EXPERIMENTAL MANIPULATION OF EXPANSION TRAJECTORY IN TRANSLOCATED BLACK-TAILED PRAIRIE DOG COLONIES IN A CHIHUAHUAN DESERT GRASSLAND

BY

MARGUERITE NICOLE HENDRIE, B.S.

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“Experimental Manipulation of Expansion Trajectory in Translocated Black-tailed Prairie Dog Colonies in a Chihuahuan Desert Grassland,” a thesis prepared by Marguerite Nicole Hendrie in partial fulfillment of the requirements for the degree, Master of Science, has been approved and accepted by the following:

Linda Lacey
Dean of the Graduate School

Bruce Thompson
Chair of the Examining Committee

Date

Committee in charge:

Dr. Bruce Thompson, Chair

Dr. Philip Alkon

Dr. Michael DeMers

Dr. Joe Truett

Dr. Walter Whitford

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VITA

December 13, 1973	Born in Detroit, MI
1992	Graduated from Pike High School, Indianapolis IN
1992-1996	B.S. in Biology from Indiana University-Bloomington Semester Program in Nairobi, Kenya Fall 1995
1996-1998	Environmental Education Instructor, North Carolina, South Carolina, Tennessee, Texas
1998-2001	Biologist, Education Director Hawks Aloft, Albuquerque, NM
2001-2004	Master's Degree Candidate, New Mexico State University, Las Cruces, NM. Research Assistant & Teaching Assistant

Professional and Honorary Societies

Phi Beta Kappa

New Mexico Chapter of The Wildlife Society

American Society of Mammalogists

American Society of Photogrammetry and Remote Sensing

President, NMSU Graduate Student Council 2003-2004

Papers Presented

Hendrie, M. H., J. Truett, B. Thompson. 2004. Teaching new dogs old tricks: The behavioral response of translocated black-tailed prairie dogs to expansion barriers. Oral presentation, Joint Annual Meeting of New Mexico & Arizona Chapters of the Wildlife Society. February 6-8. Safford, AZ.

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ABSTRACT

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Dr. Bruce Thompson, Chair

Successful conservation of black-tailed prairie dogs (*Cynomys ludovicianus*) requires the enhancement of land manager toleration of prairie dog colonies. This study was conducted to identify a set of management tools for use in manipulating expansion of *C. ludovicianus* colonies.

I collected information on 21 factors that potentially influence population and expansion of 15 translocated prairie dog colonies on Armendaris Ranch in south-central New Mexico. I created 2 ad hoc indices, "unmanaged constraint" and "managed constraint", to evaluate physical constraint of area around colony sites using distance to edge of colony, visibility through surrounding physical features, and cost of vegetation removal. I also released 120 translocated prairie dogs into 4 test

enclosures. Each enclosure consisted of two sides of stucco wire only and 2 sides of stucco wire and silt fence. I loosened soil in 10, 1x1-m plots inside each enclosure. I observed each colony for 1 week after release to record escape behaviors, and I recorded locations of burrows excavated by the prairie dogs. Using ArcView 8.3, I constructed viewsheds for each colony with respect to artificial barriers and examined placement of new burrows with respect to viewshed.

Of the 21 variables examined, number of prairie dogs originally released (r^2 = 0.274) and number of research projects conducted on the colony (r^2= 0.233) were significantly correlated with current population. Only the unmanaged constraint index was significantly correlated with current area occupied (r^2 =0.184). Climbing was the most common escape behavior and an average of 69% of climbing attempts took place on transparent barriers. Loosened soil patches were used in a non-random fashion and burrows were most often placed in areas visible from the inside of the enclosure.

Management of black-tailed prairie dogs includes both promoting and limiting population growth and colony expansion. Success of *C. ludovicianus* translocations in the Chihuahuan Desert is likely positively associated with amount of precipitation and negatively associated with intensity of predation. Loosening soil may stimulate burrow excavation by prairie dogs. A prairie dog expansion barrier with a component of visual obstruction will be more effective at limiting colony expansion than a non-visual barrier.

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INTRODUCTION

Background

As the earth's human population continues to increase by 1.13%-1.4% per annum (Population Reference Bureau 2004), potential for conflict at the interface of human settlement and wildlife habitat also increases (Foster et al. 2002, Lubow et al. 2002, Fritz et al. 2003). New technology has transformed previously inhospitable landscapes into those suitable for human development. This transformation will bring a suite of new conflicts. In extreme cases, these conflicts may result in human injuries or deaths (MacCracken & O'Laughlin 1998, Manfredo et al. 1998, Jones, D. N. & Thomas 1999, Rajpurohit & Krausman 2000). More commonly, however, concern about wildlife is related to depredation of crops (Messmer & Schroeder 1996, DeBoer & Baquete 1998, Maikhuri et al. 2000, Rao et al. 2002, Bauer 2003), livestock forage (O'Meilia et al. 1982, Zinn & Andelt 1999, Frisina et al. 2001), or ornamental vegetation (Baker & Fritsch 1997, Conover 1997, Zinn & Andelt 1999). As such issues increase, managers and biologists will continue to be charged with devising management techniques that address not only biological factors affecting populations, but also social, political, and anthropogenic factors influencing the fate of native wildlife (Riley et al. 2002).

In addressing issues of troublesome human-wildlife interactions, wildlife managers and biologists often must balance desires of land users, pressures of environmental activist groups, and capricious dictates of politicians while working within a context of limited economic resources. Krausman and Czech (2000) polled agency workers in 273 designated wilderness areas of the southwestern United States. Their results suggest that management activities occur in 67% of those wilderness areas. Included among those activities were fencing (both to exclude and to enclose wildlife from or to specific areas), human management, and problem animal and predator removal. A survey of all state and provincial wildlife agencies in the U.S. and Canada done by Wagner et al. (1997) revealed that 19 states and 7 provinces engaged in wildlife damage compensation programs. The most common financial compensation programs provided assistance for crop damage caused by ungulates and livestock depredation by bears, lions, and wolves. Many more states (34) and 7 provinces provided assistance by way of non-lethal management tools.

While providing financial compensation after damage has occurred may be the only viable solution in some instances, it can be controversial in application and does little to prevent the problem from re-occurring. Under the Department of the Interior and Related Agencies Appropriations Act of 2002 (Smith, D.P. 2002,HR 2217/Pub. L. 107-63.190.61640-61648), state and tribal wildlife agencies may distribute federal grant money in the form of landowner incentives. These incentive programs, paired with preventive management tools, may provide landowners and managers with tools needed to significantly reduce human-wildlife conflicts. Currently in the American West, 1 such controversial issue facing wildlife managers is the fate of the black-tailed prairie dog (*Cynomys ludovicianus*).

Natural History.--Within the Sciuridae family, there are 5 recognized extant species of *Cynomys* (*C. gunnisoni, C. leucurus, C. ludovicianus, C. mexicanus, and C.*

parvidens). Fossilized bone fragments and burrow casts indicate that species of this genera existed as far back as 33,000 B.P (Young et al. 1999). *Cynomys ludovicianus* have been evolving in grasslands of the western United States since the late Pleistocene (Harris & Findley 1964, Goodwin 1993). The historic geographic range of black-tailed prairie dogs included the area from Northern Mexico to Canada and from west of the Rocky Mountains to the edge of the Mississippi Valley (Hoogland 1996b, Barko 1997). In New Mexico, Vernon Bailey (1931) described 3 major areas of extensive prairie dog occupation: east of the Pecos River valley and Sangre de Cristo Mountains, west of the Pecos valley from Portales to Carlsbad, and the Animas Valley. Bailey (1931) described the Animas Valley as, "An almost continuous prairie dog town for its whole length and breadth."

Of the 5 *Cynomys* species, *C. ludovicianus* has the widest distribution and broadest range of habitat types (Hoogland 1996b). Black-tailed prairie dogs can successfully inhabit areas of Chihuahuan desert grasslands, short grass prairies, and mixed grass prairies (Mulhern & Knowles 1997). A study on the Charles M. Russell wildlife refuge in Montana indicated that prairie dog colonies were most often located on clay to silty-loam soils on gentle slopes (< 15%; Knowles 1982, Reading & Matchett 1997). Across the occupied range, black-tailed prairie dogs are associated with a variety of different grass species, but they are most often found in areas with shorter stature grasses (<30 cm; Hoogland 1995) or in disturbed areas (Knowles 1982, Licht & Sanchez 1993).

Prairie dogs are fossorial and dig extensive burrow systems. Burrows are used for predator escape, rearing young, thermoregulation, and to reduce water loss (Kinlaw 1999). Typical *C. ludovicianus* burrows have 1-2 entrances and are, on average, 5-10 m long and 2-3 m deep (Sheets et al. 1971, Stromberg 1978, Hoogland 1996b). There are records of burrows up to 30 m long and 5 m deep (Hoogland 1995). Black-tailed prairie dogs make 3 different types of burrow entrances: crater, dome, and flat. Crater and dome entrances are made of piles of excavated soil and are thought to aid in predator detection, ventilation, and flood prevention (Egoscue & Frank 1984, Cincotta, 1989, Hoogland 1995). Domes are the primary entrances to burrows while craters served as secondary entrances (Cincotta 1989). Flat burrow entrances generally lead to short, unconnected escape burrows (Sheets et al. 1971, Stromberg 1978).

Dietary preferences of the black-tailed prairie dog have been examined primarily through stomach content and fecal analysis studies. In all of these studies, the majority of the diet consists of grasses and sedges (65-87%). Studies performed in South Dakota and Colorado found most important forage items to include *Agropyron smithii, Buchloe dactyloides*, *Bouteloua gracilis*, *Sporobolus cryptandrus,* and *Carex* spp (Bonham & Lerwick 1976, Hansen & Gold 1977, Summers & Linder 1978, Fagerstone et al. 1981, Uresk & Bjugstad 1984). One fecal study from Chihuahuan desert grasslands of southern New Mexico identified *Panicum obtusum, Pleuraphis mutica, Scleropogon brevifolius,* and *Sporobolus airodes* as food sources of prairie dogs (Hartsough 2002). In all locations, forbs and cacti (especially *Sphaeralcea* spp. and *Opuntia* spp.) were an important component of fall and winter diet (Tileston &

Lechleitner 1966, Fagerstone, et al. 1981, Wydeven & Dahlgren 1982, Hartsough 2002).

Since European colonization of western grasslands, ranchers have viewed prairie dogs as pests. Prairie dogs are presumed to decrease the amount of forage available to domestic livestock, and burrows are perceived as hazards to livestock movement and safety. Around 1900, the dominant view in the west was that prairie dogs were varmints and a threat to the livelihood of ranchers (Merriam 1902). In 1915, the federal government initiated a large-scale eradication effort that continued until the early 1970s (Barko 1997). In the early 1900s, the state of Texas issued the Prairie Dog Law (Art. 191 Vernon's Civil Stat.) which mandated county sheriffs to control prairie dogs where no form of control was taking place (Cottam & Caroline 1965). During the 1900s, prairie dog colonies were expansive with the largest colony covering approximately 6,475,000 ha in Texas (Agnew et al. 1986). Widespread extermination efforts, habitat loss, and an introduced disease, sylvatic plague (*Yersinia pestis*; Van Pelt 1999) have reduced present day colony sizes and distribution. The largest existing colony is 34,580 ha in Janos, Mexico (Van Pelt 1999). Current estimates show present-day populations at approximately 1-2% of historic numbers (USFWS 2002).

Ecological Importance.--As native components of much of western grasslands, black-tailed prairie dogs have a substantial effect on natural ecosystems. Their fossorial nature and grazing habits influence many other organisms. While the magnitude of importance of prairie dogs as keystone species has been documented (Sharps & Uresk 1990, Miller et al. 1994, Miller et al. 2000) and debated (Stapp 1998, Kotliar et al. 1999, Kotliar 2000), they do have an obvious impact. Kinlaw (1999) drew attention to the importance of open burrow systems in areas that lack suitable vegetative refugia. Organisms that perform services of modifying abiotic resources to create a non-food resource have been labeled "ecosystem engineers" (Jones, C. G. et al. 1994, 1997). Ecosystem engineering of prairie dogs provides important refugia for burrowing owls (*Athene cunicularia*; Butts & Lewis 1982, Plumpton & Lutz 1993, Desmond 2000, Arrowood et al. 2001, Sidle et al. 2001), box turtles (*Terrapene ornata*; Truett & Savage 1998), rattlesnakes (*Crotalus* spp.; Osborn & Allan 1949, Kretzer & Cully 2001), and spotted ground squirrels (*Spermophilus spilosoma*; Truett & Savage 1998).

Aside from creating burrows, digging by black-tailed prairie dogs has numerous effects on soil. Biopedturbation is the term used to describe disturbances to soil caused by living animals. Burrows and foraging pits can affect soil through redistribution of minerals and materials through the profile, increasing infiltration and evapotranspiration rates, and acting as seed and litter traps (Whitford & Kay 1999). Prairie dogs mix approximately 200-225 kg of soil per burrow system (Whicker & Detling 1993) and in so doing, expose materials that alter soil pH and change texture of soil (Carlson & White 1988). Through foraging for roots, black-tailed prairie dogs leave small pits (Tileston & Lechleitner 1966) that increase soil moisture (Day & Detling 1994). Further, extensive burrow systems increase soil aeration and water infiltration rates (Munn 1993, Day & Detling 1994).

In addition to affecting abiotic resources, prairie dogs have significant impact on vegetative resources. Constant grazing increases nitrogen content and blade to sheath ratio of grasses on prairie dog colonies (O'Meilia, et al. 1982, Krueger 1986, Detling & Whicker 1987, Cid et al. 1991, Fahnestock & Detling 2002). There is also evidence to suggest that grazing selects for genetic differences between on and off-colony plants (Detling & Painter 1983, Jaramillo & Detling 1988). Efficient herbivory of prairie dogs may facilitate an increase in plant species diversity when compared to similar sites without prairie dogs (Bonham & Lerwick 1976, Uresk & Bjugstad 1984, Cincotta et al. 1989, Fahnestock & Detling 2002). Size, diurnal habits, and foraging efficiency of prairie dogs may exclude smaller, sympatric, herbivorous rodents (Agnew et al. 1986, Agnew et al. 1988, Ceballos et al. 1999). This competition paves the way for omnivorous and insectivorous rodents to occupy an area, thus indirectly affecting insect populations in and around active colonies (Agnew, et al. 1988). In addition, maintenance of short stature vegetation by prairie dogs creates suitable habitat for species such as mountain plovers (*Charadrius montanus*; Knowles et al. 1982, Manning & White 2001), horned larks (*Eremophila alpestris*; Agnew et al. 1986, Barko et al. 1999), earless lizards (*Holbrookia maculata*; Kretzer & Cully 2001), and possibly aplomado falcons (*Falco femoralis*; Truett 2002).

For predators, a prairie dog colony represents a year-round source of energy. Diet and observational studies have consistently found colonies of all prairie dog species to be important foraging grounds for large, diurnal raptors like ferruginous hawks (*Buteo regalis*), bald eagles (*Haliaeetus leucocephalus*), and golden eagles

(*Aquila chrysaetos*; Campbell & Clark 1981, Allison et al. 1995, Plumpton & Andersen 1997, Berry et al. 1998, Bak et al. 2001). In addition to aerial predators, prairie dogs have a number of terrestrial enemies such as coyotes (*Canis latrans*; Campbell & Clark 1981, List & Macdonald 2003), badgers (*Taxidea taxus*; Goodrich & Buskirk 1998), swift foxes (*Vulpes velox*; List & Macdonald 2003) and rattlesnakes (*Crotalus* spp; Osborn & Allan 1949). The black-footed ferret (*Mustela nigripes*) is the species most ecologically linked to black-tailed prairie dogs (Hubbard & Schmitt 1983, Bevers et al. 1997, Biggins & Schroeder 1998) and is bringing the most publicity to the issue of prairie dog conservation (Van Pelt 1999). Ironically, it is also one of the most ruthless predators of *Cynomys* (Powell, R. A. 1982, Andelt & Beck 1998, Vargas & Anderson 1998).

Population Decline and Status.--While black-tailed prairie dogs may play a key role in aforementioned trophic interactions, this species is subject to a variety of even more effective population control mechanisms. The bacterium *Yersinia pestis* is responsible for widespread plague epidemic among 4 of 5 *Cynomys* species. Plague was introduced from Europe around the 1900s into California. By 1950, the North American range of the disease was approximately what it remains today (Cully & Williams 2001). This disease is flea-transmitted, and there is no evidence of plague resistance in *C. ludovicianus* or *C. gunnisoni* (Barnes 1993). Mortality rates for black-tailed prairie dog colonies affected with plague typically approach 100% (Barnes 1993, Cully & Williams 2001).

Western civilization has frequently targeted the prairie dog for control directly through eradication programs and indirectly through habitat conversion. In Montana, South Dakota, North Dakota, Texas, and Wyoming black-tailed prairie dogs are still subject to 'varmint' or pest laws (Van Pelt 1999). Further, the Homestead Act of 1862 inspired 1.5 million Americans to take over 200 million acres of western grasslands (including 104 million acres of the Great Plains) for agriculture (Noss et al. 1995, Gober 2000). Current estimates regarding the amount of mixed and short grass prairie that has been converted to agriculture range from 7-90% depending on other environmental factors (Samson & Knopf 1994, Loveland & Hutcheson 1995).

Due to keystone species status and sharp decline in numbers, black-tailed prairie dogs have been petitioned for listing as a federally threatened species. The February 2000 ruling was "Warranted but Precluded" (Rose et al. 2000). In 1998, state wildlife agencies in Wyoming, Montana, and South Dakota held meetings with the National Wildlife Federation (NWF) and the U.S. Fish and Wildlife Service (USFWS) to discuss options regarding listing of this species (Van Pelt 1999). In 1999, a conservation agreement was created involving all states within the historic range of the black-tailed prairie dog. This agreement involves 2 parts: a conservation assessment and a conservation strategy. The conservation assessment charges each state to determine the status of the prairie dog in their state and to identify specific threats facing viability of the species. The conservation strategy focuses on reducing threats as defined by the conservation assessment and promotes conservation of the species (Van Pelt 1999).

The USFWS recommended that all 11 states within the historic range of the species make an effort to restore black-tailed prairie dog populations to at least 1% of potential prairie dog habitat (Miller & Reading 2002). States must employ measures that will stabilize or re-invigorate population numbers to avoid listing of this species. In some states, drastic reduction of prairie dog populations will weaken recovery efforts if reintroduction efforts are not employed (Truett & Savage 1998, Dockter-Dullum 2001). Currently in New Mexico, black-tailed prairie dogs occupy approximately 11,000 ha less than the 35,288 ha target set by the Black-tailed Prairie Dog Conservation Team (USFWS 2002, Johnson, K. et al. 2003). In the "U.S. Fish and Wildlife Service Conservation Assessment and Strategy Report for Black-tailed Prairie Dogs" priorities for research include studies to assess how habitat conditions can be altered to promote successful reintroductions and to determine effectiveness of non-lethal control methods (Van Pelt 1999).

Translocation and reintroduction efforts involve a considerable amount of time and money. Sites must be adequately prepared with vegetative treatments and artificial burrows, and prairie dogs must be trapped, transported, and released (Truett et al. 2001). Failure to provide adequate habitat would result in a tremendous waste of resources. Several studies have documented the need for black-tailed prairie dogs to inhabit areas in which there is high visibility of the surrounding area (Osborn & Allan 1949, Garrett et al. 1982, Cable & Timm 1988, Cincotta et al. 1988, Loughry 1993, Weltzin et al. 1997, Truett & Savage 1998). Prairie dogs have been known to clip, but not consume, woody vegetation found within a colony to reduce visual obstruction

(Hoogland 1981, Weltzin, et al. 1997). Researchers have observed that black-tailed and Utah prairie dogs will avoid venturing into tall grass (over 31 cm) despite the possible increase in forage quality such areas may offer (Osborn & Allan 1949, Player & Urness 1982, Cable & Timm 1988, Loughry 1993, Truett & Savage 1998). Many reintroduction efforts involve reducing height of vegetation in proposed sites to accommodate greater visibility (Player & Urness 1982, Truett & Savage 1998).

While some research has been conducted to determine appropriate reintroduction and translocation techniques (Player & Urness 1982, Ackers 1992, Robinette et al. 1995, Truett & Savage 1998, Dockter-Dullum 2001), there have been few efforts to assess long-term success or failure of such efforts. In addition, few attempts have been made to study non-lethal management methods. While new colonies may be needed to stabilize black-tailed prairie dog numbers, existing colonies may require management to make them more acceptable to private landowners. Efforts to examine non-lethal methods have primarily been based on personal observations made by agency personnel rather than through controlled experimental studies (Witmer et al. 2000).

Justification

Traditional Control Methods.--There are several traditional techniques for controlling prairie dogs. One such technique is shooting. During her doctoral dissertation research, Oakes (2000) found several historic accounts of prairie dog shooting from the 1840s. Varmint hunting is still a popular recreation in some states and prairie dog species serve as favorable targets (Vosburgh & Irby 1998, Sidle et al.

2001, USFWS 2002). An estimated 1.5 million prairie dogs were killed by recreational shooters in South Dakota in 2001 (Gigliotti 2002). Vosburgh and Irby (1998) found that shooting reduced colony populations by approximately 35% (versus a 15% decline on non-hunted colonies) in Montana, but concluded that the spatial extent of the colonies was unaffected by this technique of population control.

Use of chemicals to control prairie dogs also has a long history. Zinc phosphide is widely accepted as a rodenticide. Secondary effects of zinc phosphide on predators is minimal because zinc phosphide does not accumulate in muscle tissue of target animals and because ingestion of the digestive tract by predators is relatively rare (Johnson & Fagerstone 1994). However, there are known impacts on non-target species such as gallinaceous birds, waterfowl, and red-winged blackbirds (*Agelaius phoeniceus*; Johnson & Fagerstone 1994). Uresk and Schenbeck (1987) found that colonies in South Dakota treated with zinc phosphide increased by only 1% following treatment compared to a 65% increase on untreated colonies. Likewise, Apa et al. (1990) recorded a 77% reduction in colony size using zinc phosphide. While this chemical is initially effective at reducing prairie dog populations, recolonization into treated areas is high due to presence of unoccupied burrows. Additional applications are required approximately every 3 years (Cincotta et al. 1987, Uresk & Schenbeck 1987, Barko 1997). One effect of repeated treatments is to reduce cost-effectiveness. A study by Collins et al. (1984) estimated that a rancher would not recover costs of prairie dog colony treatments in terms of animal unit gains for 22 years after initial application. Burrow fumigants have also been proposed as lethal control methods, but application over a large area is costly, and the effect on non-target animals has not been thoroughly evaluated (Hygnstrom & VerCauteren 2000).

Chemicals can also provide non-lethal means of wildlife population control in the form of chemosterilants (Barlow 2000). Garrett and Franklin (1983) used diethylstilbestrol (DES) as a reproductive inhibitor in female black-tailed prairie dogs. DES is a synthetic estrogen that temporarily curtails reproduction. This treatment proved effective in eliminating births in a small study area (Garrett & Franklin 1983), but widespread applications have not yet been tested. Widespread use of contraceptive methods for control of prairie dogs is not likely to be available for public use, however, due to carcinogenic properties of DES (Giust et al. 1995, "10th report on carcinogens" 2002).

A few studies have identified deferred grazing as another non-lethal technique for controlling prairie dog expansion due to the correlation between high visibility areas and black-tailed prairie dog occurrence (Osborn & Allan 1949, Knowles 1982, Uresk & Bjugstad 1984, Cable & Timm 1988). Prairie dogs likely evolved with grazing of large ungulates such as bison (*Bison bison*), and historical records indicate that peaks in prairie dog abundance coincide with periods of severe grazing intensity (Truett 2002). If prairie dogs have adapted to this symbiotic relationship with large ungulates, it follows, then, that removal of grazing will affect their abilities to survive. Cable and Timm (1988) found that area occupied by prairie dogs was reduced by an average of 49% after 2 years of deferred grazing. Snell and Hlavachick (1980) also documented success in controlling prairie dogs by simply removing cattle. While deferred grazing may offer a management tool throughout much of black-tailed prairie dog range, it may not be suitable in areas where livestock grazing is not the principle land use, in areas where grass species (such as *Scleropogon brevifolius)* are naturally low in stature, or in suburban areas.

Behavioral Rationale.--Knowledge of animal behavior is often useful in developing effective wildlife management strategies (Arcese et al. 1997). Coloniality in black-tailed prairie dogs is likely driven by the increase in predator detection facilitated by larger group sizes (Hoogland 1981, Powell, R. A. 1982). Prairie dogs rely heavily on visual detection of danger and spend 10-40% of their time vigilant (Hoogland 1979, Loughry 1993, Hoogland 1996b). In some areas of their range, black-tailed prairie dogs are unable to survive without large herbivores due to predator advantage in tall vegetation (Cable & Timm 1988, Truett & Savage 1998, Truett et al. 2001). When a predator is detected, a prairie dog will immediately assume an "alert" position either in its current location or at the nearest burrow mound (Hoogland 1981). This visual signal often elicits like responses from close neighbors. If perception of danger continues, a vocal alarm may be given by 1 or more colony members. Generally this alarm stimulates the rest of the colony members to move to the nearest burrow entrance within their own territories (Hoogland 1981). Hoogland found that a vocal alarm made by 1 black-tailed prairie dog would not elicit a response by another individual unless the second individual also detected the predator (Hoogland 1995). In general, the greater the number of active prairie dogs in a colony, the less time any 1 individual must devote to vigilance behaviors, and the more time that individual has for other behaviors such as foraging (Hoogland 1981, Devenport 1989, Loughry 1993, Hoogland 1996a, Verdolin & Slobodchikoff 2002). For this anti-predator system to work prairie dogs must have an unobstructed view of their surroundings and adequate refugia must be readily available. Experimental manipulations that exploit a prairie dog's natural tendency to abandon areas with obscured views of surroundings may result in development of effective tools to manage colony expansions.

Prairie dog burrows serve several functions: sleeping, rearing young, and escape from predators and inclement weather (King 1955, Hoogland 1995). Densities of burrow entrances in prairie dog colonies can vary from 10 to 342/ha (Tileston & Lechleitner 1966, Campbell & Clark 1981, Powell et al. 1994a, Hoogland 1996b). Contrary to studies of Gunnison's prairie dogs (Verdolin & Slobodchikoff 2002), burrow density in black-tailed prairie dogs is not an accurate index of population size (Powell et al. 1994b, Severson & Plumb 1998). Prairie dogs live in family groups called coteries. Female prairie dogs are thought to remain in the same coterie territory throughout their lives while young male prairie dogs will disperse from their natal territories. Within a territory, use of specific burrow entrances will vary from year to year (Powell et al. 1994a, Dobson et al. 1998). Burrow entrances may be plugged and new entrances excavated. The cause of burrow plugging is not always known, but it has occurred in response to predators entering the burrow (Martin et al. 1984). Density of active burrow entrances may reflect habitat quality, restricted area for expansion, or predator abundance (Powell et al. 1994a). Burrows are important for escape cover, and vigilance of prairie dogs increases as distance to nearest burrow increases (Loughry

1993). In addition, it has been shown that a decrease in number of active prairie dogs in a colony will decrease distance from a burrow that a particular prairie dog is willing to forage (Devenport 1989).

Regardless of actual predation rates, perception of predation risk affects ranging behavior of prairie dogs (Verdolin & Slobodchikoff 2002). These patterns of behavior reflect the security provided by burrows. While foraging away from an available burrow is risky behavior, digging a new burrow entrance also costs energy and may be perilous (Ebensperger & Bozinovic 2000). The faster a burrow entrance can be completed, the less dangerous the activity of digging will be. Soil that is too soft may result in collapsed burrows (Miller 1957, Rhodes & Richmond 1985), but soil that is very compacted may require too much time for excavation. Time spent excavating a burrow should be a function of substrate friability and travel time to safe cover. On 4 reintroduced colonies in Chihuahuan Desert grasslands, the greatest mean nearest neighbor distance between burrows in a colony was 24 m (Appendix A). After approximately 2 months post release, average distance dropped to less than 15 meters (Fig. A-1). Altering horizontal substrate characteristics with respect to digging ability of black-tailed prairie dogs should predictably influence rate and direction of colony expansion.

Need for alternative management strategies.-- A common goal that exists for most ranchers, biologists, and environmentalists is to avoid further decline of existing black-tailed prairie dog populations. Ranchers wish to prevent listing of species, as it generally equates to less autonomy regarding management of leased and private land

(Melious & Thornton 1999, Sax 2000). The federal government may impose restrictions on use of resources if the species is listed. Biologists and environmentalists are concerned about loss of a potential keystone herbivore (Van Putten & Miller 1999, Miller & Cully 2001) and important prey source for the black-footed ferret—the most critically endangered mammal in the United States (Hubbard & Schmitt 1983, Biggins et al. 1993, Bevers et al. 1997). Finding a common ground on this issue will involve collaboration and cooperation among all parties.

Most ranchers dislike prairie dogs and do not feel that they should be forced to accept loss of available livestock forage due to prairie dogs on public lands (Lybecker et al. 2002). However, interviews of western ranchers conducted in 1993 revealed that a small number of ranchers would be interested in maintaining small prairie dog populations on public allotments (Lybecker et al. 2002). In addition, the Wyoming Agricultural Statistics Service found that 40% of ranchers with large plots of land surveyed showed interest in participating in a financial compensation program for allowing prairie dogs to occupy their land (Lybecker et al. 2002). For such a program to occur, effective techniques for both promoting and limiting prairie dog colony expansion and growth must be established.

In New Mexico, the Black-tailed Prairie Dog Working Group employs a multi-stakeholder approach involving private ranchers, federal and state agencies, concerned citizens, and biologists. The goal of this diverse coalition is to develop a strategy for conservation of black-tailed prairie dogs in the state. One of the major objectives is to develop a landowner incentive program for maintaining prairie dog habitat (Coon

2002). To provide a complete incentive package, management assistance should be provided in addition to monetary assistance. I sought to investigate specific humane and cost-effective techniques for predictably managing the distance and direction of restored prairie dog colony expansion. Such research is critical if agencies expect private landowners to participate in conservation of this species.

Past Barrier Efforts.-- The apparent success of deferred grazing in limiting prairie dog expansion has led many to conclude that a sufficient barrier can be made with vegetation (Murphey et al. 1998, Witmer, et al. 2000). For areas in which vegetation is not naturally tall, shrubs and tall grass can be transplanted. Newly planted vegetation, however, no matter how arid adapted, generally need substantial quantities of water to promote initial root establishment. While vegetation transplants may be useful in suburban areas having access to water and irrigation systems, it is not a practical proposal in many arid or extremely isolated areas. Prairie dogs may also clip or consume new vegetation. Further, the soft soil created by planting new vegetation will likely promote digging at the base of new plants. To be effective, vegetative barriers may need to be used in conjunction with additional barrier methods.

The first published account of artificial barriers as a means of prairie dog control was written by Franklin and Garrett (1989). These authors used 3 rows of 1-m burlap fence and 3 rows of cut ponderosa pine poles as barriers. After 2 months, they found a significant reduction in use of the area separated by the visual barriers. One problem noted by the authors was the constant maintenance needed to the fences due to chewing by prairie dogs and rubbing by other wildlife in the area.

In a longer term study, Hygnstrom (1996) tested effectiveness of visual barriers made of polyethylene plastic fencing for reducing recolonization into poisoned areas of colonies. One barrier design consisted of 3 bands of 15.2-cm wide plastic snow fence suspended at 10, 35, and 60 cm above ground. These fences were not able to withstand high winds and were removed after 2 weeks. The next design consisted of a thicker polyethylene plastic that was 67 cm wide. Barriers were left in place for 3 years. Hygnstrom found that these barriers were ineffective at reducing recolonization rates.

Colorado's 'front range' is an area of rapidly developing suburbs and increasing incidence of human-prairie dog conflict. The City of Fort Collins Natural Resources Division has had extensive experience with prairie dog management. The city's policy regarding prairie dogs is to maintain colonies on areas designated as "Natural Areas" so as to benefit grassland ecosystems, but to control populations that threaten to destroy adjacent property (Murphey, et al. 1998). Opinions of Fort Collins residents about prairie dogs range from those who believe that killing prairie dogs is never justified to those who feel that all prairie dogs should be exterminated (Zinn & Andelt 1999). Artificial barriers offer a potential compromise.

Donna Dees, (wildlife specialist, city of Fort Collins), reported that barrier use by the city began in 1994 (personal communication.). The city's website provides some advice on effective barriers (http://www.ci.fort-collins.co.us/naturalareas/pd-barriers.php). They recommend using a material that does not allow light to pass through and that stands >90 cm tall. When asked, Ms. Dees responded that material that lets light pass through is likely to be easier for prairie dogs to climb. She also reported that the City of Fort Collins had used 60-cm tall fences in the past, and there was a high rate of escape. The Fort Collins Natural Resources Division recommends using 90-cm wide 'Griffolyn ®,' a specially-made vinyl material with grommets placed every meter. The barrier is held upright with wooden posts every 30.3 meters and T-posts every 3 meters. Use of a horizontal, chicken wire skirt buried 7.5 cm below the surface is suggested but not necessary. The natural resources division has had a policy of removing prairie dogs that cross barriers, but Ms. Dees reported that such removals were uncommon in the past 2 years.

In nearby Boulder, Colorado, the issue of prairie dog management is equally severe. Bill Grabow of City of Boulder Open Space and Mountain Parks stated that his department has been using vinyl prairie dog barriers for approximately 15 years (personal communication). Their barriers stand 60 cm above the ground and are buried 15 cm below the surface. Mr. Grabow also reported that chicken wire or other non-smooth material enabled prairie dogs to climb fences. Prairie dogs may climb, dig, or tear at barriers to cross them. In Boulder, barriers are typically 80-90% effective at limiting movement of prairie dogs, but there have been instances in which barriers are completely ineffective (Bill Grabow, City of Boulder Open Space, personal communication).

Expanding cities are not the only cause of human-prairie dog conflict. A study conducted on Melrose Bombing Range in eastern New Mexico in 2002 investigated the interaction between prairie dog colonies and incidence of raptor-aircraft collisions (Merriman 2003). In addition to conducting raptor surveys, this project attempted to analyze effectiveness of galvanized roofing and silt fence as prairie dog barriers. In this experiment, barriers were placed on the edges of 2 existing colonies. Barriers consisted of 6.1 x 1-m strips of material spaced 1.5 m apart and extending for 100 m. Two identical rows of barriers with staggered gaps were used at each study plot, and each colony was divided into 3 plots: galvanized roofing barrier, silt fence barrier, and control. Merriman examined effectiveness of barriers by counting active burrows on either side before barrier construction and at 4, 6, 8, 10, 12, and 14 weeks post release. The results of this experiment suggest that barriers were not effective at limiting prairie dog expansion on the bombing range site. Silt barriers required substantial maintenance due to cattle and wind-induced damage.

In central New Mexico, Kirtland Air Force Base (KAFB) faces similar problems with Gunnison's prairie dog colonies. After several years of lethally controlling prairie dogs, KAFB now seeks to maintain colonies in an effort to increase burrowing owl habitat. Unfortunately, some areas of protected habitat border a city-owned park in which prairie dogs are unwanted. The border between the base and the park consisted of a chain-link fence under which prairie dogs were tunneling. To mitigate this problem, KAFB environmental services reinforced the chain link fence with stucco wire attached 30 cm above the ground and extending horizontally across the soil surface for about 90 cm. According to Carol Finley, a biologist with KAFB environmental services division, the horizontal barrier was staked to the ground but never buried (personal communication). This barrier was effective until a severe drought hit the base and caused prairie dog colonies to expand in search of food.

Many examples given describe a situation in which an agency or organization has an immediate need to control prairie dogs and a limited budget with which to do so. In such instances, it is often easier to use a method that has been shown to be successful, rather than experiment with new techniques or materials. Agency employees frequently consider aesthetics as a factor when choosing barrier materials. In suburban areas such as Colorado's front range, vinyl and vegetative barriers are the method of choice. Griffolyn ® vinyl barriers cost approximately $5.94/ m. These estimates include only raw barrier materials, not supports or labor. Such an expense is likely to be met with resistance by rural land managers and ranchers. Aesthetics is also likely to be a factor in rural situations.

The study presented here was undertaken to 1) examine previously translocated colonies in an effort to identify factors leading to greater success or failure, and 2) provide greater insight into potential effectiveness of vertical barriers. I studied behavioral responses of prairie dogs to identify factors that lead to reduced effectiveness of artificial barriers at limiting prairie dog expansion. I also intended to find effective methods of non-lethal prairie dog management that fit the following criteria:

1) Easy to install
2) Inexpensive
3) Made with readily-available materials
4) Aesthetically acceptable

Research Context

To enhance ultimate interpretation of research outcomes, it will be important to have strategic background and contextual information about study sites and associated prairie dog populations. Thus, I had an overarching descriptive objective to collect information from 15 reintroduced prairie dog colonies on Armendaris Ranch with respect to treatments performed, type of habitat, and current population and analyze these data for possible correlation between colony success and vertical structure. In addition, I evaluated costs and benefits associated with various prairie dog management techniques including time, major equipment, consumables, and effectiveness.

Based on previous research and a general understanding of natural black-tailed prairie dog behavior, the following hypotheses and objectives were developed to test specific actions to alter habitat use by prairie dogs:

Hypotheses and Objectives

Hypothesis 1.-- Altering vertical structure of the environment will predictably influence trajectory of areal expansion of translocated black-tailed prairie dog colonies in the Chihuahuan Desert because of the natural tendency to avoid areas with an obscured view of the surroundings.

Objective 1a.--To determine effectiveness of vertical, visual barriers in summer 2003 in significantly reducing number of new burrows and overall prairie dog activity in suitable habitat within 4 newly established colonies when compared to similar areas of the same colonies with non-visual barriers.

I predicted that vertical, visual obstructions will reduce number of new burrows dug by translocated prairie dogs in suitable habitat when compared to areas without obstruction or to areas behind non-visual barriers

Objective 1b.-- To examine the types and relative success of barrier crossing behaviors of translocated prairie dogs and the relative frequency of these behaviors with respect to barrier type on 4 newly established colonies.

I predicted that translocated prairie dogs will attempt to cross barriers by digging at the bottom of vertical fences, and that this behavior will occur most frequently with non-visual barriers.

Objective 1c.--To determine age and gender of prairie dogs that traverse barriers and dig new burrows in study plots in summer of 2003.

I predicted that sub-adult males will cross barriers significantly more than old males or females due to the tendencies of males to disperse more frequently than females.

Hypothesis 2.--Manipulating textural characteristics of horizontal substrate will affect placement of new burrows because while digging new burrows, prairie dogs display a threshold of movement from occupied burrows that is a function of distance and relative substrate friability, both of which affect time for return to a safe burrow.

Objective 2.--To measure, in summer of 2003, the number of new burrows located in plots treated to loosen soil compared to the number of new burrows located in untreated areas.

I expected that translocated prairie dogs would use treated areas in a nonrandom fashion.

STUDY AREA

This study area was on the Armendaris Ranch, located 20 km east of Truth or Consequences, New Mexico (Fig. 1) in the basin and range physiographic region of the state (Dick-Peddie 1993). The Armendaris Ranch is a privately-owned, 145,750-ha ranch managed to increase biodiversity through alternative, environmentally sensitive ranching practices and ongoing wildlife research projects. The ranch was purchased by Turner Enterprises Inc. (TEI) in 1994 and cattle were replaced with bison. Vegetation of the ranch is a mixture of semi-desert grassland and Chihuahuan Desert scrub. Dominant grass species include black grama (*Bouteloua eriopoda)*, alkali sacaton (*Sporobolus airodes*), and tobosa (*Pleuraphis mutica*). Common shrubs and sub-shrubs include honey mesquite (*Prosopis glandulosa*), creosote (*Larrea tridentata*), four-winged saltbush (*Atriplex canescens*), and snakeweed (*Gutierrezia* spp.). Other common flora include prickly pear (*Opuntia* spp.), cholla (*Cylindropuntia* spp.), and soaptree yucca (*Yucca elata*). The ranch borders the Rio Grande and Elephant Butte Reservoir to the west. The Fra Cristobal mountain range is located just east of the river. The northern portion of the ranch includes a small shield-type lava accumulation, the Jornada del Muerto flow. This lava flow was a result of a volcanic eruption that occurred approximately 750,000 years ago (Crumpler & Aubele 2001). Precipitation patterns peak in late summer during convective, monsoonal thunderstorms. Average precipitation in the area is approximately 24 cm. (Western Regional Climate Center, http://www.wrcc.dri.edu/index.html).

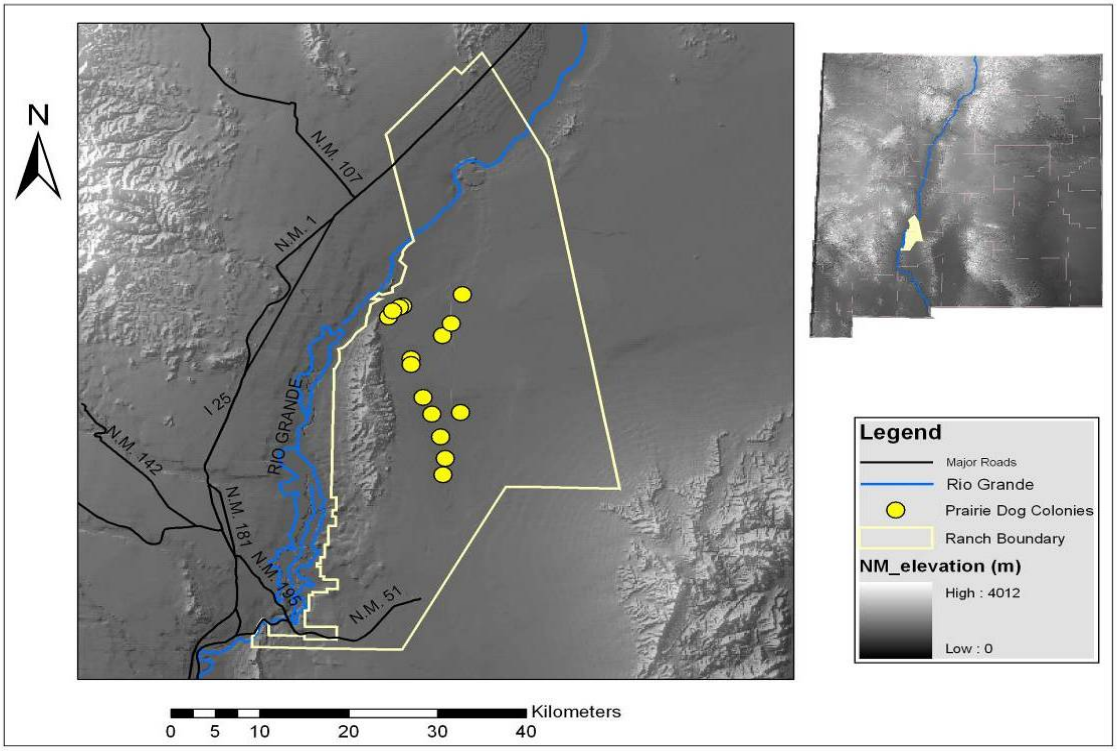

Figure 1. Map showing location of Armendaris Ranch, the study area for experimental manipulation of translocated prairie dog colonies on Armendaris Ranch, southern New Mexico, 2003.

Reintroduction of prairie dogs into locations in which they had previously existed (ca. 1965; Oakes 2000) began in 1995 (Truett & Savage, 1998). As of February 2003, there were 15 successfully re-established colonies located on the ranch (Fig.1). This study included all existing re-established colonies and 4 colonies that were established in summer 2003.

Dominant vegetation at the sites includes tobosa, burrograss, alkali sacaton with scattered cane cholla (*Cylindropuntia imbricata*), and prickly pear. Native and introduced herbivores on the ranch include pronghorn (*Antilocapra americana*), American bison (*Bison bison*), and oryx (*Oryx gazella*). Potential prairie dog predators include western diamondback rattlesnake (*Crotalus atrox*), badger (*Taxidea taxus*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), ferruginous hawk, Swainson's hawk (*Buteo swainsoni*), red-tailed hawk (*Buteo jamaicensis*), and golden eagle (*Aquila chrysaetos*). Human activities on the ranch include recreational hunting, small numbers of tours, wildlife research, and bison ranching.

METHODS

Existing Colony Data Collection

To begin the task of compiling information about existing translocated colonies on the ranch, I contacted Dr. Joe Truett, Turner Endangered Species Fund (TESF) biologist, and Mr. Tom Waddell, Armendaris Ranch Manager. Dr. Truett is the biologist responsible for prairie dog translocations on the Armendaris and other Turner Enterprise ranches. Initial contact with these 2 individuals was during in-person interviews. I followed up with an electronic mail message to Dr. Truett. Information obtained from Dr. Truett and Mr. Waddell included date of release, number of animals released, management treatments applied before and after translocations, depth of artificial burrows, and additional information regarding translocation procedures. Shawn Russell and Tracy Mader also were consulted in person and via electronic mail regarding ongoing management of colonies and colony characteristics and measurements.

At the suggestions of Dr. Truett and Mr. Waddell, I made additional contacts with New Mexico State University graduate students and professors. I sent electronic mail messages to Dr. Mark Andersen, Dr. Martha Desmond, Dr. Ed Frederickson, and Dr. Gary Roemer regarding past or present research conducted on the Armendaris Ranch prairie dog colonies. Graduate students, Heather Adams, Danielle Berardelli, Ben Duval, Aaron Facka, and Matt Hartsough also were contacted in person and through electronic mail to gather information regarding research involving the

Armendaris Ranch prairie dogs. The list of questions asked can be found in Appendix B.

Location and GIS-derived Information.--I used a Trimble GeoExplorer 3 global positioning system (GPS) unit to collect location information for each colony. In early May of 2003, I walked the perimeter of each colony (identified by vegetation change) and placed a vinyl flag with a 37.5-cm wire stake immediately next to each perimeter burrow. I then started at the first burrow identified, and walked 50-m transects in a perpendicular orientation to the shortest path between the starting burrow and the closest marked burrow. These transects were 10 m apart (Fig. 2). The purpose was to identify any additional burrows not marked during my initial perimeter search. If a new burrow was located during this process, a new set of transects was created. After completing the burrow search, I walked a continuous path between each marked burrow while logging Universal Transverse Mercator (UTM) coordinates in North American Datum 1983 at a rate of 1/second. This information was downloaded into Pathfinder GPS software and coordinates were differentially corrected. I then exported these polygons as shapefiles for use in ArcView 8.3 geographic information system (GIS) software. A complicating factor for this process was the presence of historic, collapsed burrows. Some colonies were placed in areas identified as historic prairie dog colonies. These sites often showed signs of older collapsed burrows. On occasion, prairie dogs will recondition these old burrows for use. My main interest was to identify expansion of translocated colonies rather than to compute currently active area, active burrow density, or total excavation. Historic burrows were distinguishable from new burrows by the presence of uneven ground. I used a historic burrow to delineate the perimeter only if fresh prairie dog feces were present at the entrance along with signs of soil disturbance.

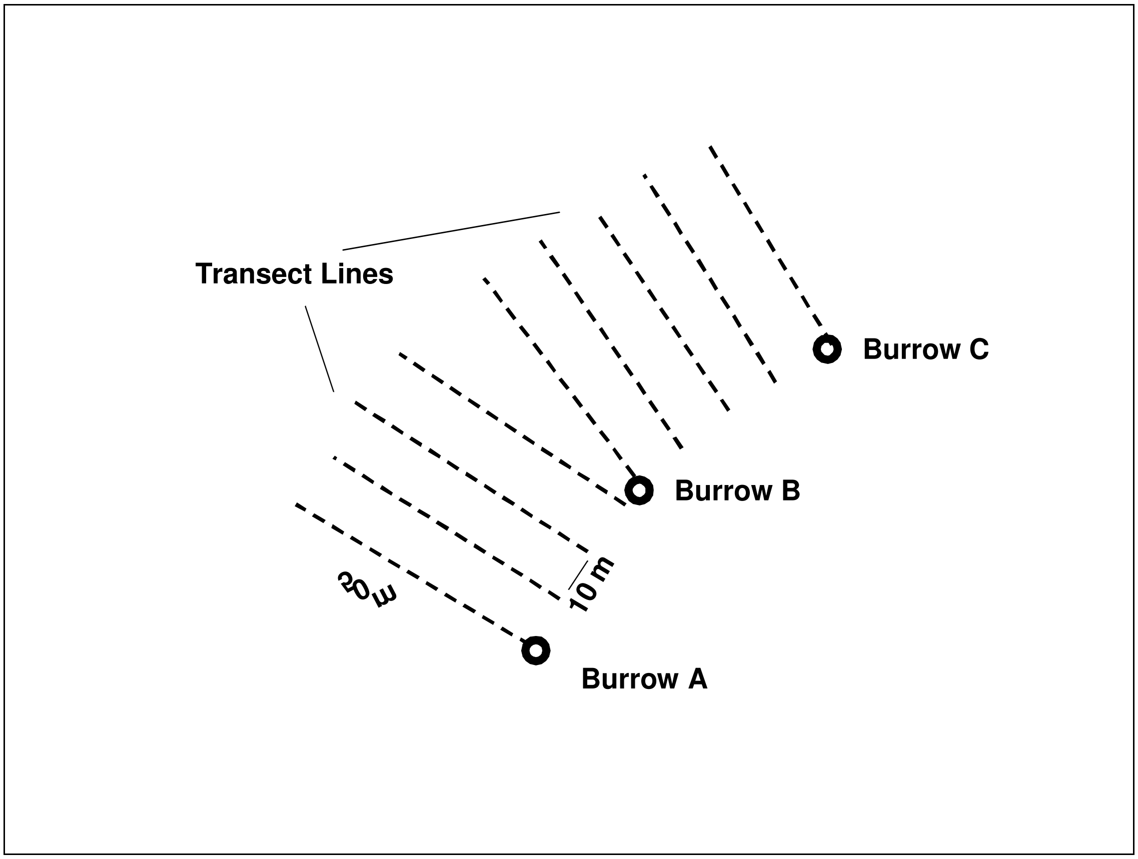

Figure 2. Pattern of transects used for locating perimeter burrows of 15 translocated black-tailed prairie dog colonies on Armendaris Ranch in May 2003

I used the colony shapefiles along with spatial data layers obtained from the Armendaris Ranch management staff, and through the New Mexico Resource Geographic Information System (RGIS) Program data clearinghouse website (http://rgis.unm.edu) to obtain additional information (Appendix C). Using ArcView 8.3, I obtained information for each colony regarding total area in 2003, soil type, elevation, distance to the nearest road, presence of power lines, and distance to the nearest colony at the time of release.

Constraining Borders and Visibility.--At each of the 15 colonies I used the Trimble GeoExplorer 3 to collect location data for tall grass (>30 cm), shrubs, and lava piles (>1 m) around each colony. I accomplished this by walking along the edge of the above features (tall grass, shrubs, and lava) closest to the active colony area. I set the GeoExplorer to record points at a rate of 1/sec and slowly walked along the edge of these features. I recorded species of grass, presence or absence of shrubs, and presence or absence of tall basalt piles.

Where there were borders of tall grass or shrubs around the colonies, I collected information on visibility at prairie dog height. To estimate visibility, I modified the technique outlined in Cincotta et al. (1988). I began by cutting a 0.5 m x 0.5 m target out of plywood. I painted a checkerboard of 25 red and white squares (10 cm x 10 cm) on the target. I used a random number table to choose a starting point along the border of interest. At the starting point, I delineated a 20-m transect perpendicular to the border orientation by staking down a 25-m measuring tape. A 3.1 mega pixel digital camera was placed 5 meters from the border at a height of 30 cm. This represents the average height of a prairie dog standing in an upright, alert posture (Hoogland 1995). I placed the target at distances of 1, 2, 5, 10, 15, and 20 m along the tape and took pictures at each location. I then used the pictures to count the number of white squares visible on each picture. I took an average of the readings at 1-5 m and an average of the readings from 10-15 m. I measured visibility every 75 m along a border. When the entire border was of a length less than 75 m, I took at least two measurements.

Soil Compaction Measurements.--At each site, soil compaction to a depth of 30 cm was measured using a dynamic cone penetrometer (Herrick & Jones 2002). The approximate colony center was located through visual estimates. I then used a random number table to pick a starting direction. I measured soil compaction every 10 m (colonies <1 ha) or every 20 m (colonies >1 ha) for a total of 4 samples along that bearing. I then returned to the starting point, added 90 degrees to the initial direction and repeated the procedure. I repeated this for a total of 4 directions (16 samples at each colony). To measure soil compaction, I placed the soil penetrometer tip on the soil surface so that the instrument was vertical to the soil surface. I raised the hammer to the top position (40 cm from the striker plate) and let it fall. I then counted and recorded the number of strikes to bury the penetrometer tip a depth of 30 centimeters. To compare between colonies, I calculated the mean, variance, and standard deviation for the 16 samples of each colony.

Constraint Index.--All colonies are located in areas with a slightly different suite of factors that may influence or constrain the ability of the colony to expand. Here the term constraint refers to natural features in the landscape surrounding prairie dog reintroduction sites that act to inhibit expansion of the colony edge. Many colonies were located within the Jornada Del Muerto lava flow region. For the purposes of this study, I estimated that exposed lava mounds acted as a total, physical, expansion barrier. Tall vegetation also prevents prairie dog expansion in some circumstances.

For this index, I assumed that tall vegetation acted as a barrier solely due to visibility factors. Therefore, constraint is inversely proportional to the visibility through a medium. Another factor is the distance between the current colony edge and the barrier. The greater the distance a colony has left to expand before encountering a barrier, the lower the constraint on the colony. The prairie dogs on Armendaris, however, live in a managed landscape. Tall vegetation can be treated to make it more hospitable to prairie dog colonies. For this reason, I factored in cost of treatment for each vegetation type. Higher costs associated with treatment result in a higher constraint value.

To derive an index of constraint I used a raster GIS model in ArcView 8.3. The first step in calculating this index was to create a 100-m buffer around each prairie dog colony. This layer was used as the analysis extent. I created a distance layer using the Find Distance function in Spatial Analyst. This algorithm creates a raster GIS layer with a distance value for every grid cell. I then imported the vegetation data that were collected on each colony, created 3 buffers directed away from the colony center (5, 20, and 100 m) and converted these to raster. The next layer I created was visibility. Visibility ranged from 1 to 0.001 corresponding to values determined in the visibility analysis for each type of vegetation. In areas with grass height < 30 cm, I assumed the visibility to be 1 (100%). Where lava was present, I assumed the visibility through the lava to be 0. The visibility value would eventually be used in the denominator of the final constraint calculation, so I gave such areas a value of 0.001. To arrive at the "un-managed" constraint index, I combined distance and visibility layers using the raster calculator of Spatial Analyst. I multiplied distance and visibility and calculated the inverse of the product. I then found the average value of the cells to find the index for the colony. For the "managed" constraint index, I created a cost layer for each cell. To arrive at this layer, I estimated the cost of removal of shrubs and grass. I gave each cell a cost value based on the dominant vegetation. Once again, values of 0 were intractable, so short grass that required no management was given a value of 0.001. Likewise, removal of lava is not likely to be a valid prairie dog management strategy. I gave areas of exposed lava a value of $\$10/m^2$. I estimated the cost of brush removal to be $\$0.0054/m^2$ (Red River Authority of Texas 2000) and the cost of mowing tall grasses to be $\$0.0025/m^2$ (Doane's Agricultural Report Newsletter, vol 62 no 21-6, 1999). I then divided the total cost of management for each prairie dog colony by the total constraint. I calculated the average of all the cells to find the colony's constraint index. The values of the indices have uncertain meaning, and they were intended only as a means of comparison among the fifteen colonies. Due to the wide range of values, I converted both unmanaged and managed values to z-scores by subtracting the overall mean and dividing by the standard deviation.

Population Indices.-- I conducted surveys at each colony to collect information on relative population size. I chose a spot at such distance that prairie dogs in the colony did not retreat into burrows upon approach, but from which at least 90% of the colony could be seen. This distance varied by colony. Observations were made using 10 power binoculars or a Kowa 20-60x spotting scope. I scanned the entire colony counting every animal seen during the scan. I then repeated the procedure starting from the opposite side of the colony. One final count was made during a third scan. I recorded the maximum number of animals seen during any 1 scan as an index of minimum population (Severson & Plumb 1998). Observations were made beginning 30 minutes after sunrise for 3 hours or starting 4 hours before sunset and continuing for 3 hours (Powell, K. L., et al. 1994b).

Statistical Comparisons.--I used SPSS Version 10.0 and SAS® 8 statistical software packages to compare numerical variables obtained for each of the 15 colonies. I used the Kolmogorov-Smirnov test to check for normality of the distributions. Most of the variables did not meet the assumption of normality so I used non-parametric tests. To look for correlations between variables, I used Kendall's tau correlation coefficient.

New Colony Establishment

Site Selection.--I identified locations for 4 new colonies in spring 2003. I chose sites that appeared to be uniform in vegetation and soil structure. I also consulted with ranch management personnel to determine desirable areas of translocated prairie dog colonies based on management goals and objectives. I established a few criteria for site selection. A desirable site would have naturally low stature grasses to avoid the need to periodically mow the area. I also identified presence of bison as an undesirable factor. While I recognize that barrier techniques may be desirable for cattle and other livestock ranchers, keeping bison from destroying fences was beyond the means of this study. It was also desirable to have sites in the same general vicinity for ease of observation. The chosen site was a flat burrograss valley. While there were no bison, there were other grazers such as pronghorn antelope, mule deer, and oryx. I examined each site for vegetative uniformity with the line intercept method. I used 5 randomly located, 10-m transects in each plot to determine average canopy cover. The only species of grass found inside plots was burrograss. No significant differences were detected using a one-way analysis of variance ($F = 0.52$, $p = 0.6758$).

Artificial Burrows.-- To prepare sites for prairie dogs, I constructed a minimum of 4 artificial burrows per site. Using a backhoe, a member of the ranch staff dug trenches that were approximately 2 m long and 0.6 m wide. The deepest point of the trench was 1.3-1.5 m deep and was approximately 0.6 m long. The remainder of the trench gradually sloped upward to the soil surface. Nest boxes were made using corrugated, polyethylene, 0.3-m diameter pipe cut in 0.6 m sections. Each section was cut in half lengthwise. A piece of plywood was fitted in either end of the semi-circular pipe. On 1 end, the plywood had a 10-cm hole cut out of the center. The other piece of plywood was left intact. I then attached 0.2 cm mesh hardware cloth to the flat side of the pipe segment (Fig 3). I placed these nest boxes in the deep end of the trench flat side down. Into the 10-cm hole, I inserted 1 end of a length of 10-cm diameter corrugated polyethylene pipe. This 10-cm pipe was cut such that it was long enough to extend at a 45 degree angle from the nest box to approximately 20 cm above ground (Fig 3). I then back-filled the trench taking measures to ensure the plastic pipe did not collapse in the process.

Artificial Barriers.-- To test the effectiveness of artificial barriers, I constructed 40 x 40-m enclosures around each new colony site. The first step in constructing artificial barriers was to take off the top layer of soil from a 0.6 m strip around the perimeter of the designated area using a small tractor fitted with a blade on the front. The blade was positioned at a slight angle such that loosened soil was pushed toward the outside of the colony. This step flattened the area and loosened a small amount of soil. The next step was to lay a piece of aluminum stucco wire (0.9 x 45.5 m) over the bladed area. I placed stucco wire so that the extra width lay to the outside (away from colony center) of the bladed strip. The stucco wire overlapped at the corners.

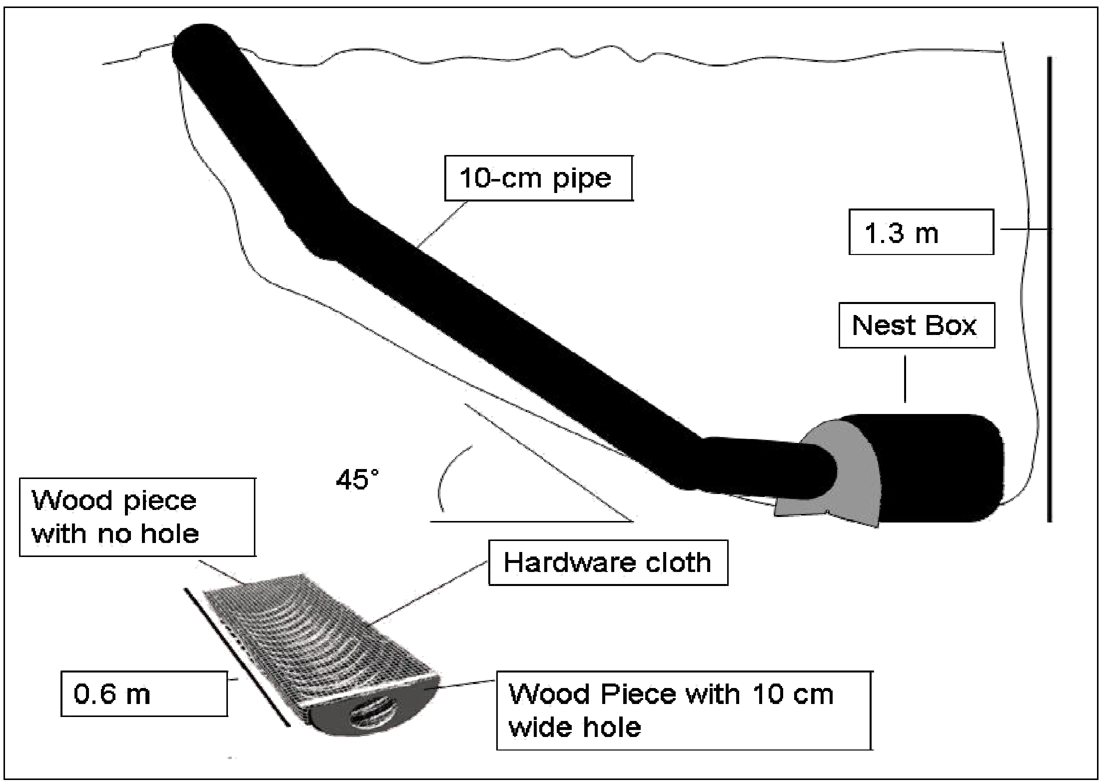

Figure 3. Artificial prairie dog burrow and nest box design with underground placement for 2003 artificial barrier study on Armendaris Ranch, New Mexico (Figure not drawn to scale).

The next step was to install wooden support posts at each corner. I used 2.4-m landscape timbers as posts. First, I cut holes in the overlapping stucco wire at appropriate spots. Post holes were dug manually to a depth of 80 centimeters. I attached a piece of smooth wire to the top of the post and secured it to a piece of buried rebar that served as a guy wire for extra support.

I then stretched smooth wire around the outside of all 4 wooden posts as tight as possible at a height of approximately 70 cm. I attached the wire to posts using wood staples. Next, I unrolled another piece of stucco wire (identical dimensions as the first) along each enclosure side. I attached 1 end of this piece of wire to the outside of a corner post using wood staples. An assistant used a fence stretcher to stretch it tight, and I attached it to the outside of the other post. Stucco wire was positioned to the outside of the smooth wire. This was done for all 4 sides.

To add additional support, I used 2, 1.5-m T-posts and 3, 1-m sections of rebar along each side of the enclosure to the outside of both pieces of stucco wire. I spaced these extra supports evenly along the side of the fence alternating between rebar and T-posts. I put an overhang on our fence to make climbing more difficult. Dr. Joe Truett and Turner Endangered Species Fund had experienced some success with this design in previous work (Truett & Savage 1998). I attached the stucco wire to supports using wire leaving the top 20 cm to hang loose. I also attached the stucco wire to smooth wire using hog rings. I folded horizontal stucco wire up to the outside of the vertical stucco wire and attached the 2 pieces together using hog rings.

Our design left the corners with no overhang, so I used excess stucco wire to make a roof over the 2 sides. I also used extra stucco wire to reinforce the area around the post so that prairie dogs could not squeeze between the stucco wire and the wooden post (Fig 4). I then went back along each side of the fence and shoveled loose dirt from the outside to cover the horizontal wire. The wire was covered with 5-10 cm of soil. All 4 colonies were prepared in the same manner.

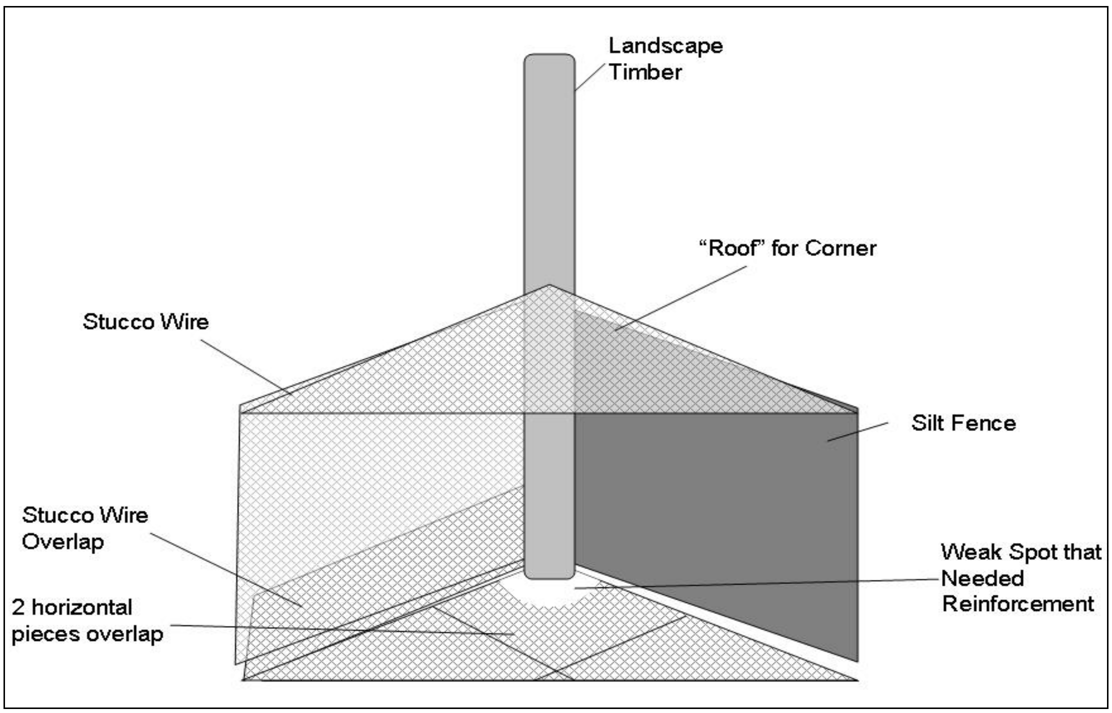

Figure 4. Design of enclosure corner for black-tailed prairie dog artificial barrier experiment on Armendaris Ranch, New Mexico in summer 2003.

The final step was to randomly assign treatments to each of the 4 sides of each enclosure. I randomly chose 2 of 4 sides of each enclosure to be fitted with visual barriers. I used 90-cm tall, 124-lb tensile strength polyethylene silt fence for the visual barrier. This material was cut to the appropriate length and attached to the outside of the stucco wire with hog rings. The extra width of silt fence was not used in the overhang, but rather was staked to the ground using 12.5 cm aluminum landscape staples.

Trapping and translocation.--The prairie dogs used for this experiment came from natural colonies located on the Vermejo Park ranch in Colfax County of northern New Mexico. Vermejo Park ranch biologists trapped prairie dogs in early July 2003 with a flushing technique. First, observations were made to ensure locations of prairie dog activity. Then biologists drove to the burrow with a water truck and released a strong burst of water for about 3-5 seconds. As water flow was reduced, trappers listened for prairie dogs. The trappers then alternated between releasing strong bursts and trickles of water until prairie dogs were forced to the burrow entrance. Care was taken to keep prairie dogs from the same burrow together. Flushed burrows were located over the entire colony (~16 ha).

To guard against plague, captured prairie dogs were dusted with flea powder and put in quarantine for 2 weeks. During quarantine, animals were housed in large metal cages and coterie members were kept in the same cage. We followed general procedures for quarantine outlined in Truett et al. (2001). After the quarantine period, on 23 July 2003, I weighed each prairie dog and marked them using fingerling eartags and Nyanzol D hair dye. I used 2 ear tags with unique numbers for each animal and a dye pattern that allowed me to distinguish individuals. Each animal was dyed with a letter placed in a unique location on its dorsum. To facilitate sexing animals, males were given letters followed by a plus sign. I marked 120 prairie dogs for this experiment (Appendix D). Animals were transported in 60x25x25-cm single-door traps.

Upon arrival at Armendaris ranch, I immediately placed 7-8 animals in each artificial burrow. Each plot received a total of 30 prairie dogs. Every attempt was made to keep animals from the same coterie in the same plot. I used a soft release procedure. Welded wire retention baskets (75x75x30 cm) were placed over each artificial burrow opening to prevent immediate dispersal and enhance animal survival (Truett, et al. 2001). These cages had openings on the bottom just big enough for the 10-cm pipe. Animals were kept in this manner for 7-14 days. Fresh vegetables and alfalfa pellets were provided for animals daily during this acclimation period.

Soil loosening

Within each plot, I randomly selected 10, 1x1m square subplots to receive soil loosening. To select a subplot, I assigned each side of the plot a number. I then randomly selected a side from which to start using a random number generator. I randomly selected a distance from the colony edge and a direction (left or right) using a random number generator. Once again, a distance in the selected direction was chosen using a random number table. Finally, I randomly chose a direction between 0 and 360˚. This direction represented the diagonal direction of opposing corners of the 1x1m quadrat. I placed a PVC quadrat frame in the proper direction and mechanically loosened soil with a mattock. I repeated this process 10 times for each of 4 study plots.

Costs of Barriers

Materials for non-visual stucco wire barriers cost approximately $2.26/linear meter and the of addition silt fence increased cost to $2.75/m (Appendix D). Each enclosure required 28-30 person hours to complete. Equipment needed for fence building included hammers, hog-ring pliers, shovels, fence stretcher, needle-nose pliers, wire cutters, T-post pounder, post-hole digger, hoe, sledge hammer, and a small tractor.

Behavioral Observations

After 7 days of acclimation, I fully released 2 of the 4 colonies. Immediately after release, I made observations from a 4.5-m tripod deer stand positioned between the 2 colonies to offer a clear view of both. I divided the day into 2 observation periods, morning and evening, due to the presence of distinct periods of prairie dog activity. I watched 1 colony in the morning and the other colony in the evening and alternated the order the following day. Observations began at sunrise and were made until < 2 prairie dogs were seen active for > 30 minutes. During observation periods, I recorded all attempts to cross barriers. I recorded individual, sex, type of barrier, side of enclosure, and time of day for each attempt. Digging was recorded if it took place within 2 m of a fence. Climbing attempts were recorded if all 4 feet of the prairie dog left the ground. I recorded a second attempt by the prairie dog only if the animal climbed down from the fence and engaged in other activities for at least 1 minute. I also recorded any interactions between prairie dogs and other species. After 1 week, I moved the observation station and released the final 2 colonies. I repeated the observation routine for 1 week.

Locating new burrows, digging sites and other observations

During the 2 weeks of release, I walked inside and outside of the plots in which prairie dogs had been released to look for new burrows every day. If a new burrow was seen, I flagged it, recorded the position with a GPS unit, and recorded any observations. I also noted any areas of partial digging. After the first 2 weeks, I looked for new burrows once/week. After 2 months, observations were reduced to once/month. I also measured patches of digging that occurred along the inside of barrier fences.

While searching for new burrows, I also noted signs indicating presence of predators in the area. I recorded information on tracks, scat, or sightings of large raptors, rattlesnakes, coyotes, foxes, or badgers.

GIS viewshed analysis

By using a geographic information system, it is possible to calculate a viewshed for a particular point in a landscape. A viewshed is simply a visual depiction of areas that can be seen from a vantage point or set of points. Viewsheds can be useful in making trails and planning developments, but can also provide insight about the landscape from a non-human perspective.

I used ArcView 8.3 to perform a viewshed analysis on the barrier plots. I began by collecting UTM coordinates at the corners of each enclosure and at each artificial burrow. I exported these coordinates as point files into ArcView 8.3. I then drew a line between 2 corners corresponding to locations of silt barriers and added a z-value of 1 m to each line. I used a 10-m USGS Digital Elevation Model (DEM) to obtain approximate elevation base values for artificial burrows. The next step was to create a polygon surface that included only the area of the 4 enclosures. Using the DEM, I added an appropriate elevation value to the surface polygon. I used the Spatial Analyst extension to convert vector features of silt barrier (polyline) and study area (polygon) to separate raster grids with a cell size of 0.1 m. The barrier raster contains values of no data in all areas except those corresponding to barriers that have a value of 1. No data values were converted to 0 to perform further analysis. I used the reclassify command in Spatial Analyst to perform this task. I then used Raster Calculator in Spatial Analyst to add the barrier raster grid to the area raster grid. The combined grid served as the elevation grid from which to calculate a viewshed. The calculate viewshed command in Spatial Analyst was used to produce the final viewshed grid (Fig. 5). After the viewshed was created, I imported the point files from the new burrows. I recorded the number of burrows that were located in the visible and the non-visible areas for each viewshed.

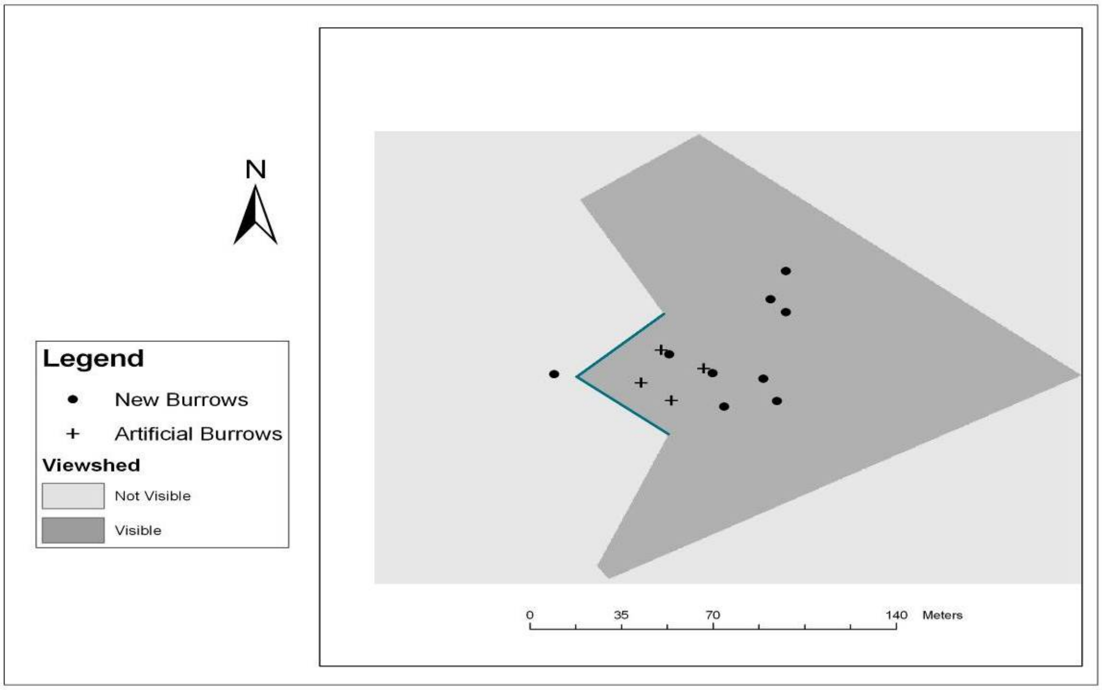

Figure 5. Viewshed created as a result of artificial barrier placement on 4 translocated black-tailed prairie dog colonies on Armendaris Ranch, New Mexico in summer 2003

RESULTS

Summary of Existing Colonies

Physical characteristics and management variables varied widely among the 15 translocated prairie dog colonies on Armendaris Ranch (Appendix F). Total area of existing colonies range from 0.7 ha to 11.0 ha (Table F-1). Colonies located in areas dominated by alkali sacaton (Table F-2) required vegetation manipulations prior to release (Table F-3) and were often sites of historic colony locations. Soil compaction measurements were highly variable on colonies and among colonies (Fig. F-1). I did not find significant correlation between 2003 colony area and any of the following variables: 2003 population index, number of released animals, size of original cleared area, age of colony, soil compaction, distance to nearest colony, or distance to nearest road.

With the exception of colonies released in 2002, information on sex ratios of released prairie dogs was not recorded, but the number of animals released was always recorded. The original number released was significantly correlated (using nonparametric correlation) with 2003 population index values ($r^2 = 0.274$, $p = 0.027$). The other variable significantly correlated with 2003 population index values was number of research projects conducted on site ($r^2 = 0.233$, $p = 0.020$). These 15 colonies have been used as study sites for at least 14 research projects (Table F-4) and every colony on the ranch has been utilized by researchers for at least 1 project. Burrowing owl-related studies comprised 3 of 14 projects (Table F-5). Presence of power lines, soil type, vegetation type, depth of artificial burrows, and initial treatments did not have a predictable effect on area occupied or population of prairie dogs.

Constraint

Results of visibility tests were similar across the 3 vegetation types studied (alkali sacaton, shrubs, and tobosa). Average visibility in the first 5 m was 70%, and the next 15 m averaged around 20% for all vegetation types. Z-scores for unmanaged and managed constraint indices were highly skewed to the left indicating that most of the colonies had similar constraint values (Table F-2), but a few colonies had extremely high values that increased the overall average (Fig. 6). The only significant ($\alpha = 0.05$) nonparametric correlation detected was between 2003 colony area and the unmanaged constraint value (Fig. 7). The r^2 value for this correlation, however, was 0.184 (p= 0.026) indicating a very weak correlation.

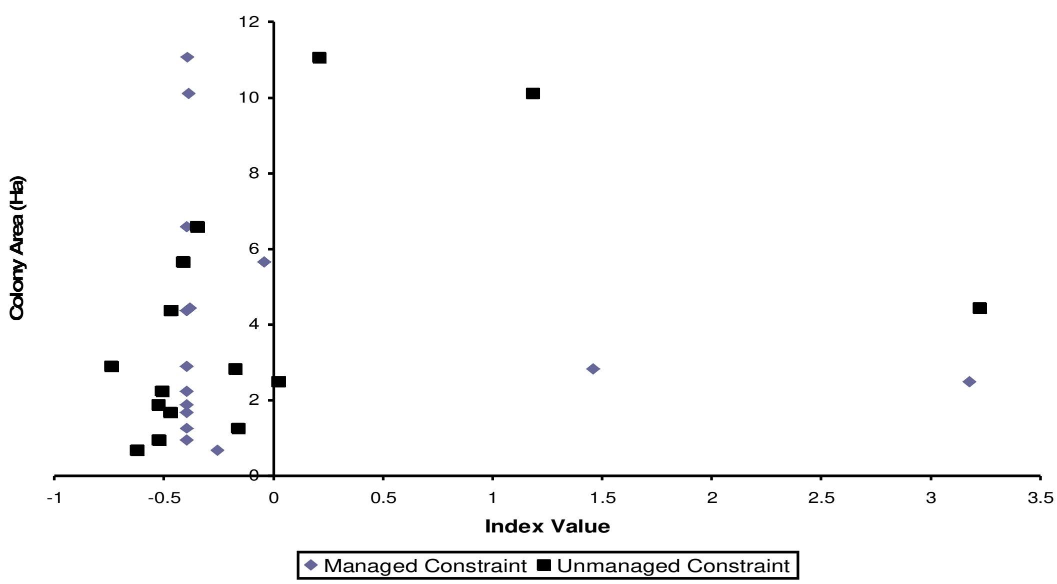

Figure 6. Colony area and managed and unmanaged constraint indices of 15 translocated prairie dog colonies on the Armendaris Ranch in south-central New Mexico in summer 2003.

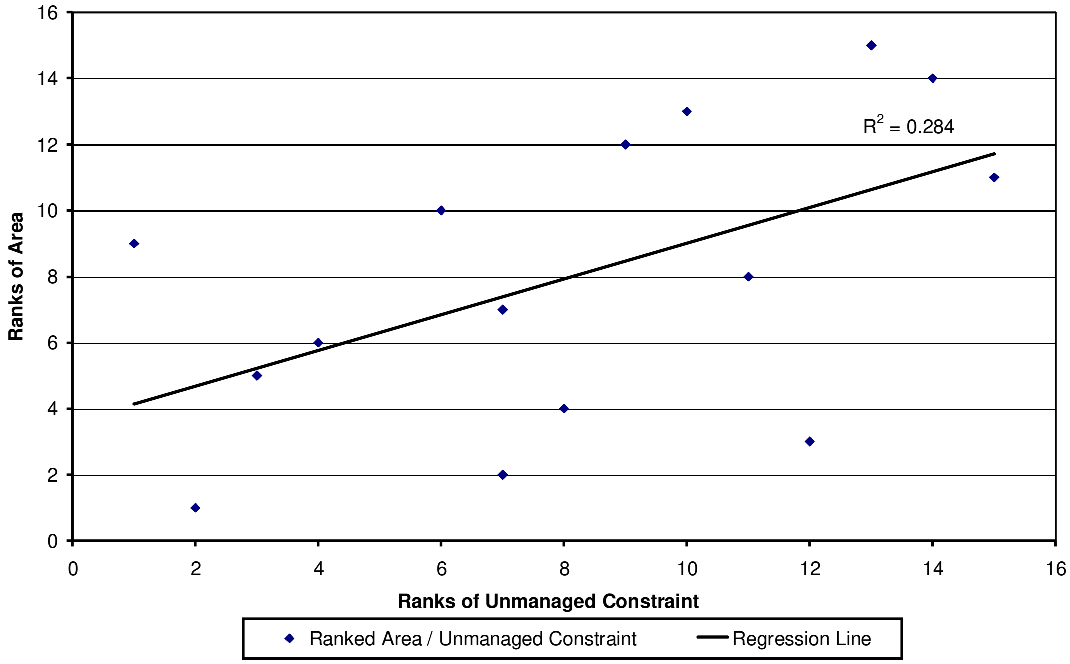

Figure 7. Correlation between unmanaged constraint ranks and colony area of 15 translocated black-tailed prairie dog colonies on Armendaris Ranch, New Mexico in summer 2003.

Soil Loosening

Prairie dogs released in summer 2003 excavated few burrows. Less than 10% of the 61 new burrows created in each colony were placed in the 10 m^2 of soil (0.7% of total area inside enclosure available for digging) loosened inside each new colony enclosure (Table 1). Of the 29 new burrows that were excavated inside enclosures, however, an average of 12.9% were located in patches of loosened soil. Most digging that occurred in loosened patches did not result in formation of a new burrow. In 3 of 4 colonies, prairie dogs used loosened patches in higher proportion than available in the habitat, but small sample sizes for each colony made it very difficult to assess influence of soil loosening on burrow placement.

TABLE 1. Digging Behavior of Translocated Prairie Dogs in 4 Colonies on the Armendaris Ranch, New Mexico with Respect to 1-m^2 Patches of Loosened Soil in Summer 2003

Colony	Total No. New Burrows	No. Burrows Inside Enclosure	'ercent Total Burrows in oosened Soil Patches	Percent Burrows Inside Fence and in Loosened Soil Patches	Percent Loosened Patches with Any Digging Activity
A	13	4	7.7	25.0	20.0
B	7	2	0	0	0
C	20	12	5.0	8.3	50.0
D	21	11	9.5	18.2	50.0

Behavioral Observations

During the 2-week observation period, I observed a total of 453 climbing attempts by 64 individuals. Sixty-eight percent of the attempts were made during morning hours. Nearly 50% of all prairie dogs were not observed making climbing attempts and most prairie dogs attempted ≤ 10 climbs (Fig. 8). Over 50% of the total observed attempts were made by 8 prairie dogs. Only 17 of 453 observed attempts were successful. These successful attempts were made by 11 individuals.

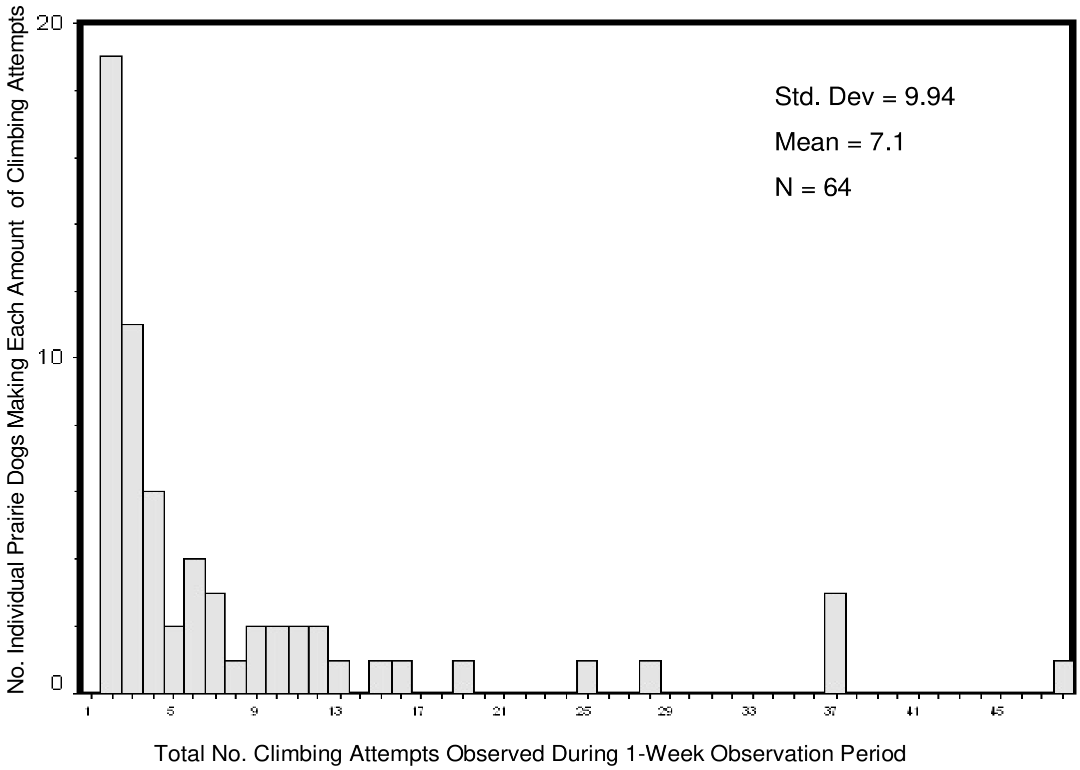

Figure 8. Frequency of climbing attempts per individual black-tailed prairie dog during artificial barrier experiment on Armendaris Ranch, southern New Mexico, in summer 2003.

I was not able to adequately record prairie dogs that were attempting to cross barriers by digging; however, prairie dogs in 3 of 4 study plots tunneled under a section of stucco wire fence allowing free movement to the outside of the enclosure. Only 1 of these tunnels was excavated before the conclusion of the 2-week observation period. In addition, I recorded soil disturbances, which did not result in burrows, found at the junction of horizontal and vertical stucco wire or silt fence pieces. In all 4 colonies, 54 pits were created from inside the enclosure at a non-visual barrier and 29 pits were excavated at silt barriers. Escapees also tried to tunnel into enclosures from outside.

There were 25 holes created from outside of stucco wire barriers and only 3 from outside silt barriers.

The majority of climbing attempts were made on non-visual, stucco wire fences (Fig. 9). Of the 17 successful attempts, 64.7% were on stucco wire fences, 23.5% were at a junction, and 5.9% were on silt fences. I created the 'junction' category because visual and non-visual barriers were both present at 2-4 corners of each enclosure. Climbing at corners was fairly common for all 4 sites: 59%, 38%, 44%, and 12% for colony A, B, C, and D, respectively. Four successful attempts occurred at a corner.

Total climbing attempts by female prairie dogs occurred at higher percentages than proportion of females in each colony in 75% colonies (Fig. 10). However, some individuals made several climbing attempts. The percentage of individual females observed climbing was lower than female composition of population in 3 of 4 colonies (Fig. 11).

Although I made every attempt to keep coterie members together in the same plot, I was forced to divide 1 coterie between 2 enclosures. Climbing frequency of each coterie compared to expected number of climbs (based on percentage of each coterie in the population) revealed that the divided coterie did not climb at a higher rate than other colonies (Fig. 12). In fact, the divided coterie made only slightly more attempts than predicted by its proportion of the total population.

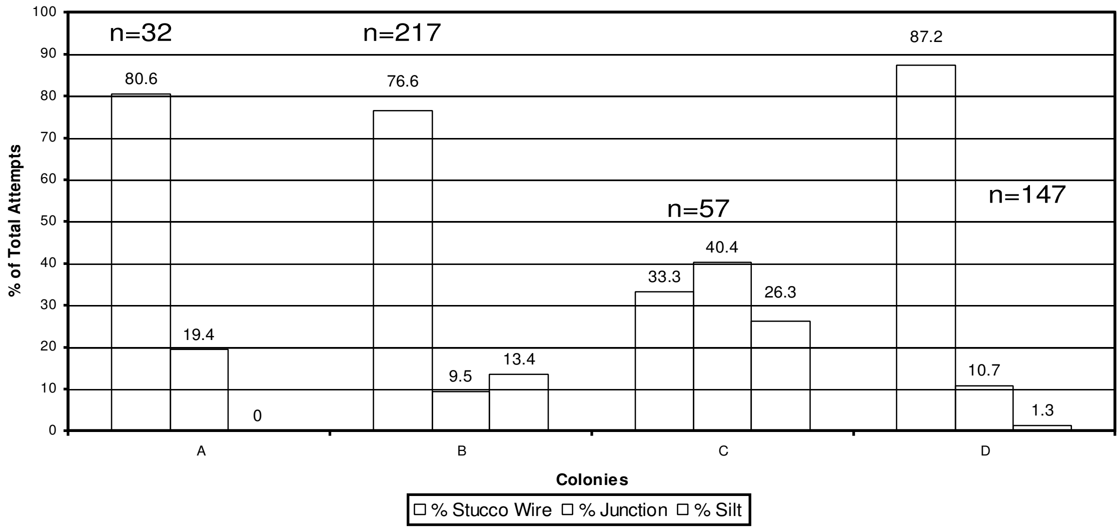

Figure 9. Percentage of black-tailed prairie dog climbing attempts among 4 colonies at 3 categories of fence during summer 2003 study of artificial barrier effectiveness on Armendaris Ranch, New Mexico.

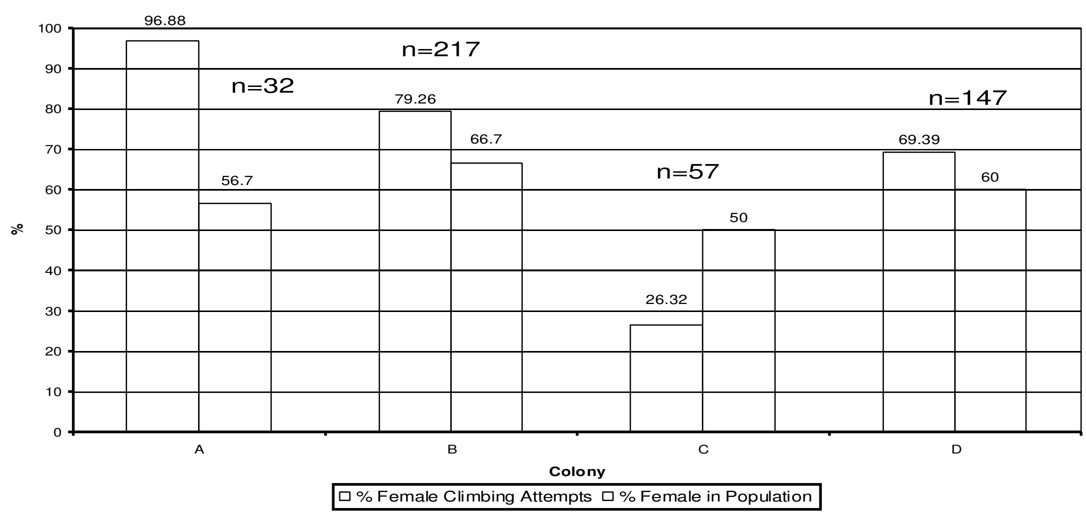

Figure 10. Percentage of total climbing attempts in 4 colonies by female black-tailed prairie dogs compared to percent of females in population during summer 2003 study of artificial barriers on Armendaris Ranch, New Mexico.

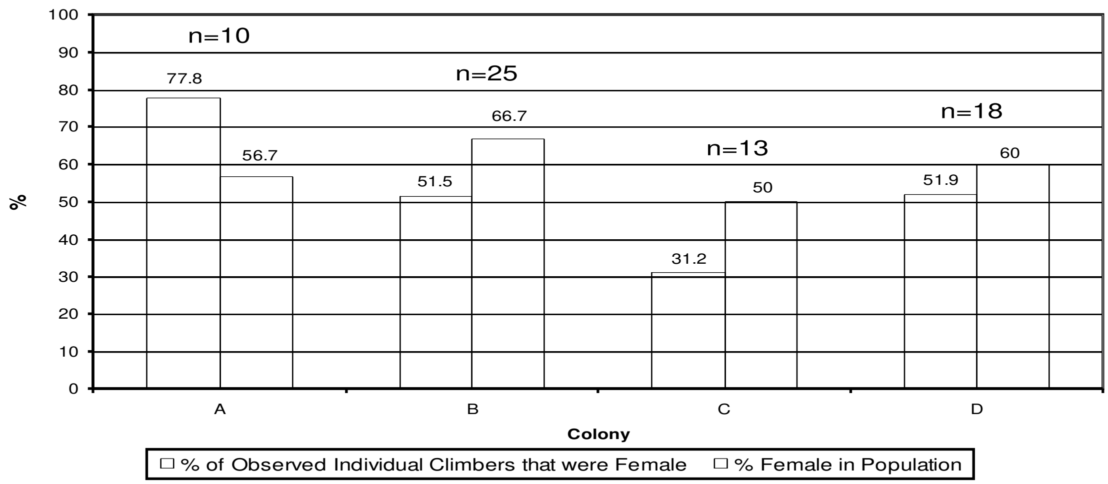

Figure 11. Relative percent of population of individual prairie dogs observed climbing that were female during summer 2003 study of artificial barriers on Armendaris Ranch, New Mexico (Total sample size > 64 due to individuals climbing in > 1 enclosure).

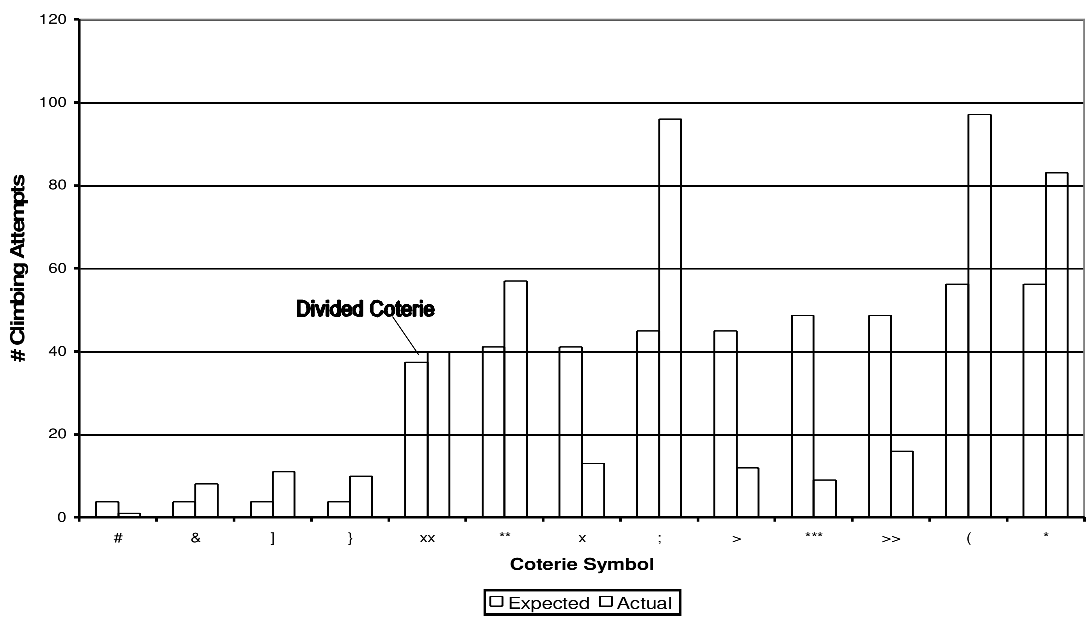

Figure 12. Frequency of climbing attempts for each black-tailed prairie dog coterie during summer 2003 artificial barrier study on Armendaris Ranch, New Mexico (Divided coterie = single coterie split between 2 enclosures).

New Burrow Locations and Viewshed Analysis

Colonies released in similar burrograss habitat on Armendaris Ranch in 2002 (Appendix A) excavated 2-7 times the number of burrows as colonies released in 2003 (Fig. 13). In colonies A, B, and C, 78 – 100% of new burrows were located in areas within the viewshed of the artificial burrows of those colonies (Table 2). In colony D, only 40% of new burrows were placed within the viewshed. Burrows associated with colony D that fell in the non-visible area were likely a result of use of a nearby abandoned colony by prairie dogs that escaped from enclosures. Because I cannot accurately determine the visual limitations of prairie dogs with respect to distance, I also created a viewshed using all 4 colonies in combination. For the combined viewshed, 88% of new burrows were located within the visible area of any of the 4 groups of artificial burrows.

Predator Observations

In September 2003, I began to notice an increase in coyote tracks and scats around the enclosures. On 4 occasions in October, a female coyote was observed in the vicinity of the barrier colonies. The coyote would lie down outside the enclosures with a silt fence between herself and the colony. After approximately 20 minutes, she would spring over the barrier and chase the prairie dogs. I never observed a successful hunt, but the number of scats and her persistence even when disturbed by humans, indicated that this was rewarding behavior.

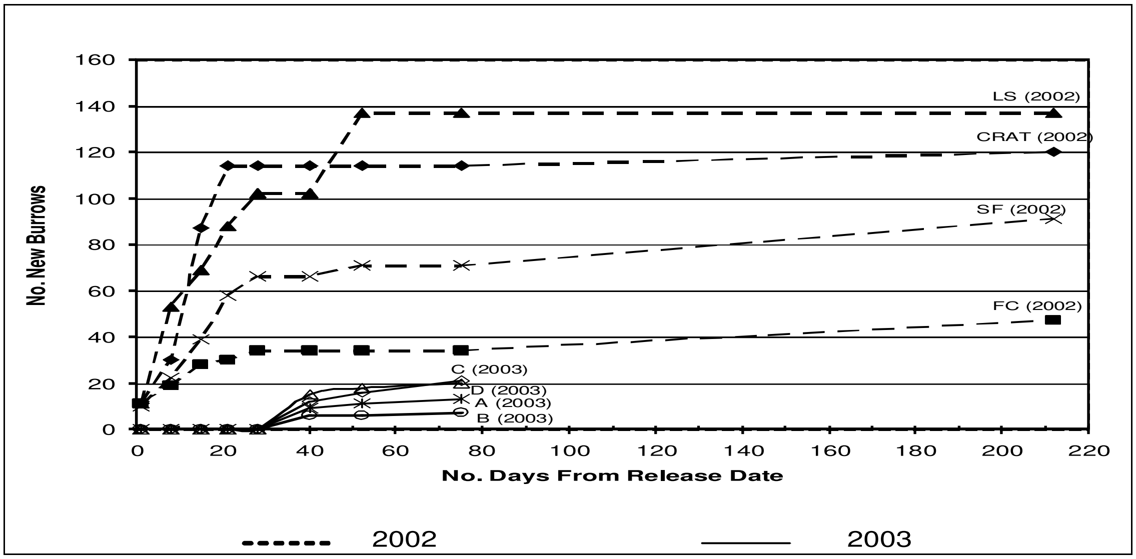

Figure 13. Comparison of number of new burrows created by translocated black-tailed prairie dogs in 4 colonies on Armendaris Ranch, New Mexico in 2002 with 2003

TABLE 2. Percent New Burrows Excavated by Translocated Prairie Dogs in 4 Colonies on the Armendaris Ranch with Respect to Viewsheds Created by Artificial Barrier Placement in Summer 2003

		Percent In 'Visible' Area	
Colony	**No. Outside Fence**	**Individual Viewshed**	**4-Colony Combined Viewshed**
A	9	77.7	88.9
B	5	80.0	100.0
C	8	100.0	100.0
D	10	40.0	70.0

DISCUSSION

Summary of Armendaris Translocations

Reintroduction of black-tailed prairie dogs to the Chihuahuan Desert grasslands is challenging due to current drought conditions. According to the Western Regional Climate Center (http://www.wrcc.dri.edu/index.html), the average cumulative rainfall for the months of May-December for Elephant Butte Dam (approximately 12.8 km from Armendaris ranch headquarters) from 1917-2003 was 19.85 cm. Figure G-1 shows monthly rainfall data collected at Elephant Butte Dam for the years 2001-2003 during the months of May through December. The total rainfall recorded for these 8 months during the 3 years shown is 19.82, 11.21, and 6.59 cm respectively. Due to natural patchiness of summer convective storms, it is difficult to compare total amount of rainfall recorded at Elephant Butte to that falling on prairie dog colonies, but the pattern of decreasing rainfall from 2001 to 2003 is likely similar. Extreme drought during the first years after release most certainly increases mortality rates.

Another important factor not directly measured in this study was predation risk. Evidence of predation by coyotes was present at all 15 translocation sites. While visibility and constraint could influence predation rates, density of coyotes throughout the ranch is unknown. Correlation between prairie dog population and amount of research done on a colony could be an artifact of lower predation rates due to human disturbance.

Despite original intentions, Armendaris Ranch management and TESF biologists recognize that it is unlikely that populations of black-tailed prairie dogs on the Armendaris will reach sufficient numbers to sustain black-footed ferrets (Dr. Joe Truett, TESF biologist, personal communication). Constant mowing or heavier grazing intensity will be required for colonies to thrive in alkali sacaton-dominated areas. Prairie dog colonies in these areas exist in a paradoxical situation. Low rainfall decreases vigor of grasses, reduces forage quality, but allows colonies to expand. On the other hand, high rainfall provides an increase in forage quality, but also increases density of grasses. This decreases visibility and ability of colonies to expand. The more recent prairie dog translocation efforts in areas dominated by burrograss do not have the same problems. Unfortunately, patches of burrograss suitable for prairie dog colonies are sporadically located throughout the Jornada del Muerto lava flow area. These colonies are naturally constrained and separated by exposed basalt. In addition, diversity of vegetation at these sites is much lower which may put prairie dogs at greater risk of starvation during drought years.

For colonies on the Armendaris Ranch, the parameter combination estimated with the "constraint" index presented in this document was evidently not a major deterrent to colony growth. In fact, data presented show a positive correlation between unmanaged constraint and occupied area. This is contrary to what was expected given literature indicating that degree of visibility through vegetation is a limiting factor for black-tailed prairie dog colony expansion. When measuring colony expansion, I searched for burrows without determining current activity levels at those burrows. It is possible that prairie dogs excavated burrows near tall vegetation out of necessity, but were killed by predators shortly after making the burrow. It is also possible that other factors mentioned above have a greater influence on colony area than visibility through surrounding vegetation.

Cost and Maintenance of Barriers

The barriers I used for this experiment were cheaper than those used by agencies in Colorado ($2.75/m compared to $5.94/m for Griffolyn ® barriers). However, silt fence used in this experiment required daily maintenance. Winds of 20 m/s were common during summer 2003. I re-attached the silt to stucco wire and repaired tears. The length of time this material would be useful as a barrier is short. The amount of shredding and tearing could have been reduced by installing grommets every 1 m at the top and bottom of the silt fence using a manual grommet setter prior to attaching it. Using 2 layers of stucco wire on either side of the silt fence will improve durability of the fence.

Behavior and Artificial Barriers

When faced with a vertical barrier, the initial reaction of translocated black-tailed prairie dogs on the Armendaris ranch, contrary to my prediction, was to climb. It was difficult to observe prairie dogs in the act of digging in this experiment, but there was evidence of digging at the junction of vertical and horizontal pieces of stucco wire inside each enclosure. In 1 location, prairie dogs eventually chewed through the stucco wire fence. Even after a successful escape tunnel was created, prairie dogs continued to climb fences. Clearly, more escape attempts were made at non-visual barriers. Even with the low (3.8%) success rate that was observed, more attempts can generally be equated to more successful escapes.

Prairie dogs that were successful fence climbers used the loose overhang to their advantage. Generally, successful climbers started at a rigid point in the fence directly opposite a T-post or metal support stake. The animals climbed to the overhang and continued climbing the loose stucco wire. The wire would sag, and the prairie dog would let go with its hind feet. At places where the overhang was too long, the prairie dog could stand on the ground on its hind feet and maintain a grip on the overhang with its front feet. Once on the ground, it would reach 1 fore foot over the top of the overhang and pull itself over the top.

This experiment does not represent a typical barrier situation. Enclosures were made small to force escape behaviors. Animals used in this experiment were given a choice of barriers. A more thorough experiment would, perhaps, have included enclosures with a single type of fence. However, given a situation in which a land manager does not wish to limit expansion altogether, but rather to direct it in a particular direction as in the case of Kirtland Air Force Base (C. Finley, personal communication), the experiment presented here may provide useful insight about the importance of visually-obstructive components of prairie dog barriers.

I predicted that young, male prairie dogs would engage in escape behaviors with the greatest frequency. This was not the case. In this study, female prairie dogs made an average of 68% of the total climbing attempts observed. However, in terms of number of individuals attempting to cross barriers, females were represented at approximately the same percentage as they existed in the population (53.1% observed climbing, 58.4% of population female).

I was unable to examine the effects of age on frequency of barrier crossing behavior because it was very difficult to determine age of prairie dogs that were trapped at Vermejo Park Ranch. Size is typically the manner for determining juvenile (1st year) animals. At time of capture, juvenile prairie dogs were larger than normal (D. Long, personal communication). I therefore, made no attempt to distinguish juveniles from adults; however, high numbers of individuals found in coteries during burrow flushing seems to indicate that the majority of the translocated animals were juvenile. The average mass of prairie dogs for each of 4 populations was 635, 588, 634, and 646 g respectively indicating similar age structure among the 4 colonies.

Absolute numbers of climbing attempts varied among the 4 enclosures. I observed 32, 217, 57, and 147 total climbing attempts at plots A, B, C, and D respectively. Colony A was the first to tunnel out of the enclosure. While animals continued to climb after the tunnel was created, the presence of an easier method of escape likely reduced overall climbing numbers. The low number of observations at colony C cannot be explained in the same manner. Very few individuals attempted escape from this plot even during the first days of release. Colony C had the highest percentage of males. If gender is a factor in propensity to climb, then perhaps females are more likely to engage in such behaviors than males. Recent translocations may also have differentially affected males and females. Female *C. ludovicianus* generally occupy the same territory for their entire lives while males switch every 2 years or so (Hoogland 1995). If this is true, translocated females may have a greater incentive to find a good territory immediately after release. The results observed may also have been a case of natural variation among individual prairie dogs.

Environmental Variables

Prairie dogs that successfully climbed or tunneled out of an enclosure frequently re-entered the same or a neighboring enclosure after a short period of time. Soil surface temperatures during July and August typically exceeded 38˚ C creating a dangerous environment for mammals in open grasslands. Prairie dogs need burrows for thermoregulation (Hoogland 1995). Especially during times of food and moisture stress, a prairie dog without a burrow could die of heat exhaustion. On 2 occasions, I found prairie dogs that had escaped from their enclosures and entered enclosures of colonies that had not yet been released. One prairie dog was found dead at the base of a cholla, and 2 died after attempting to dig under the acclimation cages of the unreleased animals. A veterinarian determined that dehydration was likely the cause of death.

Along with high temperatures, animals released for this experiment faced extremely dry conditions (Figure G-1). A rain gauge mounted on a corner post of plot B collected only 4.52 cm of rain from July – mid October. Vegetation on the colonies showed no signs of green. Fearing a massive die-off, supplemental food and water were placed inside and outside of the enclosures after the conclusion of the observation period. During previous translocations, it has been noted that large rain events will stimulate excavation of new burrows (pers. obs, Dr. J. Truett, personal communication, Dustin Long, TESF biologist, personal communication). Hard, dry soil and poor forage quality probably limited the number of new burrows created by prairie dogs translocated during this experiment.

Design Considerations

Another potential factor influencing the ability of translocated prairie dogs to dig was the experimental design of the study plots. Observations from previous translocations revealed that prairie dogs often spend the first day of release exploring their new environments. During the initial release period, black-tailed prairie dogs scatter in several directions and often permanently leave the area (Truett et al. 2001). My enclosures were designed to serve 2 purposes: 1) to test effectiveness of artificial barriers, and 2) to increase retention of prairie dogs on release sites. Unfortunately, completely enclosing the artificial burrows denied easy access to a safe haven for escapees. Digging new burrows is probably a risky, labor-intensive process (Ebensperger & Bozinovic 2000). The experimental design may have created an overly risky environment that inhibited burrow digging behavior.

Although the prairie dogs used in this study did not dig a large number of burrows, the data indicate they did use loosened soil patches in a non-random fashion. It is difficult to make any inferences from such a small sample size, however. Many of the soil treated areas contained incomplete burrows or shallow diggings. This may be an indication that treatments did not reach sufficient depths to make a significant impact on prairie dog behavior.

Another design consideration that may have influenced behavior of prairie dogs was placement of enclosures. Sites were chosen based on habitat similarity, low-stature grasses, absence of bison, and management goals of the ranch. Installing artificial burrows, trapping prairie dogs, transporting animals, and feeding animals during quarantine cost time and money. I chose to build the plots close to each other because of overall space limitations and to increase chances of survival for each of the small populations. There were existing colonies on either side of the valley chosen for enclosure placement. One such colony, Burrograss SW, was completely abandoned as of spring 2003. I underestimated the distance prairie dogs would travel. The 2 colonies furthest from Burrograss SW were released first. Animals that escaped from these enclosures traveled the length of the valley (0.45-0.55 km) and began to occupy the abandoned colony. Some attempts were made to trap the animals and block passage into the abandoned burrows, but such attempts were unsuccessful. The presence of this abandoned colony likely influenced the number of new burrow excavations performed by the translocated animals.

Influence of enclosure populations on one another was unclear. Escapees frequently entered other enclosures and may have influenced behaviors of the residing population. However, the side of a particular enclosure that faced neighboring colonies was not always the side on which the most climbing attempts occurred. The close proximity of colonies also may have influenced placement of new burrows.

Management documents regarding artificial prairie dog barriers often allude to the benefits of attracting predators to colonies (Snell & Hlavachick 1980, Andelt & Hopper 2000). Suggestions include installing raptor perches and hiding places for terrestrial predators. Based on my observations of coyotes in the area, the artificial barriers used in this study did appear to facilitate predation of prairie dogs.

MANAGEMENT IMPLICATIONS

Management of black-tailed prairie dogs has changed since the early 1900s. The ultimate goal has moved from total extermination to balancing anthropogenic and ecological needs. Relocations and reintroductions will likely increase as humans continue to reconfigure the environment. For the 15 translocated colonies located on the Armendaris Ranch used in this study none of the following factors seemed to influence current population status or total occupied area: soil compaction, soil type, visibility, age, distance to nearest road, distance to nearest colony, visibility of surrounding vegetation, number of released animals, or release procedures. It is likely that in Chihuahuan Desert grasslands the most important factors affecting success of translocations are amount of precipitation (positively associated) and intensity of predation (negatively associated).

In 2 colonies used in this study, 50% of patches treated to loosen soil had signs of digging activity by prairie dogs. Deeper soil loosening treatments may have resulted in higher use of treated patches as new burrow locations. Unfortunately, mechanically loosening soil generally destroys vegetation. Where expansion of a colony in a particular direction is desirable, mechanically loosening soil may stimulate digging of new burrows by prairie dogs in the target area, but consideration for minimizing vegetation disturbance may be needed.

It is unlikely that a perfect prairie dog barrier will ever be devised. The results presented here validate the assumption of many involved with prairie dog management that a visual barrier will likely be more effective at inhibiting colony expansion than a non-visual barrier. As predicted, prairie dogs attempted escape at the stucco wire fence more often than at the silt fence in this study. While I do not have evidence that complete containment of a prairie dog colony is possible, I observed that artificial barriers with a component of visual obstruction can be an effective means of predictably directing expansion of black-tailed prairie dog colonies. A primary challenge to wildlife managers will be to find barrier material that can withstand high winds.

My prediction that prairie dogs would most often dig out of enclosures was refuted by behavioral observations. In this study, prairie dogs attempted to climb more often than dig. However, after a burrow was excavated that allowed free movement of prairie dogs to the outside of the enclosure, it was impossible to contain the colony. Climbing prairie dogs can possibly be thwarted by a slightly taller fence. Perhaps constructing a fence at less than a 90˚ angle toward the colony would be beneficial. A horizontal 'skirt' consisting of a piece of stucco wire stretched flat along the ground and buried with approximately 10 cm of soil was not sufficient. The technique of using a trencher and burying the skirt deeper (Truett & Savage 1998) perhaps would be more effective.

For recently translocated prairie dogs, gender of animals did not influence climbing behavior. There were differences in climbing behavior with respect to individual prairie dogs. In situations in which time or resources are not limited, making behavioral observations of prairie dogs in the vicinity of barriers might provide useful management information. Identification and removal of individuals most frequently attempting escape may increase overall effectiveness of artificial barriers.

On the Armendaris Ranch, natural predators appear to be effective in prairie dog population control. Unfortunately, in some areas, 1 of the most effective prairie dog predators, the coyote, is also targeted for control (Knowlton et al. 1999). Artificial or vegetative barriers will never be sufficient control mechanisms without some kind of population regulation. Land managers should consider the benefits of barriers as a tool to direct expansion, and as an aid to predation.

APPENDICES

APPENDIX A

DESCRIPTION OF PROCEDURES AND BURROW DATA COLLECTED FROM 4 TRANSLOCATED COLONIES RELEASED IN SUMMER 2002 ON THE ARMENDARIS RANCH IN SOUTHERN NEW MEXICO

APPENDIX A

DESCRIPTION OF PROCEDURES

In July of 2002, 4 new black-tailed prairie dog colonies were established in the lava flow area of the Armendaris Ranch. Ranch staff installed 6-8 artificial burrows at each location. Each site received 38-55 prairie dogs which were trapped on Vermejo Park Ranch in northern New Mexico. I used a Trimble GeoExplorer 3 GPS unit to collect UTM coordinates (Datum NAD 83) of new burrows excavated by prairie dogs. I differentially corrected the coordinates using GPS pathfinder software. Burrow locations were mapped at 7, 14, 21, 28, 52, and 212 days post release. I used this information. I used ArcView 3.2 to calculate nearest neighbor distances and distance to center of the colony from each burrow (Figure A-1, A-2).

APPENDIX A

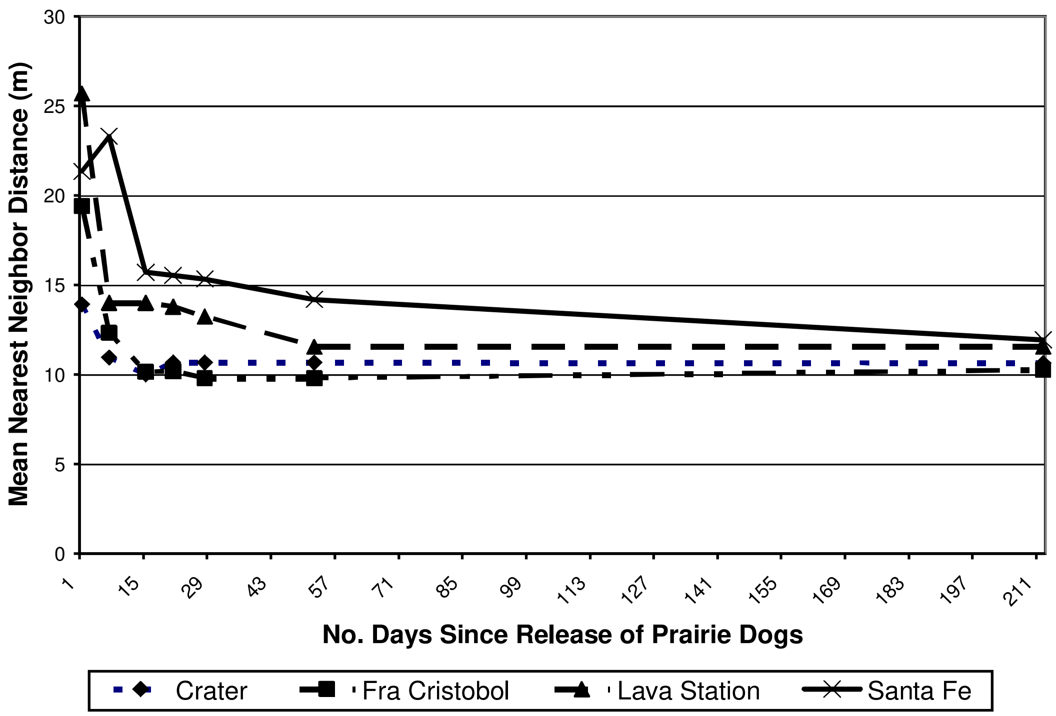

Figure A-1. Change over time in mean nearest neighbor distances between burrows created by black-tailed prairie dogs in 4 translocated colonies on the Armendaris Ranch in 2002

APPENDIX A

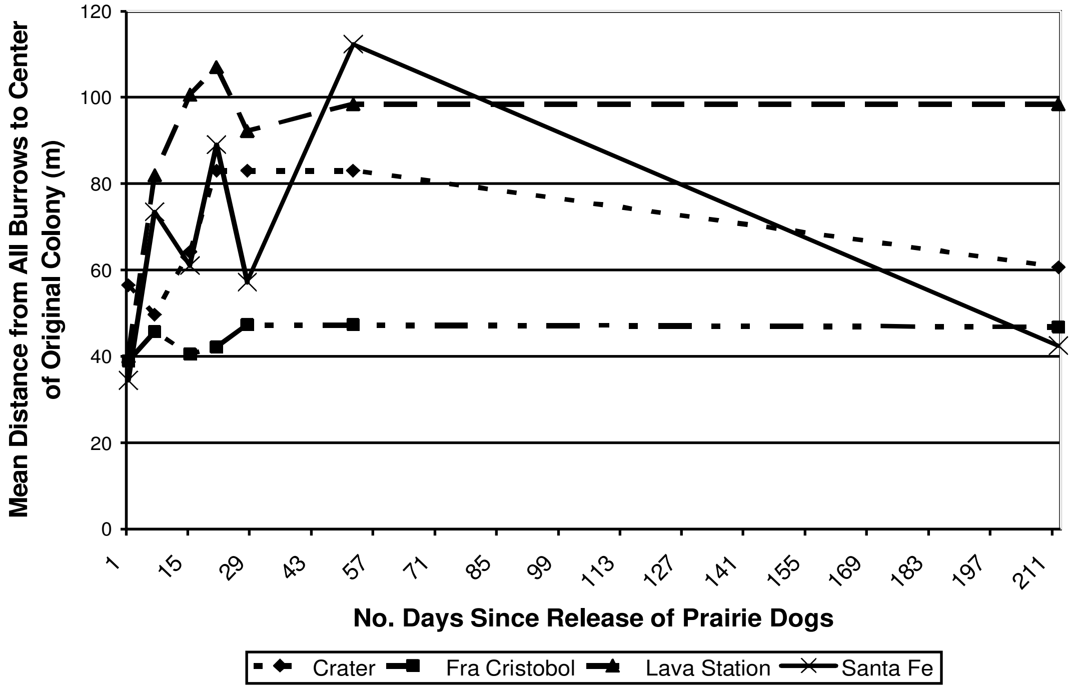

Figure A-2. Change over time in distance from the center of the colony to new burrows created by translocated black-tailed prairie dogs in 4 translocated colonies on the Armendaris Ranch in 2002.

APPENDIX B

LIST OF QUESTIONS USED IN SPRING 2003 TO OBTAIN INFORMATION FROM RANCH STAFF AND ASSOCIATES ABOUT EXISTING TRANSLOCATED PRAIRIE DOG COLONIES ON THE ARMENDARIS RANCH IN SOUTHERN NEW MEXICO

APPENDIX B

QUESTIONS

1. How many artificial burrows were created at each site?
2. To what depth were artificial burrows dug?
3. What vegetation or other manipulations were performed prior to release of prairie dogs?
4. What was the size of the area treated prior to release of prairie dogs?
5. Was this a location identified as an historic prairie dog colony site?
6. Please give the month and year of prairie dog release at this site.
7. How many prairie dogs were released?
8. Was sex ratio information collected? If so, what was the sex ratio of released animals?
9. Was information on age of animals collected? If so, what was the ratio of adults to juveniles?
10. Where was the source population for animals placed at this site?
11. Have there been any vegetative or other treatments applied to this site since the release of prairie dogs? If so, do you have approximate dates?
12. Is this site grazed by bison?
13. Have researchers used this site for projects? If so, what kind of research and when was it performed?
14. Have you supplemented this population with additional prairie dogs since the original release? When?
15. Do you have additional information that might be useful?

APPENDIX C

GEOGRAPHIC INFORMATION SYSTEM LAYERS AND AVAILABLE METADATA USED IN 2003 COMPARISON OF 15 REINTRODUCED BLACK-TAILED PRAIRIE DOG COLONIES ON ARMENDARIS RANCH, NEW MEXICO

APPENDIX C

TABLE C-1. Geographic Information System Layers and Available Metadata Used in 2003 Comparison of 15 Reintroduced Black-tailed Prairie Dog Colonies on Armendaris Ranch, New Mexico

Title	Source	Description	Date
State Soil Geographic Database for New Mexico (STATSGO)	U.S. Department of Agriculture, Natural Resource Conservation Service	A broad-based inventory of soils and nonsoil areas that can be cartographically shown at this scale (1:250,000). Created by generalizing more detailed soil survey data and from Landsat Satellite Imagery interpretation.	1994
10-m Digital Elevation Models	U.S. Geological Survey	7.5 minute digital elevation data produced from scanned topographic contour maps and scanned National Aerial Photography Program photos. The result is a grid with cells 10x10 m.	2001
Armendaris Roads	Turner Enterprises, Inc., Armendaris Ranch. Andrea Ernst, GIS specialist	A vector file showing all roads located on the Armendaris Ranch. A ranch worker drove down all the roads with a Trimble GeoExplorer 3 GPS unit set to collect line data. The resulting data were cleaned using Do and Digital Line Graphs	2002
Armendaris Prairie Dog Colonies	Turner Endangered Species Fund, Tracey Mader	The burrows on the edge of 10 prairie dog colonies were flagged and a researcher walked around the edge of the colony to each flag holding a Trimble GeoExplorer 3 GPS unit. The result is a set of polygons showing the colony area.	2002

APPENDIX D

BASIC DESCRIPTION OF BLACK-TAILED PRAIRIE DOGS TRANSLOCATED FROM VERMEJO PARK RANCH FOR USE IN 2003 ARTIFICIAL BARRIER STUDY ON ARMENDARIS RANCH, NEW MEXICO

APPENDIX D

TABLE D-1. Basic Description of Black-tailed Prairie Dogs Translocated from Vermejo Park Ranch for Use in 2003 Artificial Barrier Study on Armendaris Ranch, New Mexico

Colony	Total No.	Male:Female	Mass Range (g)	Avg. Mass (g)	No. Coteries w/ >2 animals	No. Coteries with < 2 animals
A	30	13:17	480-1190	635	3	1
B	30	10:20	410-790	588	2	3
C	30	15:15	500-1190	644	3	1
D	30	12:18	430-1210	646	4	2

APPENDIX E

COST OF CONSTRUCTION MATERIALS NEEDED FOR VISUAL AND NON-VISUAL PRAIRIE DOG BARRIERS USED IN SUMMER 2003 STUDY ON ARTIFICIAL BARRIER EFFECTIVENESS ON ARMENDARIS RANCH, NEW MEXICO

APPENDIX E

TABLE E-1. Cost of Construction Materials Needed for Visual and Non-Visual Prairie Dog Barriers Used in Summer 2003 Study on Artificial Barrier Effectiveness on Armendaris Ranch, New Mexico

Material	Cost per Unit	Amount Needed / Enclosure	Total Cost for Enclosure
Hog Rings	$ 2.59/ box of 100	5 boxes	$12.95
Smooth wire	$18.98/ 400 m	180 meters	$8.54
0.9-m Stucco wire (Stucco wire)	$42.99/ 45.5 m	360 meters	$340.14
0.9-m Silt fence	$148/ 151.5 m	90 meters	$87.92
1.8-m T-posts	$2.59/ post	8	$20.72
2.4-m landscape timbers	$2.29/ post	4	$9.16
0.2-cm rebar	$5.25/6.06 m (including cost of cuts)	12, 1.2-m pieces	$12.60
Extra wire	$2.49/ 15.2 m	1 roll	$2.49
Total Visual			**$494.52**
Total Non-Visual			**$406.60**

APPENDIX F

ATTRIBUTES OF 15 TRANSLOCATED BLACK-TAILED PRAIRIE DOG COLONIES ON ARMENDARIS RANCH OF SOUTH-CENTRAL NEW MEXICO IN SUMMER 2003

APPENDIX F

TABLE F-1. Known Population Demographics of 15 Translocated Black-tailed Prairie Dog Colonies on Armendaris Ranch, New Mexico as of Summer 2003

Site Name (Abbreviation)	Date of Release	No. released [No. Additional released (Mo/Yr)]	Male:Female	Juveniles/ Adults	2003 Population Index	2003 Area (Ha)
Burrograss I (BG)	9/00	51	U	U	29	6.6
Burrograss NE (BGNE)	8/01	35	U	U	20	2.8
Burrograss SW (BGSW)	9/01	35	U	U	9[1]	0.7
Crater (CRAT)	7/02	39	0.857	0.026	8	2.5
Deep Well (DW)	7/99	56	U	U	30	4.4
Drinker (DRINK)	9/00	53	U	U	18	2.2
Fra Cristobol (FC)	7/02	55	0.719	0.145	9	1.9
Ishmaelite (ISH)	7/95	4	U	U	15	1.3
Lava Crossing (LC)	7/95	39 [42(8/01)]	U	U	10	1.7
Lava Station (LS)	7/02	38	0.652	0.211	2	5.7
Red Gap Road (RG)	11/01	?	U	U	8	0.9
Red Lake N (RLN)	7/95	28	U	U	7	2.9
Red Lake S (RLS)	8/98	66	U	U	50 (90[2])	11.1
Santa Fe (SF)	7/02	38	1.235	0.0	15	4.4
S-curve (SC)	7/99	59	U	U	45 (80[b])	10.1

[1] These were animals that disbursed from the experimental colonies.
[2] Estimates provided by Aaron Facka, NMSU graduate student, March 2004.

APPENDIX F

TABLE F-2. Physical Characteristics of Release Sites of Translocated Black-tailed Prairie Dog Colonies on Armendaris Ranch of South Central New Mexico as of Summer 2003

Site Name	Vegetation[3]	Soil Compaction Index[4]	Soil Type Label[5]	Elevation (m)	Distance to Road (m)	Power lines?	Distance to Nearest Colony (m)	Grazed by Bison?	Constraint Indices	
									Unmanaged	Managed
Burrograss I	SCBR	68	A	1376	195	No	670	No	-0.348	-0.396
Burrograss NE	SCBR/SPAI/PLMU	81	A	1377	8	No	160	No	-0.622	-0.257
Burrograss SW	SCBR/SPAI/PLMU	69	A	1377	24	No	160	No	-0.174	1.456
Crater	SCBR	84	A	1448	206	No	1606	Yes	0.025	3.177
Deep Well	SPAI	159	B	1407	83	No	1870	Yes	3.223	-0.383
Drinker	SPAI/SCBR	158	B	1400	0	No	2580	Yes	-0.508	-0.397
Fra Cristobol	SCBR	107	A	1381	0	No	730	No	-0.524	-0.397
Ishmaelite	SCBR/SPAI/PLMU	136	B	1418	12	Yes	470	No	-0.160	-0.396
Lava Crossing	PLMU/SPAI	67	B	1412	111	Yes	470	No	-0.471	-0.397
Lava Station	SCBR	86	A	1445	153	Yes	1606	Yes	-0.412	-0.042
Red Gap Road	SPAI/PLMU	150	B	1417	19	No	1870	Yes	-0.523	-0.397
Red Lake N	SPAI/SCBR	99	B	1408	34	No	1950	Yes	-0.740	-0.396
Red Lake S	SPAI/SCBR	126	B	1394	0	No	1950	Yes	0.208	-0.394
Santa Fe	SCBR	52	A & C	1438	17	No	3680	Yes	-0.467	-0.397
S-curve	SPAI/SCBR	113	B	1402	40	Yes	2900	Yes	1.184	-0.388

[3] 4-letter species codes. *Pleuraphis mutica* (PLMU), *Sceleropogon brevifolius* (SCBR), *Sporobolus airodes* (SPAI) ,
[4] See Figure E-1 for graph showing average and standard deviations
[5] See Table E-6 for soil descriptions

APPENDIX F

TABLE F-3. Information about Manipulations and Conditions of Black-tailed Prairie Dog Release Sites on the Armendaris Ranch in Southern New Mexico Collected in Summer 2003

Site Name	No. Artificial Burrows	Depth of Artificial Burrows (m)	Manipulations prior to release	Source Population	Size of cleared area (Ha)	Historic Colony Site?
Burrograss I	10	0.6	none	Vermejo Park	NA	likely
Burrograss NE	6	0.9	mow	Vermejo Park	0.81	Yes
Burrograss SW	6	1.8	mow	Vermejo Park	0.81	Yes
Crater	6	1.2	none	Vermejo Park	NA	Unknown
Deep Well	11	0.6-0.9	mow	Vermejo Park	1.21	Yes
Drinker	10	0.6	mow	Vermejo Park	0.81	likely
Fra Cristobol	8	1.2	none	Vermejo Park	NA	Unknown
Ishmaelite	NA	NA	Self-started	Lava Crossing	NA	Yes
Lava Crossing	NA	NA	Mow/fence	Carrizozo	0.4	Yes
Lava Station	6	1.2	none	Vermejo Park	NA	Unknown
Red Gap Road	12	0.6 (no nest box)	mow	Vermejo Park	0.81	Yes
Red Lake N	NA	NA	Mow/fence	Carrizozo	0.4	Yes
Red Lake S	23	0.6-0.9	mow	Vermejo Park	8.09	Yes
Santa Fe	6	1.2	none	Vermejo Park	NA	Unknown
S-curve	10	0.6-0.9	mow	Vermejo Park	1.62	yes

APPENDIX F

TABLE F-4. Research Projects Conducted and Colony Centroid Coordinates on Translocated Black-tailed Prairie Dog Colonies of the Armendaris Ranch, New Mexico as of Summer 2003

Colony	X-Coordinate[6]	Y-Coordinate[a]	Research Code[7]
Burrograss 1	307638.1474	3709392.436	A, H, I,
Burrograss NE	308402.2774	3709859.913	A, H
Burrograss SW	308756.8111	3710007.395	A
Crater	314245.8189	3707771.420	F, H
Deep Well	313533.0320	3690513.325	A, B, C, D, E, G, M, N
Drinker	313024.6900	3693265.734	A
Fra Cristobol	307168.0638	3708606.788	F
Ishmael	309724.3920	3702548.926	A, D, J
Lava Crossing	309692.2630	3703260.420	A, D, J, N
Lava Station	313227.7606	3706232.893	F
Red Gap Road	313311.2626	3688457.944	A
Red Lake N	311089.2288	3698322.204	A, D, J
Red Lake S	312038.0044	3696206.492	A, B, C, D, H, J, K, L, M
Santa Fe	315460.0181	3711472.853	F
S-Curve	315271.4223	3696389.373	A, B, C, D, G, H, K, L, M, N

[6] North American Datum 1983
[7] Codes defined in Table E-5

APPENDIX F

TABLE F-5. List of Codes and Description of Research Conducted on Translocated Black-tailed Prairie Dog Colonies on Armendaris Ranch, New Mexico as of Summer 2003

Code	Research	P.I.	Year	Publication
A	On-going burrowing owl monitoring	Dr. M. Desmond (NMSU), Ms. T. Mader (TESF)	On-going	None yet
B	Prairie dog diet analysis	Mr. M. Hartsough (NMSU)	1999-2001	Hartsough, M. 2002. Foraging ecology, dietary preferences, and diet quality of black-tailed prairie dogs (*Cynomys ludovicianus*) in northern Chihuahuan Desert grasslands. Master's Thesis, NMSU.
C	Effects of burning and mowing on prairie dog expansion	Dr. P. Ford (USFS), F. Frederickson (USDA, JER)		Ford, P., F. Frederickson, M. Anderson, J. Truett 2002. Fire as a management tool to facilitate expansion of reintroduced black-tailed prairie dog colonies. Poster. Society for Conservation Biology 15th Annual Meeting

TABLE F-5 Continued

Code	Research	P.I.	Year	Publication
D	Factors influencing nest success of burrowing owls	Ms. D. Berardelli (NMSU)	1999-2002	Berardelli, D. 2003. A comparative study of burrowing owl (*Athene cunicularia*) nest success and factors that influence success between urban and grassland habitats. Master's thesis.
E	Activity budgets of black-tailed prairie dogs	Ms. H. Adams (NMSU)	2001-2003	Adams, H. 2003 Activity budgets of black-tailed prairie dogs (*Cynomys ludovicianus*) on the Armendaris Ranch (NM). Master's Thesis.
F	Study of dynamics of initial colony expansion	Ms. M. Hendrie (NMSU)		Hendrie, M. 2004. Expansion of black-tailed prairie dog colonies: Can temporal patterns provide clues to behavioral processes? Poster 2004 SWAN Conference**,** April 15-17, San Antonio, TX.
G	Artificial food preference trials	M. Hendrie (NMSU)	Summer 2002	No

TABLE F-5 Continued

Code	Research	P.I.	Year	Publication
H	Burrowing owl diet study and invertebrate pitfall trapping	Mr. B. Duval (NMSU)	2003-04	Thesis in progress
I	Pilot barrier study	Ms. M. Hendrie (NMSU)	Summer 2003	No (Part of Thesis prep.
J	Initial translocation survival study	Dr. J. Truett (TESF)	1996	Truett, J., T. Savage. 1998. Reintroducing prairie dogs into desert grasslands. Restoration and Management Notes. **16** 189-195.
K	Energetics study using doubly-labeled water 2003-04	Dr. G. Roemer (NMSU), Mr. A. Facka (NMSU)	2003-04	In progress
L	Survivorship estimates using mark-recapture	Mr. A. Facka (NMSU)	2003-04	Thesis in progress
M	Colony Expansion Modeling	Dr. F. Fredrickson (USDA,JER), Mr. J. Northcott (NMSU)	2000-04	Thesis in progress
N	Raptor Foraging Study	Ms. Gail Garber (Hawks Aloft, Inc)	2000	No

APPENDIX F

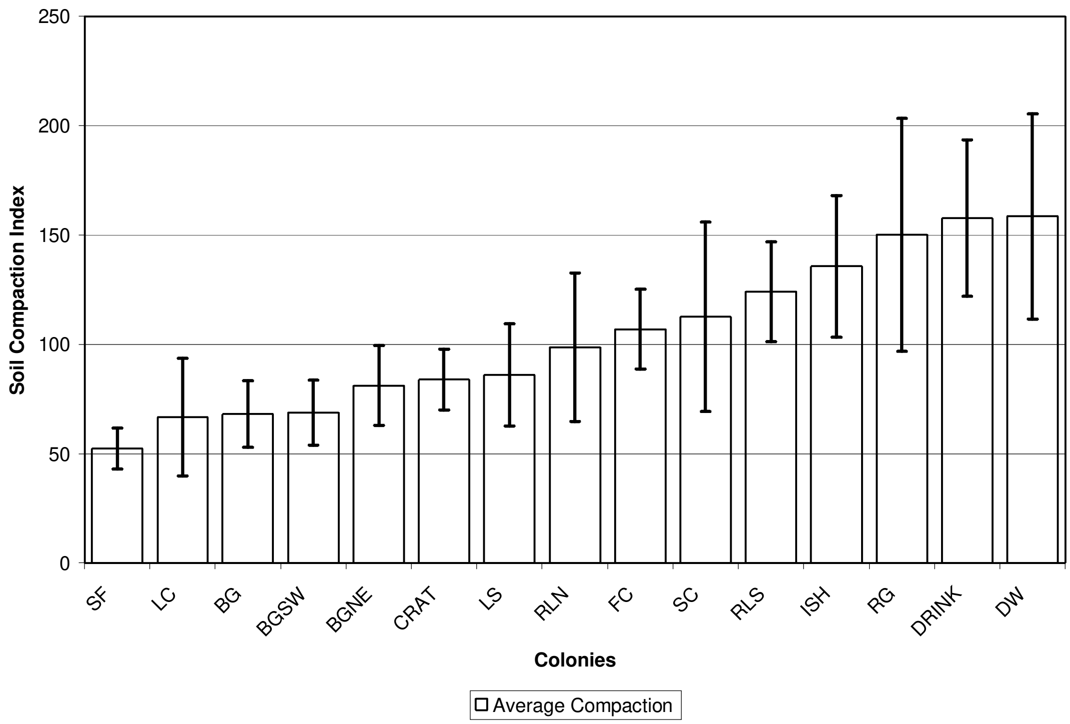

Figure F-1. Soil compaction index averages and standard deviations from 15 black-tailed prairie dog colonies on Armendaris Ranch measured with dynamic cone penetrometer in summer 2003. [8]

[8] Site abbreviations correspond to those in Table E-1

APPENDIX F

TABLE F-6. Descriptions of Soil Types found on Black-tailed Prairie Dog Translocation Sites on Armendaris Ranch of New Mexico in Summer 2003 as Identified by STATSGO Database (1994)

Soil Label	Soil Class No.	Map Unit ID	Soil Class 1	PCT 1	Soil Class 2	PCT 2	Soil Class 3	PCT 3
A	1419	NM881	Lithic torriorthents, loamy-skeletal mixed calcareous, thermic	45	Lithic haplargids, loamy mixed thermic	28	Lithic torriorthents, sandy skeletal, mixed thermic	12
B	1350	NM1641	Typic haplargids, fine-loamy, mixed thermic	35	Ustollic haplargids, fine mixed thermic	17	Typic cambothids, fine silty, mixed thermic	15
C	1443	NM877	Typic haplargids, fine-loamy mixed thermic	35	Ustollic haplargids, fine, mixed thermic	17	Typic cambothids, fine silty, mixed thermic	15

APPENDIX G

PRECIPITATION DATA COLLECTED NEAR ARMENDARIS RANCH, (SITE OF BLACK-TAILED PRAIRIE DOG TRANSLOCATION STUDY) FOR THE MONTHS OF MAY-DECEMBER 2001-2003.

APPENDIX G

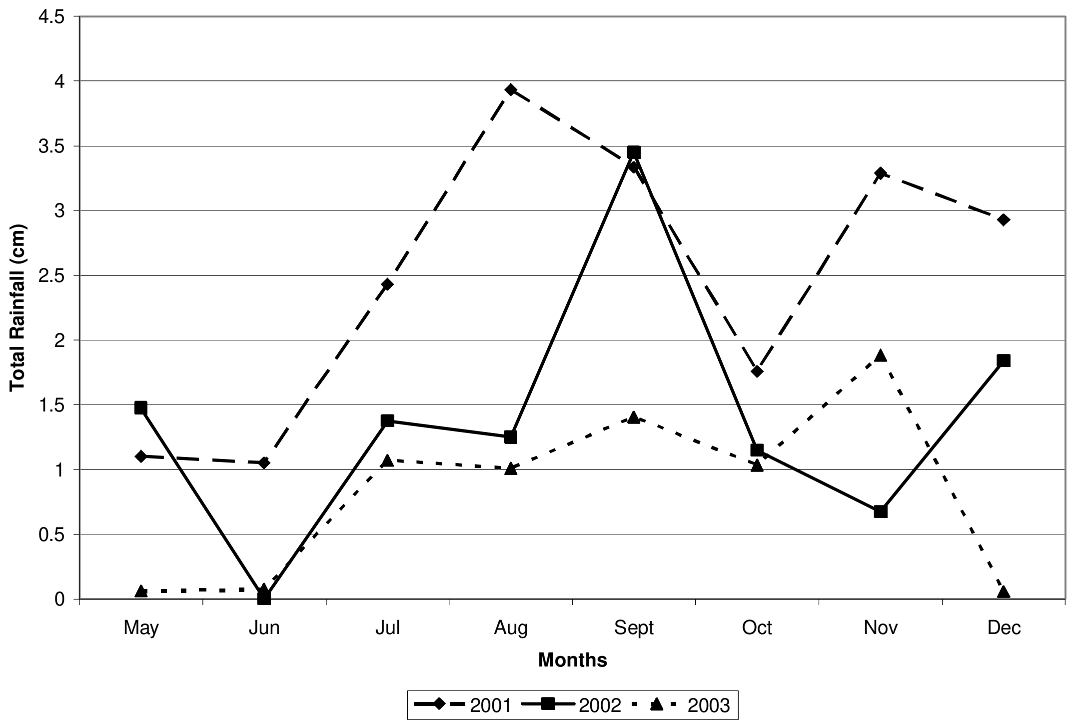

Figure G-1. Precipitation data collected near Armendaris Ranch at Elephant Butte Lake for May-December 2001-2003 showing gradual reduction in precipitation from 2001-2003.

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