*Populus tremuloides*)	Intermountain West	Periodic fire with limited herbivory	Bartos et al. (1991), White et al. (1998)
Henslow's sparrow (*Ammodramus henslowii*)	Tallgrass prairie	Ungrazed and unburned for > 2 yr	Coppedge et al. (2008), Herkert (1994)
Plains cottonwood (*Populus deltoides*)	Great Plains	Periodic bare ground	Braatne et al. (1996), Mahoney and Rood (1998)
Gopher tortoise (*Gopherus polyphemus*)	Gulf coastal plain	Frequent fire	Ashton et al. (2008), Landers and Speake (1980)
Ruffed grouse (*Bonasa umbellus*)	Northern forests and mountains	Young forest < 20 yr	Jones et al. (2008), Dessecker and McAuley (2001)
Sage thrasher (*Oreoscoptes montanus*)	Intermountain West	Sagebrush without juniper	Reinkensmeyer et al. (2007)
Horned lark (*Eremophila alpestris*)	Western North America	Recently disturbed areas	Reinkensmeyer et al. (2007)
Upland sandpiper (*Bartramia longicauda*)	Tall and mixed prairie	Recently burned prairie	Fuhlendorf et al. (2006)
Cotton rat (*Sigmodon hispidus*)	Tallgrass prairie	Unburned and ungrazed prairie	Cully and Michaels (2000)
Regal fritilary (*Speyeria idalia*)	Tallgrass prairie	Unburned and ungrazed prairie	Swengel (1998), Vogel et al. (2007)
Black-backed woodpecker (*Picoides arcticus*)	Western Forests	High fire severity, recently burned	Hutto (1995), Koivula and Schmiegelow (2007)
Cassin's sparrow (*Aimophila cassini*)	Great Plains	Undisturbed shrubland	Kirkpatrick et al. (2002)

appropriate targets for rangeland management. This is not a phenomenon confined to North America. Recent studies of piospheres in Australia (James et al. 1999; Hoffmann and James 2011) and communal grazing in Africa (Rutherford and Powrie 2011) suggest that management that would be considered inappropriate from a traditional rangeland management approach might actually contribute to regional patterns of biodiversity. Therefore, it should be of little surprise that the definition of *poor* range condition, often termed the at-risk community phase (Briske et al. 2005, 2008), is strikingly similar to habitat requirements of many imperiled plant and wildlife species in a variety of rangeland types from across the world that are highly valued by society (Table 1). Furthermore, the concurrent loss of abundance of these species on rangelands worldwide could be viewed as indicators of significant deviations from historic processes.

This evidence indicates that biodiversity and ecological processes have not moved forward as fundamental elements of the rangeland profession. This is likely a legacy of larger agricultural and rural society in the first half of the 20th century that viewed wildlife as competitors and conflicting with livestock production and disturbance as reducing productivity reflected in early range management textbooks (Stoddard and Smith 1943; Sampson 1952). Although the profession's attitudes and perceptions of wildlife have changed over time, wildlife continue to be considered by the rangeland profession to be largely a source of economic return or a land use objective rather than as an ecosystem component (Holechek et al. 2004). In contrast to systematic efforts to establish indicators of rangeland health to include ecological processes (water cycle, energy flow, and nutrient cycles) and biotic integrity that supports ecological processes (Pellant et al. 2005), no systematic effort has translated scholarly efforts (e.g., West 1993) into principles and practices for conserving biodiversity or restoring the full suite of ecological processes on complex rangeland landscapes. Efforts to focus on ecological processes are often limited to a single process without consideration of the full potential suite of processes (e.g., water purification, water cycle, carbon sequestration, nitrogen cycling, and so on). Rangelands continue to be described as simple homogeneous states despite the volumes of data that suggest that these complex systems are in fact dynamic in space and time and that complex patterns are essential to a full suite of ecosystem services (Table 1). Despite changing social perspectives that question the range profession's self-image associated with livestock (Brunson and Steel 1994) and research demonstrating that grazing was not responsible for all changes in rangeland ecosystems (Westoby et al. 1989), the science and management of rangelands have lagged behind other disciplines—and arguably the public—in embracing an expanded view of rangelands as complex ecosystems that support multiple land use objectives and provide a full suite of ecosystem services including biodiversity (West 1993; Krausman 1996; Havstad et al. 2007).

The evidence clearly indicates that utilitarian principles of rangeland management that focused on dominant forage species and soil protection represent a century of scholarly effort that improved rangelands throughout the world. However, society dictates and research confirms that livestock-centric approaches are incapable of providing an effective template that optimizes all ecosystem services. Svejcar and Havstad (2009, p. 30) suggested, "Science has provided basic principles for management tied to the spatial and temporal scales and uses of the 20th-century land manager. . . . What has changed is the demand for a wider variety of goods and services." This statement acknowledges that providing ecosystem services in addition to livestock production requires a new rangeland management paradigm that links pattern and process at multiple scales.

Ample evidence indicates that rangeland capacity to produce goods and services valued by 21st-century society has declined in the past half century or so. The North American Breeding Bird Survey is one of the longest (1966 to present) and most extensive ecosystem monitoring efforts covering most of North America and evaluating birds across all landscape types. Classification of species based on their preferred habitat type (grassland, aridland, forest, and wetland) indicates that some species groups are stable (forests) or even increasing (wetlands), while those associated with rangelands (defined here as grasslands and aridlands) are the most rapidly declining group of species in North America (Fig. 2). Examples include the McCown's longspur (2.1% annual decline, 1966–2006), Henslow's sparrow (8.3% annual decline, 1966–2006), and Cassin's sparrow (1.5% annual decline, 1966–2006; Sauer et al. 2008). Diverse communities of species require habitat heterogeneity that includes intensively disturbed habitats (i.e., bare ground and relatively short-statured vegetation) and habitats with minimal disturbance dispersed as a shifting mosaic across a complex landscape (Fig. 3; Table 1; Knopf 1996; Fuhlendorf et al. 2006, 2009). Studies of rangeland birds from the shortgrass steppe (Knopf 1996), intermountain West (Reinkensmeyer et al. 2007), and Africa (Skowno and Bond 2003; Krook et al. 2007; Gregory et al. 2010) have also indicated similar relationships in which bird community composition is dependent on variable patterns of fire and grazing. While other factors are certainly involved, declines in grassland and aridland birds of North America were simultaneous with nationwide improvements in rangeland condition and rangeland health, as our profession has defined these terms (Holechek et al. 2004). This suggests that our approach to defining rangeland condition and health is insufficient to determine ecosystem health that reflects societal values. A recent meta-analysis of the relationship between animal species diversity and habitat heterogeneity found that over 80% of all studies surveyed found a positive relationship (Tews et al. 2004). Studies included relationships with arthropods, birds, mammals, amphibians, and reptiles in all types of ecosystems across the globe, clearly supporting the view that heterogeneity is the root of biodiversity and therefore should be the basis for conservation of rangelands and other ecosystems (Wiens 1997; Fuhlendorf et al. 2006).

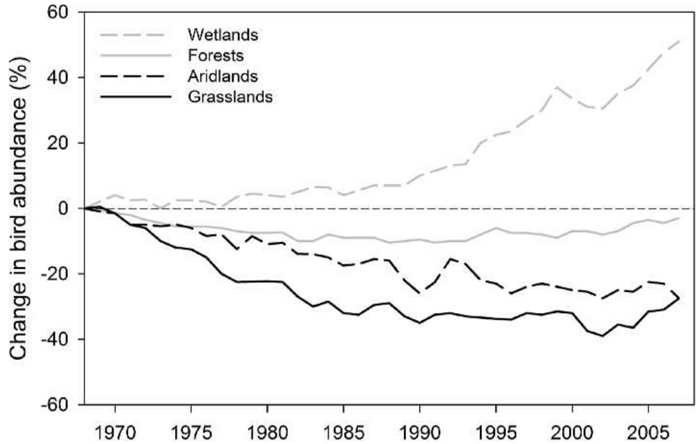

Figure 2. Change from a baseline of 1966 in bird populations associated with four major habitat types reported by the North American Breeding Bird Survey (North American Bird Conservation Initiative, U.S. Committee, 2009). Rangeland habitats are most closely approximated by grasslands and aridlands, which have seen the greatest decline since 1966 in birds native to these habitats.

RANGELAND MANAGEMENT TO CONSERVE PATTERN AND PROCESS

Conservation of rangeland biodiversity is most threatened by regional losses of rangeland through cultivation, woody plant

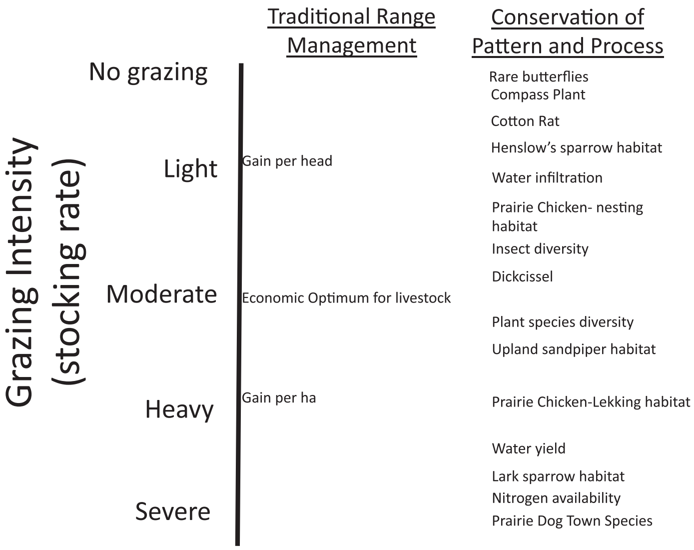

Figure 3. Objectives achieved through the utilitarian paradigm ("proper" range management) when constrained to a single stocking rate contrasted to complete rangeland conservation in which stocking rate varies in space and time. Conservation of pattern and process examples are mostly from North American prairies, but examples also exist for Mountain Big Sagebrush (Reinkensmeyer et al. 2007) and African (Gregory et al. 2010) rangelands.

encroachment, suburban sprawl, invasive species, and desertification. Conservation must first consider large-scale patterns on rangelands and areas that have experienced severe fragmentation and/or species invasions are constrained by those changes (Fuhlendorf et al. 2002). This is particularly relevant in areas of the American West where annual grasses are rapidly altering plant composition and function to a new state. Thus, historic patterns and processes may not be appropriate or feasible. Large-scale fragmentation and alteration make conservation decisions more complex. Yet they do not alter the reality that disturbance processes shape plant community structure, biodiversity, and ecosystem function even when those disturbances are highly altered from historic conditions.

For large-scale patterns, it is useful to compare the foundational principles of rangeland (grazing) management as a framework for contrasting conservation management under the utilitarian paradigm with an alternative paradigm to rangeland management that conserves pattern and process. We approach this by developing new principles for rangeland management based on several key aspects related to grazing management principles, namely, grazing intensity and distribution of grazing in time and space. To these we add fire because most rangelands of the world are fire-dependent ecosystems and because, until recently, fire has received infrequent attention in both the science and the management of rangelands (Axelrod 1985; Bond and Keeley 2005). We do not include kind and class of animals because matching the type of animal with the environment is equally important to utilitarian management and management for conservation of pattern and process.

Grazing Intensity

Grazing intensity (proportion of the aboveground net primary production consumed by grazing animals) is considered the most important principle of grazing management (Heitschmidt and Taylor 1991; Milchunas and Lauenroth 1993; Holechek et al. 2004). Although grazing intensity and stocking rate are not synonyms, the two are often discussed together because the concepts overlap considerably. Numerous experimental studies have demonstrated that optimum animal gains per unit area are accomplished through fairly heavy stocking, optimum gain per individual animal occurs at light stocking, and economic optimum is near moderate stocking where 25–30% of the forage is harvested (i.e., moderate utilization) by domestic livestock (Hart et al. 1988; Heitschmidt and Taylor 1991; Torell et al. 1991). Achieving moderate utilization is a challenging objective for nonequilibrial ecosystems because of highly variable interannual weather patterns. Under utilitarian management, "proper" stocking (i.e., moderate utilization) maintains the dominant forage species, minimizes soil loss, and optimizes economic returns.

From a conservation perspective, optimal stocking rate becomes much more complex because no single stocking rate is optimum for all species and processes (Fig. 3). Table 1 includes examples of species that either require heterogeneity (from severely disturbed to undisturbed habitat) or require habitat that is either severely disturbed or undisturbed. Because no single stocking rate is most appropriate for all species and processes, there is no single "proper" stocking rate if the goal is biodiversity by maintaining ecosystem processes. Therefore, there is a conservation paradox of grazing intensity because the full range of stocking rates must be present at the appropriate scales to maintain biodiversity. This paradox can be addressed within the conservation of pattern and process paradigm by focusing on heterogeneity in space and time and considering grazing as a disturbance process that interacts with other disturbances across complex landscapes (Fuhlendorf and Engle 2001; Archibald et al. 2005; Fuhlendorf et al. 2009). At the landscape scale, this necessitates that managers consider the context of landscapes in making decisions. Removal or moderation of grazing on patches may be most important on landscapes that are uniformly and heavily grazed, while landscapes with minimal grazing should focus on creating disturbed and variable habitats. At the local scale, management should strive to achieve a dynamic management such that the system is variable at small scales while stable at increasing scales if conservation of biodiversity is the objective. Inherent to this approach is that no single species or plant community is maximized across all spatiotemporal points; rather, the full suite of species and conditions for that system would be optimized. This will not be consistent with some objectives in some places. Thus, recognition should be given that maximizing any one thing is to the detriment of others.

Distribution of Grazing in Space and Time

The management goal of most grazing systems, termed "management to the middle" (Fuhlendorf et al. 2006, 2009), promotes uniform dominance of the most productive forage species while maintaining efficient use of these species through moderate and even use across the landscape (Stoddart et al. 1975; Bailey 2004). The focus on uniform utilization in space and time resulted from the growth of range management during a time when the primary concern on rangelands was overuse and concentration of animals near water and other attractants. As expressed by Stoddart et al. (1975), "Overgrazing on a range is not dependent entirely upon the number of animals; all the attendant results can be realized locally if stock are not distributed properly." Standardized uniform and efficient utilization developed from the attempt to maximize livestock production (e.g., Hart et al. 1993) and minimize degradation of riparian areas (Vallentine 2001; Bailey et al. 2006). To conserve the larger landscape, sacrifice areas, particularly around specific watering and mineral locations, often would be targeted for moderated grazing (Vallentine 2001). Although still necessary in some situations (e.g., riparian areas), this focus developed into a standard that may now be a historical artifact no longer appropriate for meeting the full suite of conservation goals. That no "proper" stocking rate exists for all aspects of rangeland ecosystems applies equally to distribution of grazing in space and time.

When animals are allowed to graze at moderate stocking rates across a large landscape, their distribution in space and time is highly variable and dependent on water, topoedaphic features, vegetation structure and composition, and previous disturbance (Heitschmidt and Taylor 1991; Ash and Stafford Smith 1996; Bailey et al. 1996; Holechek et al. 2004). Animals will preferentially select previously grazed or otherwise disturbed areas that have short-statured regrowth, a phenomenon that works counter to uniform moderate grazing (Coppedge and Shaw 1998; Fuhlendorf and Engle 2001; Limb et al. 2010b). This kind of selective grazing behavior results in heterogeneous vegetation structure and composition within the landscape where some local areas are heavily grazed and some areas can be ungrazed or nearly so (Coppedge and Shaw 1998; Fuhlendorf and Engle 2004). Assuming that the disturbance is not static and becomes a regime that shifts across the landscape, this heterogeneity or mosaic generally benefits biodiversity (see reviews by Adler et al. 2001; Fuhlendorf and Engle 2001).

A negative perception of heterogeneity arose out of concern that heavily grazed locations will be grazed heavily and repeatedly over a series of years, resulting in loss of productivity, soil damage, and impaired water quality. While this is an understandable concern when disturbance is static and treated as a discrete event, historically it functioned because of the dynamic nature of the interactions and scales of multiple disturbance regimes. A consequence of the alteration of these regimes has been the decline of disturbance-sensitive and disturbance-dependent plants, such as compass plant (*Silphium laciniatum* L.) and blowout penstemon (*Penstemon haydenii* S. Watson). Species that require vegetation structure at the extremes of stocking rate—either heavy use or no use—are also susceptible to decline from grazing management for the middle (Table 1).

To counter this, our profession has often applied high stock density and rotational grazing by cross fencing pastures to force less selectivity and more uniformly utilize each paddock in the rotation so as to minimize bare ground and maintaining late seral stage vegetation (Savory 1999). Although this management has been argued to be consistent with historic grazing patterns with migrating large ungulates (Savory 1999), in practice the intent is typically to uniformly graze (often multiple times) each year, resulting in a landscape that has little or no ungrazed vegetation. Ironically, rotational grazing has been viewed as a conservation-based alternative to continuous grazing because it reduces patch grazing and heterogeneity (Teague et al. 2004, Teague et al. 2009). However, the management objective of uniform grazing is not consistent with meaningfully variable grazing patterns across the landscape that are essential to heterogeneity that supports the conservation of biodiversity (Fuhlendorf et al. 2006) and in some cases animal productivity (Anderson et al. 2006; Limb et al. 2011). Broad grazing ecology research from the Serengeti and South Africa demonstrates that grazing animals benefit from local, heavy utilization or patch grazing on grazing lawns through increased forage quality and nitrogen availability (McNaughton 1984; McNaughton et al. 1997; Archibald et al. 2005). The utilitarian paradigm of uniform distribution of grazing in space and time is incapable of maintaining or enhancing biodiversity and productivity on rangelands at large scales.

Fire as a Rangeland Ecosystem Process

Utilitarian management views fire as a vegetation management tool primarily used to control unwanted plants (Scifres and Hamilton 1993; Ansley and Taylor 2004; Holechek et al. 2004) even though rangeland ecologists were among the first to recognize the central role of fire in developing and maintaining ecosystems (Humphrey 1962). Fire regime was referred to as the "fire climate" to reflect the duality of fire in both formation and maintenance of rangeland—equivalent to climate (e.g., see Wright and Bailey 1982). However, the utilitarian approach limits fire to maintain dominant forage species and control of woody plants while minimizing factors that are perceived as negative to simple livestock objectives (Holechek et al. 2004). Management recommendations also caution against the increase of undesirable forage species, exotic plants, bare ground, and soil erosion (Teague et al. 2010), which, while justified, fail to account for the effect of *no fire* on fire-dependent landscapes.

Most rangelands of the world evolved with lightning ignitions and anthropogenic fires (Pyne et al. 1996). Although some rangelands have been degraded by an increase in fire frequency (e.g., Great Basin, USA; Whisenant 1990), fire suppression and barriers to using prescribed fire led to fire exclusion on the vast majority of rangelands that resulted in woody plant encroachment and biosimplification of many rangelands worldwide (Humphrey 1962; Hamilton and Ueckert 2004). Invasion of woody plants into grasslands is a dominant cause of the global loss of rangelands over the past several decades (Fuhlendorf et al. 2002; Bond and Keeley 2005; Limb et al. 2010a). Fire clearly maintains herbaceous dominance in many grasslands, but even in rangelands with persistent herbaceous dominance with infrequent fire return intervals, fire can be used to restore heterogeneity and alter grazing patterns in a manner than enhances biodiversity (Anderson et al. 2006; Fuhlendorf et al. 2009). Most rangeland fauna and flora respond to fire in a manner similar to grazing intensity in the sense that some species increase and others decrease after fire depending on time since fire, fire season, and fire intensity (Fuhlendorf et al. 2006; Reinkensmeyer et al. 2007).

The conservation of pattern and process paradigm suggests that historical and potential plant communities are complete as management guides only if fire is included in the landscape. Fire is a pattern-driving process on rangelands that interacts with other disturbances to contribute to heterogeneity. While fire can be a useful tool for managing woody plant invasion, it is shortsighted to relegate fire to a toolbox of other options considering that its importance as an evolutionary process has been exhaustively documented. Management of rangelands focused on maintaining or enhancing biodiversity cannot be accomplished without restoring historic fire regimes, including variable fire season and fire intensity together with other disturbance interactions, across the landscape. This is as true in rangelands with long fire intervals as it is in systems with frequent fire. Furthermore, the simple reintroduction of fire is not the only requirement because fire should interact with other disturbances to create a dynamic pattern—a shifting mosaic of fire, grazing intensity, and vegetation structure—across the landscape that preserves the historical processes under which most rangeland evolved (Fuhlendorf and Engle 2001). Some landscapes may have crossed thresholds where the mere restoration of fire may have limited impact (e.g., closed-canopy juniper woodlands) or because of their susceptibility to shifting to a new state (brome-invaded Great Basin shrublands), but once these degraded landscapes have been restored, interactive patterns of fire and grazing should be a conservation objective. In the interim, holding these at risk communities in a relatively stable state will constrain the species that can be conserved to only species that fit that stable state. Thus, research and management focused on maintenance of historical plant communities without considering spatial and temporal patterns of disturbance processes will always have limited success.

NEW PRINCIPLES FOR CONSERVATION OF PATTERN AND PROCESS ON RANGELAND ECOSYSTEMS

Our appeal is that range science and management should embrace a broader conservation perspective using biodiversity and ecosystem processes as primary guiding principles (Fig. 3; Table 2) while recognizing that livestock production, a service that results from healthy rangelands, will not be the primary driving factor in management decisions. Therefore, we propose the following principles of rangeland conservation of pattern and process. We are certain these principles are not exhaustive, and they are not intended to entirely replace all of the traditional principles of range (grazing) management. Instead, we intend these principles to serve as an initial starting place for developing a new conservation paradigm for rangelands.

1. Maintenance of large continuous tracts of rangelands is critical for conservation of patterns and processes so that disturbance processes can interact with complex landscapes and form multiscaled mosaics.
2. Grazing intensity (i.e., stocking rate) is the primary factor influencing the effect of grazing on rangeland, but no single grazing intensity is "proper." For ecosystems that evolved with grazing, all evolutionarily appropriate grazing intensities are, by definition, essential to conservation of biodiversity across large, complex landscapes.

Table 2. Attributes of traditional range management contrasted with range management aimed at conservation of processes and patterns.

Attributes	Traditional range management	Conservation of pattern and process
Outcome	Single use/optimal livestock production	Biodiversity and processes
Distribution	Uniform	Nonuniform
Ungrazed area	Minimal	Substantial
Severely grazed area	Minimal	Substantial
Rate of rotation among fenced units	Rapid	None or slow
Application of fire	Uniform	Patches
Fire perspective	Brush control tool for forage production	Critical ecological process
Philosophy of management goals	Uniformity	Heterogeneity
	Simplicity	Complexity
	Equilibrium	Dynamic
	Management for the middle	Management for extremes

3. Obtaining uniform distribution of grazing in time and space across a landscape is neither possible nor desirable. Managing grazing distribution for heterogeneity as a shifting mosaic across the landscape should be the goal.
4. Shifting mosaics are necessary for maintaining ecosystem structure and function and achieving multiple objectives. Managing for a single condition, state, phase, or successional stage might maximize and sustain livestock production but will not be capable of promoting biodiversity or multiple uses.
5. Conservation of rangelands ultimately should consider all species of animals and plants. Individual species and groups can be used as diagnostic indicators of response to management, but plants and animals should not be considered "sacrifice species" or "management objectives" across an entire landscape.
6. Disturbance regimes, such as fire and grazing, are as vital to ecosystem structure and function as climate and soils. They must be viewed as interactive processes if we are to have any hope of maintaining biodiversity.

MANAGEMENT IMPLICATIONS

The rangeland management profession has clearly advanced natural resource conservation worldwide. Our discipline has grown from the initial concern of maintaining sustainable forage and livestock production on rangelands to one of conservation of complex rangeland landscapes for multiple uses that encompass all ecosystem services, including agriculture, biodiversity, and aesthetics. While we have made an important transition in recognizing the importance of these other services, we must begin to apply management that will achieve these broader goals. We must also recognize that no single state exists in space or time that is most desirable for all objectives, and the patterns that exist (both inherent topoedaphic and disturbance driven) on rangelands are fundamentally important to the functioning of these complex ecosystems. We need to embrace management and monitoring approaches that encourage conditions that support all native plants, animals, and ecological processes at large scales—conservation management. Recent research has demonstrated that conservation management can be consistent with agricultural production objectives (Fuhlendorf and Engle 2004; Limb et al. 2011). These studies indicate that management that promotes heterogeneity can provide greater stability and at least equivalent productivity on North American grasslands. Thus, these new principles hold promise both at small scales to meet production and single species objectives and at large scales to conserve biodiversity. This will require critical planning at multiple scales while always being cognizant of the landscape context. Thus, policy would need to encourage various states and conditions that are dynamic at small scales and increasingly stable at larger scales. This will be a dramatic shift from our current management and will necessitate a much deeper level of planning, monitoring, and understanding of rangelands.

Changes in our research approaches and the development of a paradigm for conservation of pattern and process would offer several benefits to the rangeland profession. First, by focusing on pattern and processes rather than simple management objectives, system sustainability will be maintained, and thus conservation and production can be achieved simultaneously. Second, by changing our conservation paradigm, the range profession will be a leader in broadening the conservation ethic and working with other natural resource disciplines to move to a more systems-based approach that is capable of efficiently linking science, management, and policy. Finally, rangeland science will be in a strategic position that is in line with societal views on the importance of rangelands and the goods and services expected from their management (Brunson and Steel 1994). Implementation will face many social and policy barriers. It is our hope that this article will serve as a catalyst for a rigorous and spirited dialogue on the contextual specifics of the paradigm and how to implement it on rangelands worldwide.

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United States Department of the Interior

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Rick
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Rick Cables, Regional Forester
U.S. Forest Service
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Dear Mr. Cables: Rick

I wanted to thank you for the productive meeting February 9 regarding coordination of endangered species issues between Region 2 of the U.S. Forest Service (Forest Service) and the U.S. Fish and Wildlife Service (Service), Region 6. I am writing to followup on some of our discussions and recommendations made during the meeting to expand black-footed ferret (ferret) recovery opportunities on other National Grasslands across the central plains.

Previous Forest Service commitments to ferret recovery and its success at Conata Basin significantly advanced the overall ferret recovery. No other reintroduction effort has yet achieved the level of success of Conata Basin, and given current habitat extent and presence of plague over much of the western prairie habitats, there are few sites that can realistically hope to match that success today. Moreover, Conata Basin is an essential donor source for wild born ferret kits and has helped initiate and/or bolster reintroduction efforts at three other sites in South Dakota, as well as recovery sites in three other States. The Forest Service's contribution to ferret recovery is enormous and deserving of recognition and appreciation of the Service and all of the other partners involved in ferret recovery.

However, despite considerable recovery progress since the mid-1980s, the ferret remains a critically endangered species. Potential recovery sites across North America are limited. Perhaps no other agency or identity can contribute to more assured and rapid recovery of the ferret than the Forest Service. Ferret recovery cannot be achieved on National Grasslands alone, but likewise, the establishment of adequate numbers of ferret populations across the historical range of the species (a recovery plan objective) may not be possible without concerted support by the Forest Service and expansion of field recovery efforts across more of the Forest Service's vast western holdings. Even with more focused Forest Service management and development of additional sites for prairie wildlife, the amount of managed land actually required to meet these needs would represent a small percentage of the almost 4 million acres of National Grasslands.

The Forest Service manages more lands distributed over plague-free, high-value black-tailed prairie dog habitat than any other State or Federal agency (i.e., in North and South Dakota). There may be excellent opportunities to expand reintroduction efforts into portions of other National Grasslands in Colorado, Kansas, Oklahoma, New Mexico, Texas, and Wyoming. I have enclosed a draft "recovery site" evaluation table currently being finalized by the Conservation Subcommittee of the Black-footed Ferret Recovery Implementation Team. That document is designed to identify existing and potential recovery areas; it shows that National Grasslands throughout the Plains States represent the greatest long-range potential to expand ferret recovery. We understand that many Forest Service sites are highly fragmented in Forest Service/private ownership and that plague is present at many as well. It may or may not be feasible in some cases to consolidate land ownership in a similar manner as was accomplished at Conata Basin. Still, the Service and other recovery partners are pursuing establishment of smaller "nursery" populations and development of plague management capabilities with a view that successful distribution of small sites in the near term may be crucial to spreading population extinction risk, while simultaneously increasing numbers and distribution in the wild. Moreover, we are working on some innovative administrative procedures (via Endangered Species Act section 10(A)(1)(a)) whereby we can implement experimental recovery actions in a more timely and cost effective manner (as opposed to requiring a costly and protracted 10(j) rulemaking process, while still ensuring the protections afforded by 10(j) on adjacent landowners). Our hope is that we can get more small populations started and maintained, while simultaneous efforts can be made to manage for expanding habitat base and consolidating land ownership.

It is important then that the Forest Service examine all possible opportunities to expand recovery efforts across grassland units. While habitats the size and quality of Conata Basin are certainly desirable, we understand that such habitat development is not possible for most units, and that actual development of suitable prairie dog habitats for ferrets may take considerable time to accomplish. Nevertheless, the planning for recovery sites/grassland unit should be initiated as soon as feasible. Wherever possible (especially on plague free units), small nursery populations of ferrets should be established on suitable complexes where 1,500 to 3,000 acres of prairie dogs occur and can be maintained and managed for ferret recovery.

Finally, it is important to understand where the recovery program stands with respect to implementation and monitoring of ferret projects. Recovery partners are now trying to establish as many populations as possible as broadly as possible across the ferret's historical range. Funding for monitoring and research that was typically involved in earlier recovery efforts is largely unavailable today. Consequently, we are looking at more "hands-off" approaches to recovery that entail only basic monitoring requirements (e.g., one fall spotlight effort/year for the first 3 years, perhaps only every 3–5 years thereafter). We know that the cost of implementing recovery actions is becoming a greater problem for partners and it has become more important from a recovery perspective to establish more and better distributed populations.

I look forward to working more closely with you and your staff on ferret recovery and other issues of mutual interest. If you would like to discuss any of these concepts further, please contact me at 303-236-7920; Mike Stempel, Assistant Regional Director, at 303-236-4510; or Mike Lockhart, Black-footed Ferret Recovery Coordinator, at 307-760-8605.

Sincerely,

Deputy Regional Director

Enclosure

DRAFT

BLACK-FOOTED FERRET REINTRODUCTION SITE EVALUATION (Updated, modified 1/10/07)

SITE	HAB	DIS	4X	MST	SCON	RePr A B C	TOTAL	RANK	COMMENTS
ACTIVE REINTRODUCTION SITES (in order of ranked priority)									
Conata Basin/Badlands, SD	5	5	40	5	3	5, 5, 5	63	1	Large, closely distributed prairie dog complexes; sustained, high annual recruitment; outstanding monitoring & scientific contributions; principal donor site of wild kits; site conservation potential diminished in recent years.
Cheyenne River Sioux, SD	4	5	36	5	3	5, 5, 1	55	2	High habitat values; developed prairie management plan; high survival & production levels; second site to contribute wild kits to other emerging reintroduction areas.
Rosebud Sioux, SD	3	5	32	5	3	3, 3, 1	47	3	One of largest overall expanses of black-tailed prairie dog acreage in North America; however, aggressive prairie dog management limits core recovery complexes; prairie dog colonies moderate size & more scattered than other sites.
Shirley Basin, WY	5	0	20	5	3	5, 5, 5	43	4	First ferret reintroduction site; impacted by plague in mid-1990s; extensive prairie dog recovery in 2000s; mixed landownership but massive geographical habitat area to support widespread, large ferret population.
Arizona	3	3	24	5	--	3, 5, 5	42	5	Perhaps best Gunnison's prairie dog site for abundance/distribution. Success, wild recruitment has improved substantially over recent years.
Kansas	4	5	36	3	3	--	42	5	Fragmented but moderate, relatively dense black-tailed prairie dog habitat with no evidence of plague.
Lower Brule Sioux, SD	3	5	32	5	3	--	40	6	Small, widely distributed prairie dog colonies; moderate potential for expansion. New reintroduction effort.
Wind Cave, SD	3	5	32	3	5	--	40	6	Small, scattered distribution with moderate potential expansion potential; important site for education benefits.
Mexico	1	5	24	5	--	3, 3, 1	36	7	Once supporting largest single colony of prairie dogs in North America, habitat now seriously degraded (grazing/drought); residual number of ferrets persist. Conservation efforts underway to improve habitat quality.
Vermejo Park, NM	3	3	24	3	3	--	30	8	Small colonies with good complex configuration; developing release site for nursery population. Good long-term conservation potential (Turner property).
Colorado/Utah	2	0	8	5	5	3, 3, 5	29	9	Scattered prairie dog colonies over extensive area; important experimental programs & contributions; on-site preconditioning & breeding pens.
Phillips County, MT	3	0	12	5	3	1, 1, 5	27	10	Locally moderate habitat values, but more widely distributed colonies; significant losses of habitat from plague in recent years; remaining ferret population minimal; outstanding scientific contributions.

SITE	HAB	DIS	4X	MST	SCON	Ref. A B C	TOTAL	RANK	COMMENTS
INACTIVE REINTRODUCTION SITES (in order of ranked priority)									
Standing Rock, ND/SD	3	5	32	--	--	--	32	11	Habitat thought to consist of moderate, scattered prairie dog complexes but data generally lacking.
Western ND	3	3	24	1	5	--	30	12	Moderate prairie dog colonies. Potential opportunity for shared National Park/NG reintroduction site.
Bad River Ranch, SD	1	5	24	1	3	--	28	13	Small but growing colonies of prairie dogs (2,900 acres). Good long term conservation potential (Turner prop).
Ft. Pierre NG, SD	1	5	24	1	5	--	28	13	Small, scattered prairie dog colonies (1,700 acres); potential for cooperative effort with Lower Brule.
Grand River NG, SD	1	5	24	1	3	--	28	13	Small but growing colonies (1,800 acres), decent Federal land base.
Ft. Belknap, MT	3	0	12	5	3	1, 1, 1	23	14	Moderate prairie dog complexes, poor prior success in reintroduction effort; area impacted by plague.
Thunder Basin, WY	4	0	16	3	3	--	22	15	Formerly with high habitat values, but compromised by two recent plague episodes. Reintro plans proceeding.
Pine Ridge Sioux, SD	5	0	20	--	--	--	20	16	Formerly largest prairie dog complex in North America; extensively poisoned; recent large plague epizootic; high potential but little/no Tribal support.
NE Utah	1	3	16	1	--	--	17	17	Private lands with small scattered white-tail colonies. No historic evidence of plague on site.
Crow Reservation, MT	3	0	12	1	--	--	13	18	Small to moderate colonies with locally suitable complex configurations; recent plague episode impacted site.
Northern Cheyenne, MT	3	0	12	1	--	--	13	18	Moderate colonies with good connection to make suitable complexes; historic plague episode, nothing recent.
Trans-Pecos, TX	3	0	12	1	0	--	13	18	Private lands. Moderate colonies, good complex configurations. No known plague in prairie dogs within area.
Custer Creek, MT	1	0	8	1	3	--	12	19	Small prairie dog population; rebounding from plague; complexes divided by river; checkerboard ownership.
Cisco Desert, UT	1	0	4	1	5	--	10	20	Moderate, scattered acreage of prairie dogs; area improving after plague episode; almost entirely public land.
Comanche NG, CO	1	0	4	1	5	--	10	20	Small/moderate prairie dog colonies; impacted by plague, apparently rebuilding; scattered public/private lands.
Cimarron NG, KS	1	0	4	1	5	--	10	20	Small/moderate prairie dog colonies with favorable complex configuration.
Rita/Kiowa NG, TX/NM	1	0	4	1	5	--	10	20	Small/moderate prairie dog colonies; impacted by plague; scattered public/private lands.

SITE	HAB	DIS	4X	MST	SCON	RePr A B C	TOTAL	RANK	COMMENTS
Pawnee NG, CO	1	0	4	1	5	--	10	20	Small, highly fragmented prairie dog colonies; potential for developing small nursery recovery site.
Pueblo Army Depot, CO	1	0	4	1	5	--	10	20	Small, but well distributed colonies that could be intensively managed for a nursery site.
Navajo Reservation, AZ	1	0	8	--	--	--	8	21	Current data limited; widely distributed population of Gunnison's prairie dogs.

Hab = Habitat Factors; **Dis** = Disease Factors; **4X** = Adjusted Weight Factor; **Mst** = Management Status; **Scon** = Site Conservation Factors; **RePr** = Reintroduction Program Attributes; **NG** = National Grassland, administered by USDA Forest Service.

Habitat Factors

5 = Black-tailed prairie dog; 15,000–20,000+ acres with large core complexes, closely distributed, and relatively high densities (e.g., Conata Basin, SD)
5 = White-tailed prairie dog; mix of small, moderate and large colonies distributed over massive geographic area (e.g., Shirley Basin, WY)
4 = Black-tailed prairie dog; 8,000-15,000 acres with moderate/large core complexes but more widely distributed
3 = Black-tailed prairie dog; 2,000-8,000 acres, smaller/moderate complexes, more widely distributed
3 = White-tailed/Gunnison's prairie dog; large, relatively closely distributed complexes
2 = White-tailed/Gunnison's prairie dog; large complexes, more widely distributed
1 = Black-tailed prairie dog; residual, highly fragmented complexes
1 = White-tailed/Gunnison's prairie dog; small-moderate complexes, widely distributed

Disease Factors

5 = No historical evidence of plague on or within 20 miles of reintroduction area
3 = Documented plague within 20 miles of reintroduction area, but core release areas with no recent documented evidence of plague
0 = History of plague within, or immediately adjoining, release area(s)

4X Biological suitability of the site (i.e., both the quality of the habitat and the occurrence of plague) is given substantially greater weight in an evaluation of overall reintroduction site merit. This same weight factor has been used by the Fish and Wildlife Service since 1996 to develop allocation priorities for distribution of ferrets to reintroduction projects. The sum of the scores for habitat and disease are multiplied by a factor of four.

Management Status

5 = All rulemaking, planning and approval processes necessary to implement reintroduction program complete; reintroduction efforts underway
3 = Active planning to implement recovery program
1 = Expressed interest/preliminary planning
0 = No expressed interest/planning

Site Conservation

5 = Reintroduction area comprised of predominantly Federal and/or State public lands with assurance of long-term ferret conservation
3 = Federal, State, Tribal, or private lands (or mixtures) with conservation agreements and/or moderate potential for long-term conservation of ferret populations
0 = Reintroduction area includes substantial private, or Tribal lands with no specific conservation easements/agreements for ferret management

Reintroduction Program Attributes

5 = Demonstrated high short term, post release ferret survival; good long term survival (over multiple years) demonstrated
3 = Moderate to high short term survival; little or no know long term survival; or modest long term survival
1 = Low to moderate short term survival rates; minimal documented long term survival; or, survival significantly reduced from previous levels

5 = Active/successful reintroduction effort, substantial wild production, likely self sustaining, donor site for translocation of wild kits
3 = Active reintroduction effort, documentation of wild production over successive seasons
1 = Inactive reintroduction project; active but with minimal documentation of wild production; or, previously successful but compromised by disease or management problems

5 = Significant scientific contributions to recovery programs (i.e., intensive experimental practices re. population monitoring, predator management, disease management, pen breeding, etc.)
3 = Moderate levels of scientific contribution to recovery program
1 = Employs basic procedures to monitor prairie dog and ferret populations