THESIS

FINE-SCALE HABITAT USE BY BLACK-FOOTED FERRETS (*MUSTELA NIGRIPES*) RELEASED ON BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) COLONIES IN NEW MEXICO

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JENNIFER G. CHIPAULT ENTITLED FINE-SCALE HABITAT USE BY BLACK-FOOTED FERRETS (*MUSTELA NIGRIPES*) RELEASED ON BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) COLONIES IN NEW MEXICO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

FINE-SCALE HABITAT USE BY BLACK-FOOTED FERRETS (*MUSTELA NIGRIPES*) RELEASED ON BLACK-TAILED PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) COLONIES IN NEW MEXICO

Black-footed ferrets (*Mustela nigripes*) are among the most endangered animals in North America. The dependency of ferrets on diminishing prairie dog (*Cynomys spp.*) colonies for prey and shelter has been detrimental to their persistence in the wild. Reintroductions of captive-born ferrets into remaining prairie dog complexes have become crucial to the conservation of the species. Gaps in knowledge of ferret behavior hinder the success of these reintroductions. In this study, fine-scale prairie dog burrow density use by captive-born ferret kits was analyzed to inform future management.

In September 2007, captive-born ferrets were released on a black-tailed prairie dog (*C. ludovicianus*) colony on the Vermejo Park Ranch in northern New Mexico. Locations ($n = 46$) from 16 ferret kits experimentally released in areas of comparatively low and high prairie dog burrow densities were obtained via spotlight surveys. Ten kits were subsequently translocated to low and high burrow density areas on other Vermejo colonies and located thereafter ($n = 53$). For two months, habitat use was quantified by mapping all burrow openings within a 30 m radius of where ferrets were located. Spatial autoregressive models and spatially-explicit t-tests were used to account for

autocorrelation in the used burrow densities. It was hypothesized that ferrets released in, or translocated to, areas of low burrow densities would move so as to increase their localized burrow densities as they spent more nights in the wild. It was also hypothesized that ferrets released in, or translocated to, high burrow density areas would maintain high used burrow densities.

There was an inverse relationship between used prairie dog burrow densities and nights in the wild for ferrets released in high burrow density areas. For ferrets translocated to high burrow density areas, a pattern was not detected in burrow densities over time, which does not contradict the hypothesis for these ferrets. However, burrow densities used by ferrets released in, and translocated to, low burrow density areas did not increase over time as expected. With the number of nights in the wild converted to release or translocation burrow densities versus ferret-used burrow densities, average used burrow densities increased for ferrets placed in low burrow density areas, and average used densities decreased for ferrets placed in high burrow density areas. Used burrow densities on most inhabited colonies were similar to available densities, except for one colony, where used densities were lower than available densities.

Because newly-released ferrets in this study used burrow densities similar to densities available at the colony level, releasing ferrets on colonies offering overall high burrow densities might increase reintroduction success rates. Furthermore, burrow densities directly correlated with prey densities in this study. Ferrets used higher burrow densities before midnight; future research on ferret habitat use should consider within-night variation. Other studies on ferret habitat use after release are necessary; kits

monitored for more than two months, or with experience in the wild at a younger age,

might select high burrow density areas within colonies as predicted.

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TABLE OF CONTENTS

INTRODUCTION

Black-footed ferrets (*Mustela nigripes*, hereafter "ferret") are nocturnal, solitary, and semi-fossorial members of the family Mustelidae. Mustelid subfamilies include Enhydrinae and Lutrinae (otters), Melinae, Mellivorinae, and Taxidiinae (badgers), Mephitinae (skunks), Guloninae (wolverines), and Mustelinae (black-footed ferrets and other weasels) (Anthony 2005). The black-footed ferret arrived in North America via the Bering land bridge an estimated 100,000 years (Anderson et al. 1986), or longer (Owen et al. 2000), ago. The closest genetic relative of the black-footed ferret is the Siberian polecat (*M. eversmannii*) (O'Brien et al. 1989).

While similar in many ways, black-footed ferrets differ from Siberian polecats in having a more narrowly defined niche (Anderson et al. 1986, Biggins and Godbey 2003). Black-footed ferrets are extreme habitat specialists, with ~90% of their diet consisting of prairie dogs (*Cynomys spp.*) (Campbell et al. 1987, Sheets et al. 1972). Ferrets also depend on prairie dog burrows for caching food, rearing young, escaping predators, thermoregulation, and shelter (Forrest et al. 1985, Forrest et al. 1988, Henderson et al. 1974, Hillman 1968, Paunovich and Forrest 1987, Richardson et al. 1987, Sheets et al. 1972). While ferrets have been observed outside of prairie dog colonies (e.g., Henderson et al. 1974), the vast majority of locations of radio-tagged ferrets were within the boundaries of prairie dog colonies, with most off-colony ferrets returning to the colony of

1

origin or moving to a different prairie dog colony (Biggins et al. 1985, Biggins et al. 2006a).

Prairie dogs were abundant historically, with an estimated population size of 5 billion (Forrest and Luchsinger 2006, Hoogland 1995) covering 41 million hectares of grassland in the early 1900s (Anderson et al. 1986, Proctor et al. 2006). The 1-kg, agile ferret with powerful jaws is equipped for successful nocturnal hunting of diurnal prairie dogs within burrow systems (Anderson et al. 1986, Svendsen 2003). Further, colonial living of prairie dogs made them a concentrated source of prey for ferrets. This might partially explain why the historic range of the black-footed ferret closely coincides with that of the three species of prairie dogs that had large, contiguous ranges: black-tailed prairie dog (*C. ludovicianus*), Gunnison's prairie dog (*C. gunnisoni*), and white-tailed prairie dog (*C. leucurus*) (Anderson et al. 1986).

Beyond their role in black-footed ferret ecology, prairie dog colonies have a pronounced effect on the biodiversity of prairie ecosystems, leading to the consideration of prairie dogs as keystone species (Kotliar et al. 1999, Miller et al. 2000). Prairie dogs alter the distribution and chemical properties of the soil by excavating burrows (Munn 1993). The presence of prairie dogs also increases the diversity and richness of plant species (Archer et al. 1987) and increases the digestibility and crude protein content of forage on colonies (Coppock et al. 1983a, Fahnestock and Detling 2002, Krueger 1986). Because of these changes in vegetation, ungulates such as bison (*Bison bison*) and pronghorn (*Antilocapra americana*) have been found to spend more time on prairie dog colonies than in adjacent mixed-grass prairie (Coppock et al. 1983b, Krueger 1986). More generally, reports have indicated high numbers of animal species associated with

prairie dog colonies (e.g., Agnew et al. 1986, Campbell and Clark 1981, Davidson and Lightfoot 2007, Reading et al. 1989) or certain species tightly associated with colonies (e.g., black-footed ferret, Biggins et al. 2006a; burrowing owl (*Athene cunicularia*), Desmond et al. 2000, Tipton et al. 2009; mountain plover (*Charadrius montanus*), Knowles et al. 1982, Tipton et al. 2009; swift fox (*Vulpes velox*), Lebsock 2009). While the influence of prairie dogs on the local environment might not be prominent in the shortgrass prairie (Detling 2006a, Guenther and Detling 2003, Winter et al. 2002) and species richness patterns are not consistent (Kotliar et al. 1999, Shaughnessy and Cifelli 2004), overall, prairie dogs alter nutrient cycling, grassland structure, and animal distributions (Whicker and Detling 1988) and the keystone species designation is probably still warranted (Miller et al. 2000).

While once plentiful, prairie dog colonies are diminishing in size and becoming more fragmented due to the loss of prairie habitat, ranching practices that involve poisoning prairie dogs, and the human-introduction of plague caused by the bacterium *Yersinia pestis* (Cully 1989, Cully et al. 1997, Cully and Williams 2001, Lockhart et al. 2006, Miller et al. 1990a). As a result, prairie dogs now occupy ~2% of their historic range (Miller et al. 1994, USFWS 1988). The loss of biodiversity associated with the destruction of prairie dog colonies is detrimental to the prairie ecosystem, making prairie dog colonies sites for ecosystem conservation (Miller et al. 1994, Miller et al. 1996).

As prairie dog dependents, ferrets had a corresponding population decline and were included on the inaugural list of endangered species in 1967 (Lockhart et al. 2006). Furthermore, fragmentation of habitat and prey populations sometimes resulted in ferrets subsisting on isolated prairie dog complexes. Ferret populations became reduced to the

point where stochastic events, such as some diseases (Thorne and Williams 1988), were potential threats to regional persistence (Bright 2000, Harris et al. 1989, O'Grady et al. 2004, Shaffer 1981).

The distribution of ferrets dwindled until there was one known wild population located in South Dakota (Henderson et al. 1974). However, this population of ferrets was small and it vanished by the late 1970s (Biggins and Schroeder 1988). The black-footed ferret was thought by some to be extinct until 1981, when a population was discovered near Meeteetse, Wyoming. Unfortunately, canine distemper and plague were detected in this population in 1985 (Ubico et al. 1988, Williams et al. 1988). Plague can decimate the prey-base of the black-footed ferret, sometimes killing almost all prairie dogs on infected colonies (Cully and Williams 2001), and can infect ferrets directly (Williams et al. 1994). The ferret population became dangerously low and, by 1987, researchers had captured the last 18 wild ferrets for a captive-breeding program (Thorne and Belitsky 1989, Thorne and Williams 1988). Of those 18 individuals, 15 bred and all extant ferrets have descended from 14 ferrets (D.E. Biggins, U.S. Geological Survey, pers. comm.).

There have been many advances in the captive-breeding of black-footed ferrets (Howard et al. 2006, Marinari and Kreeger 2006). The captive population is now at ~250 adults and kit production is reliable (Lockhart et al. 2006). The United States Fish and Wildlife Service (USFWS) allocates captive-born ferrets to reintroduction sites in North America yearly (Jachowski and Lockhart 2009). The goal for down-listing, as set by the black-footed ferret recovery plan, is to establish 1,500 breeding adults in the wild at ten or more reintroduction sites with at least 30 adults in each population, preferably by the year 2010 (USFWS 1988). Despite the release of more than 3,000 ferrets since 1991, as

of December 2008, at most, four reintroduced populations are considered successes and there are only ~300 breeding adult ferrets in the wild (Jachowski and Lockhart 2009).

Many publications call for large complexes of prairie dog colonies to save black-footed ferrets (e.g., Bevers et al. 1997, Biggins et al. 1993, Houston et al. 1986). While there is little doubt that ferret recovery benefits from large complexes that have ample prey and burrows (Bevers et al. 1997, Harris et al. 1989), large prairie dog colonies and complexes are currently rare (Proctor et al. 2006) and, considering the dynamics of disease transmission, areas of substantial prairie dog coverage do not guarantee a stable ferret population (Biggins et al. 1993, Lockhart et al. 2006, Miller et al. 1993, Seal 1989). Therefore, there is wide-spread acknowledgement that the use of small, highly managed colonies and complexes are appropriate for ferret reintroductions (e.g., Biggins et al. 1993, Brussard and Gilpin 1989, Forrest et al. 1985, Harris et al. 1989, Lockhart et al. 2006, Truett et al. 2006).

Besides being limited in number and increasing the risk of rapid spread of disease, large prairie dog colonies do not always imply high quality colonies. Evidence is mounting that ferrets select areas of relatively high burrow entrance densities (hereafter "burrow entrances" are referred to as "burrows"; Hoogland 1995) within a prairie dog colony (Biggins et al. 1985, Biggins et al. 2006a, Eads 2009, Jachowski 2007a, Livieri 2007), and one study found that ferret litter sizes are greater in areas of high burrow density (mentioned in Biggins et al. 2006b). But burrow density is not always positively related to colony area (Reading et al. 1989). Prairie dog densities decline over time on older colonies (Yeaton and Flores-Flores 2006). Young colonies have higher prairie dog reproductive success, litter sizes, rates of juvenile growth, proportions of reproductive

yearlings, and predation rates on both juvenile and adult prairie dogs are lower (Garrett et al. 1982). Also, drought often causes colonies to expand as prairie dogs search for forage (Hanson 1993), without necessarily maintaining high prairie dog densities throughout the colony (Truett et al. 2006).

While there is increasing awareness that within-colony areas of high burrow densities are important to ferrets, the process by which captive-born ferrets select quality habitat in the wild is not well understood (Biggins et al. 2006a, Carlson 1993). Ferret habitat within prairie dog colonies is patchy (Biggins et al. 2006a, Jachowski et al. 2008) and understanding the influence of environmental heterogeneity on space use of ferrets may increase the effectiveness of ferret reintroductions. In general, the success rates of species relocations are low (Griffith et al. 1989, Morell 2008, Stamps and Swaisgood 2007, Wolf et al. 1996), but the success of the reintroduction of martens (*Martes americana*), members of the same subfamily as ferrets, is attributed in large part to advanced knowledge of habitat suitability at release sites (Chapin et al. 1997, Slough 1994). The outcome of ferret reintroductions is mixed and progress sometimes seems slow (Grenier et al. 2007, Jachowski 2007b, Lockhart et al. 2006); increased understanding of how habitat attributes affect black-footed ferret behavior and population dynamics can aid the recovery of this critically endangered species.

This experiment was conducted to examine fine-scale habitat use by captive-born ferrets released in areas of various prairie dog burrow densities. From 4 September – 6 November 2007, ferrets obtained from the USFWS National Black-footed Ferret Conservation Center were preconditioned at Vermejo Park Ranch, New Mexico (hereafter "Vermejo"). Wild preconditioning gives naïve ferrets time to adjust to the

prairie while being intensively monitored via spotlight surveys (Biggins et al. 2006c, Campbell et al. 1985), thereby increasing their long-term chances of survival following recapture and subsequent transportation to permanent release sites (Biggins et al. 1998, Biggins et al. 1999, Miller et al. 1990b, Vargas and Anderson 1998a, Vargas et al. 1998). In this study, six ferret families were released on one black-tailed prairie dog (*Cynomys ludovicianus*) colony; three families in areas of low prairie dog burrow density and three in areas of high burrow density. Subsequent habitat use by 16 kits that became independent from their family units was quantified by mapping burrows within a 30 m radius of locations where kits were seen during nightly spotlight surveys. Because the release colony was not large enough to contain territories for all kits, 10 were translocated to sites of various localized burrow densities on four other Vermejo colonies and subsequently monitored; their post-translocation used burrow densities were quantified in the same manner as pre-translocation burrow densities were determined. It was hypothesized that used burrow densities would increase over time since release, or time since translocation, for kits placed in low density areas and that relatively high used densities would be maintained by kits placed in high density areas.

METHODS

SITE DESCRIPTION

Vermejo is a privately owned ranch in Colfax County, northern New Mexico. Approximately 24,000 ha of Vermejo is contiguous shortgrass prairie dominated by blue grama (*Bouteloua gracilis*). The Vermejo prairie has a semi-arid climate, with a total rainfall of 260 mm in 2007 (Vermejo Park Ranch, unpublished data). In 2007, the

Vermejo prairie contained a complex (Biggins et al. 1993) of 48 black-tailed prairie dog colonies totaling 2,031 ha and ranging in size from 1 to 416 ha (D.H. Long, unpublished data).

BLACK-FOOTED FERRET RELEASE AND MONITORING

Pre-Translocation Ferret Locations

Six ferret families (26 individuals) were released on one 416 ha prairie dog colony (the "Phoneline" colony) for wild preconditioning (Table 1, Figure 1). Each family, as determined by the National Black-footed Ferret Conservation Center, consisted of a dam and her biological or "adopted", i.e., not genetically related, kits. Three families (A, C, and F) were released in areas of relatively high burrow densities (99.0 – 109.6 burrows/ha), while the other three families (B, D, and E) were released in areas of relatively low burrow densities (53.1 – 63.7 burrows/ha) (Table 1). Families were randomly assigned to a burrow density category and specific release site, equalizing the number of ferrets in each category. There were six male and four female kits released in each burrow density category.

Release sites were pre-determined by searching for obvious high and low burrow density areas and then quantifying densities at the 0.28 ha (Table 1) and 4 ha scales by counting burrows in circular and square plots, respectively, centered on release burrows. Both scales were considered when selecting release sites, but only the 0.28 ha numbers were used in data analyses because this corresponds with the 0.28 ha scale of used habitat (see below). Burrows within these assessment plots were mapped using a Trimble® Global Positioning System Pathfinder® Pro XRS receiver with differential correction

Table 1. Six black-footed ferret (*Mustela nigripes*) family groups (A – F) released on the Phoneline colony on 4 September 2007 at the Vermejo Park Ranch, New Mexico. Studbook numbers were given to each ferret at the National Black-footed Ferret Conservation Center, Colorado. Each family group of kits was released with a dam that was 2 – 3 years old. Release and translocation densities (burrows/ha) are based on counting black-tailed prairie dog (*Cynomys ludovicianus*) burrows within circular plots with 30 m radii (0.28 ha) centered on the ferret release or translocation burrow. Ferrets listed as recaptured were recovered by the end of the wild preconditioning period (6 November).
* Disappeared (temporarily or permanently) without independent locations logged; no locations from these ferrets in the pre-translocation data set.
** Disappeared immediately after translocation; no locations from this ferret in the post-translocation data set.

Family Letter	Studbook #	Sex	Release Burrow Density (Category)	Translocation Colony	Translocation Burrow Density (Category)	Recaptured?
A	5686 *	M	109.6 (high)	Windmill	106.1 (low)	Yes
	5687	M	109.6 (high)	99-4	92.0 (low)	Yes
	5688 *	M	109.6 (high)	99-5	109.6 (high)	Yes
	5689	F	109.6 (high)	---	---	Yes
B	5676 **	M	60.1 (low)	Drift	N/A (high)	No
	5677	M	60.1 (low)	---	---	Yes
C	5700	M	102.6 (high)	Drift	49.5 (low)	Yes
	5701	M	102.6 (high)	Windmill	137.9 (high)	Yes
	5702	M	102.6 (high)	---	---	Yes
D	5738	M	53.1 (low)	99-4	127.3 (high)	Yes
	5739	M	53.1 (low)	---	---	Yes
	5740 *	M	53.1 (low)	---	---	No
E	5788	F	63.7 (low)	Drift	95.5 (high)	Yes
	5789	F	63.7 (low)	---	---	No
	5790 *	F	63.7 (low)	---	---	No
	5792	M	63.7 (low)	---	---	No
	5793	F	63.7 (low)	Drift	53.1 (low)	Yes
F	5759	F	99.0 (high)	Windmill	127.3 (high)	Yes
	5760	F	99.0 (high)	---	---	No
	5761	F	99.0 (high)	Windmill	67.2 (low)	Yes
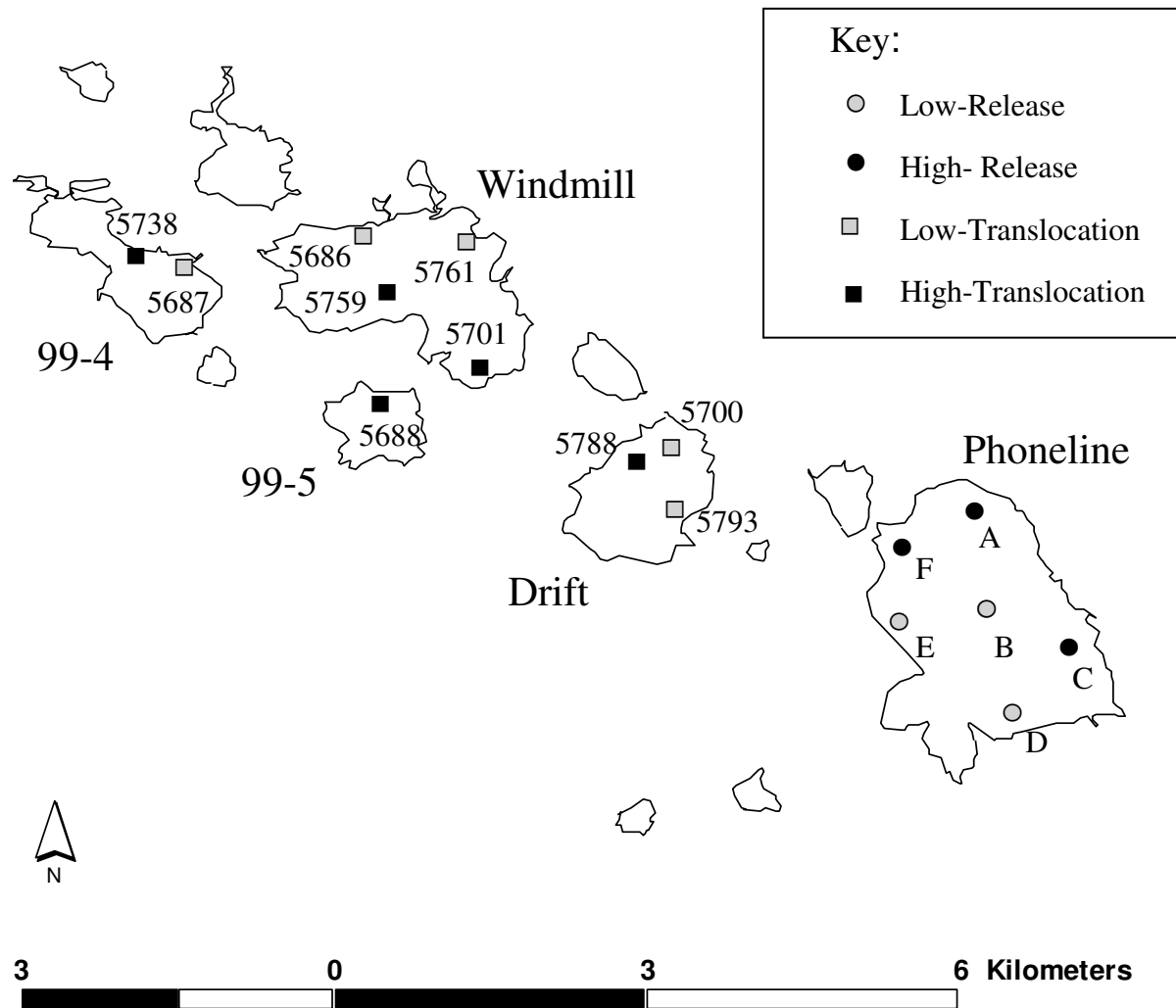
Figure 1. Black-footed ferret release sites (6) on Phoneline colony, and kit translocation sites (10) on 99-4, 99-5, Drift, and Windmill colonies, Vermejo Park Ranch, New Mexico, 2007. Categorized as high or low based on prairie dog burrows/ha at 0.28 ha scale. Ferret family letters and kit stud numbers (Table 1) are indicated next to release and translocation sites, respectively.

and 1-m accuracy (Trimble Navigation Limited, Sunnyvale, CA, hereafter "GPS").

Release locations were dispersed on the colony to decrease the probability of family

territories overlapping (Figure 1). The specific burrow entrances chosen had large,

conspicuous mounds of soil (Hoogland 1995), fresh prairie dog digging and scat (Biggins

et al. 1993), and were not connected to other burrow entrances as determined by using

smoke generators (Superior Signal Company, Spotswood, NJ) and a leaf blower (similar

to Eads and Biggins 2008).

Further preparations for ferret release included erecting an electric fence around

the colony to deter terrestrial predators, primarily coyotes (*Canis latrans*) (Breck et al.

2006). Also, aboveground retention pens (~120 cm x 90 cm x 60 cm) were placed over

each release burrow entrance to facilitate a soft-release, allowing access to a natural

prairie dog burrow system, but keeping ferrets confined while they adjusted to their new

environment (Long et al. 2006). Lastly, spotlight surveys (Biggins et al. 2006c,

Campbell et al. 1985) were conducted using a high-intensity spotlight (500,000 – 730,000

candle power, LightForce™ Performance Lighting, Corona, CA) from an all-terrain

vehicle (ATV) or mini-truck to verify that ferrets from previous years of wild

preconditioning were no longer present. Search patterns were not pre-determined, but

observers tended to follow two-track roads through colonies with departures from roads

to view areas otherwise not visible.

Ferrets and 1 – 2 eviscerated prairie dogs per ferret family were placed into the

six retention pens on the afternoon of 2 September 2007. On the evening of 3 September,

1 – 2 live prairie dogs were added to each pen. At dusk on 4 September, retention pens

were removed and ferrets were allowed to disperse freely. The kits were an average of

85.4 days of age ± 1.0 SE ($n = 20$, range = 79 – 91 days old). Spotlight surveys were conducted nightly, with active monitoring performed irregularly from dusk until dawn. Passive integrated transponder (PIT) tags (American Veterinary Identification Devices®, Norco, CA) were implanted during captivity. After a ferret was detected in the wild via eyeshine, a ring transponder reader was placed on the burrow opening into which it submerged; when the ferret exited the burrow, the unique number encoded in the PIT tag registered (Fagerstone and Johns 1987, Stoneberg 1996). The locations at which ferrets were first spotted were mapped with the GPS, and date and time (MST) were noted. The goal was to find each ferret once per night. Only locations from kits that had become independent of their family units were used in analyses. Some ferrets remained on the Phoneline colony the entire preconditioning period while others were translocated to other colonies.

Post-Translocation Ferret Locations

Because liberal estimates of ferret home ranges are ~75 ha for females and ~150 ha for males (Biggins et al. 1985, Forrest et al. 1985, Jachowski 2007a, Livieri 2007, Richardson 1986), the Phoneline colony was not large enough to contain territories for all surviving kits. Allowing natural between-colony dispersal of naïve ferrets might increase the odds of mortality (Biggins et al. 1999, Stamps and Swaisgood 2007). Therefore, when dispersing kits were observed (18 September – 1 October), they were trapped (Biggins et al. 2006c, Sheets 1972) and translocated to pre-determined locations on four other Vermejo colonies (Table 1, Figure 1). A prairie dog carcass (half or whole) was placed into the translocation burrow with each kit. Assisted dispersal of kits involved moving them to colonies that were not encircled by electric fencing.

13

The Vermejo prairie dog colonies that were used for ferret translocations were established in 1999 and 2000 via the transplanting of prairie dogs into relic colonies or recipient sites with suitable prairie dog habitat (Long et al. 2006, Truett et al. 2006). The ferret translocation colonies averaged 145.9 ha (± 43.9 SE, range = 54 – 262 ha) in 2007 (D.H. Long, unpublished data). Ferret translocation sites were pre-selected by searching for areas of relatively low and high burrow densities within colonies and quantifying burrow density at the 0.28 ha scale. Because ferret translocation burrows were pre-determined, assisted dispersal allowed another experimental manipulation of the burrow density into which ferrets were placed; however, burrow densities on the translocation colonies were not as dichotomously "low" and "high" as on the Phoneline colony (Table 1). Translocation sites were dispersed on each colony (Figure 1) to decrease the chance of territorial disputes affecting habitat use (Biggins et al. 2006a). The first kit trapped from a family was translocated to an area with the opposite localized burrow density category as its Phoneline release site, a second kit from that family was moved to an area with the same density category as its release site, and a third kit trapped in a given family was moved to an area with the opposite density category as its release. Four kits from different families (studbook numbers 5689, 5677, 5702, and 5739; Table 1) were randomly selected to remain on the Phoneline colony. Data from locations of these kits were maintained in the pre-translocation data set because an experimental translocation was not part of the behavioral history of these four ferrets.

Monitoring of all ferrets on Vermejo continued via nightly spotlight surveys during and after the translocation of kits. Only four of 64 nights of preconditioning (4 September – 6 November) lacked surveys. At the conclusion of the study, fourteen ferret

14

kits were recaptured (Table 1) during 2 – 6 November and were then transported to Aubrey Valley, Arizona for permanent release. The remaining six kits were not recaptured and were presumed dead (Appendix II).

USED PRAIRIE DOG BURROW DENSITIES

Habitat use by ferrets was quantified by using the GPS to map all prairie dog burrow openings within a 30 m radius (0.28 ha) of each independent kit location. A pole with an attached steel measuring tape was inserted in the ground near the used burrow opening. Burrows were marked with white flour as they were mapped to prevent re-mapping. Circular plots were allowed to overlap (Biggins et al 2006a). Mapping of burrows was conducted within four days, and the majority of plots (73.7%) within two days, of the ferret observation.

Mapped burrow openings were at least 7 cm in diameter (Biggins et al. 1993). Unlike other recent studies of ferret habitat (Biggins et al. 2006a, Eads 2009, Jachowski 2007a, Jachowski et al. 2008, Livieri 2007), plugged and inactive (Biggins et al. 1993) prairie dog burrow openings were included in counts. Plugged burrows were included because mapping was conducted immediately after a ferret occupied an area; many plugged openings were likely the result of antipredator responses of prairie dogs to ferret presence (Clark 1978, Fortenbery 1972, Henderson et al. 1974, Hillman and Linder 1973, Jachowski 2007b, Martin et al. 1984). Inactive burrows were included because they are refugia for ferrets even if not occupied by prairie dogs. Few (21/2486) burrows in ferret-used areas were classified as inactive. The same field procedure was used to quantify habitat at the 0.28 ha scale for release and translocation sites; burrows were mapped after

15

ferrets had been on site so that release and translocation site burrow densities were comparable to used densities.

Locations of mapped burrows were downloaded using Pathfinder® Office version 2.90 (Trimble Navigation Limited, Sunnyvale, CA) and viewed with ArcView™ Geographic Information System version 3.1 (Environmental Systems Research Institute, Redlands, CA, hereafter "GIS"). Plots not fully within 2007 colony boundaries (D.H. Long, unpublished data) were removed from the data set (Biggins et al. 2006a). Counts of burrow openings were converted to densities (burrows/ha) for analyses.

AVAILABLE PRAIRIE DOG BURROW DENSITIES

Remote sensing, via geo-referenced Quickbird satellite images (DigitalGlobe Corporate, Longmont, CO) with 1-m resolution obtained in 2005, was used to determine available prairie dog burrow densities for Vermejo colonies or wards (Biggins et al. 2006d). Wards are portions of colonies separated by a physical barrier from the rest of the colony (Hoogland 1995, King 1955). Because a railroad grade divides the Phoneline colony, the main ward will be referred to as the Phoneline colony and the small, southernmost ward will be called Phoneline South Ward. Available burrow densities were compared to used densities on each colony or ward used by ferret kits (Biggins et al. 2006a).

Because prairie dog colonies on Vermejo are young and dynamic (D.H. Long, unpublished data), satellite images acquired in 2005 needed to be adjusted to 2007 burrow densities determined in the field. Furthermore, not all burrow openings can be visually detected in a satellite image so calibrating burrow mounds seen in the satellite image to burrow openings mapped in the field adjusts for this discrepancy as well. Using

16

GIS, circular plots of 30 m radii were created around 2007 ferret-used locations (including ferret family and dam locations not used elsewhere in this study). Circular plots completely within 2005 colony boundaries (D.H. Long, unpublished data) were used for calibration ($n = 81$). The percentage of each 2005 colony used for calibration ranged 2.5% – 5.1%. Within the circular plots, a point was added to a GIS layer over every light-colored area on the 2005 image that resembled a burrow mound (Biggins et al. 2006d). Burrow mounds in areas where multiple plots overlapped were only counted once. The total number of burrow mounds counted and the total area covered for each colony was determined and compared to the densities of burrows mapped in the field in 2007 in those same areas. The percent increase or decrease between 2005 satellite-based and 2007 field-based burrows/ha for each colony was calculated and correction factors were: + 25.9 % for colony 99-4, + 12.0% for 99-5, + 12.7% for 00-3, + 11.7% for Drift, + 26.7% for Phoneline, - 31.7% for Phoneline South Ward, and + 65.2 % for Windmill.

To estimate available burrow densities on colonies in 2007, five random locations for each location used by an independent kit were generated within corresponding 2005 colony or ward boundaries (Cooper and Millspaugh 2001, Manly et al. 1993, McFadden 1978). Random locations were manually moved to the nearest burrow mound on the satellite image. Plots with 30 m radii were created around these burrow-centered locations; overlap was allowed (Biggins et al. 2006a). At least 5% of each colony was sampled, as recommended by Biggins et al. (1993); 45 locations were generated for colony 99-4, 15 for 99-5, 30 for 00-3, 75 for Drift, 175 for the Phoneline, 15 for Phoneline South Ward, and 115 for Windmill. A GIS layer was created that consisted of points within these plots over burrow mounds on the satellite image. The density of

available burrows on each 2005 colony or ward was calculated and then the

corresponding correction factor was applied to estimate 2007 available burrow density.

STATISTICAL ANALYSIS

Program R version 2.8.1 (Ihaka and Gentleman 1996) was used for analyses, with

a probability of committing a Type I error (α) set at 0.10 for checking statistical

assumptions, and $\alpha = 0.05$ for statistical testing. Due to the small number of ferrets

monitored in this study, the number of locations, not the number of ferrets, was used as

the sampling unit. Several assumptions had to be considered to appropriately analyze and

interpret ferret habitat use (Appendix I).

Spatial Independence

The assumption of spatial independence (e.g., Hoeting 2009, Lichstein et al. 2002,

Wagner and Fortin 2005) was assessed for raw data and residuals via the Moran's *I*

statistic (Cliff and Ord 1981, Moran 1950), and regression-adjusted Moran's I_k (Bonham

and Reich 1999, Cliff and Ord 1981, Reich and Bonham 2001), respectively. If Moran's

I statistics under normal approximation indicated spatial dependence, spatially explicit t-

tests were run instead of classical t-tests to account for distances between ferret-used

locations predicting some of the variation in localized burrow densities (Cliff and Ord

1981). For non-normal data with spatial autocorrelation, a Wilcoxon rank sum test was

performed on the residuals from a spatial autoregressive model with intercept only.

Gaussian spatial autoregressive models that account for spatial dependence by

using weight matrices (Bonham and Reich 1999, Reich and Bonham 2001) based on

inverse distances between all ferret-used locations were presented instead of ordinary

least squares models when the residuals from ordinary least squares models were spatially autocorrelated via Moran's I_k (Bonham and Reich 1999, Lichstein et al. 2002, Metzger et al. 2005, Reich and Bonham 2001). Spatial autoregressive models were also preferred to ordinary least squares models when likelihood ratio tests indicated that the former was a significant improvement over the latter (Bonham and Reich 1999). An estimator of spatial autocorrelation intensity and direction, λ, was reported when spatial autoregressive models were presented (Bonham and Reich 1999, Reich and Bonham 2001). The correlation between the observed and predicted values squared, called FIT, was considered a more reliable measure of model fit for spatial autoregressive models than R^2 (Doreian 1981).

Hypothesis Testing

The hypotheses were that ferret kits released in or translocated to areas of low prairie dog burrow densities (low-release and low-translocation, respectively) would select increased burrow densities over time and ferret kits released in or translocated to areas of high burrow densities (high-release and high-translocation, respectively) would maintain high burrow densities over time. To test these hypotheses, ordinary least squares or spatial autoregressive models of burrow densities (release or translocation and used burrow densities combined) vs. nights in the wild (Table 2) were calculated for each treatment group (high or low burrow density at release/translocation site) within each data set (pre- or post-translocation). The interaction between treatment groups and the number of nights in the wild was assessed to see if trends over time differed between treatments. Release or translocation burrow densities (Table 2) were also checked as predictors of used densities to determine if ferrets preferred burrow densities similar to

Table 2. Variables considered as predictors of black-tailed prairie dog (*Cynomys ludovicianus*) burrow densities (burrows/ha) at locations used by black-footed ferret (*Mustela nigripes*) kits, Vermejo Park Ranch, New Mexico, 2007.

Variable Type	Variable Name	Definition
Response	Used Burrow Density	Burrow density (burrows/ha) within 30 m of a ferret observed via spotlight.
Predictor	Nights in the Wild	Number of nights the ferret observed had been free-ranging at the time of the observation, with the night of release (4 September 2007) being night one.
	Low- or High-Release	Burrow density classification of the site where the ferret observed was released with its dam.
	Release Burrow Density	Burrow density (burrows/ha) within 30 m of the release site for the ferret observed.
	Low- or High-Translocation	Burrow density classification of the site to which the ferret observed was translocated during 18 September - 1 October.
	Translocation Burrow Density	Burrow density (burrows/ha) within 30 m of the translocation site for the ferret observed.
	Sex	Sex of the ferret observed.
	Minutes Since Sunset	Time of night of the observation, reported in minutes since sunset. Sunset times were based on the U.S. Naval Observatory sunset chart for Maxwell, New Mexico.
	Available Burrow Density	Burrow density (burrows/ha) available on the colony on which the ferret was observed. Determined via remote sensing.

those in which they were released (Davis and Stamps 2004, Stamps and Davis 2006, Stamps and Swaisgood 2007). Interactions of the nights in the wild and release, or translocation, burrow densities were assessed. Quadratic forms of predictor variables were assessed as well to check for non-linear relationships. Normality, homoscedasticity, linearity, and influence were checked via Shapiro tests on standardized residuals, plots of fitted values vs. model residuals, plots of predictors vs. model residuals, and Cook's distance tests, respectively. When spatial autoregressive models were used, residuals of the models were checked for spatial autocorrelation with a Moran's I statistic to ensure that the spatial weight matrices sufficiently accounted for the spatial patterns in burrow densities.

The influence of ferret sex (Table 2) on used burrow densities was assessed by using sex as a predictor in regression models. This determined if locations from males and females could be pooled.

Further Analysis

Paired two-tailed Student's t-tests, or paired spatial t-tests, were performed to determine if there was an overall change from release or translocation burrow densities to used densities; burrow densities used on different nights were compared to the release or translocation burrow density of the ferret observed. Unpaired t-tests were performed to compare the used burrow densities of the two treatment groups in each data set. Used burrow densities were also compared to available densities on each colony using paired t-tests. Equality of variances was checked using Levene's tests and normality was checked using Shapiro tests; Welch's t-tests and Wilcoxon rank sum tests, respectively, were used if necessary.

An extended list of possible predictors (Table 2) was used to determine if factors other than nights in the wild and release or translocation burrow density accounted for trends in used burrow densities when examined via regression models. Forward selection with $\alpha = 0.05$ for added predictors was used to create final models. Quadratic forms of predictors were assessed. If a model included more than one predictor, interactions were examined. If a final model was better as a spatial autoregressive model than a classical ordinary least squares model, then other similar models were checked via spatial autoregressive models to be sure the spatial autocorrelation in the data did not alter significance of related models differently than would be expected with non-spatial data. Normality, homoscedasticity, linearity, and influence were checked for each final model. Residuals of spatial autoregressive models were checked for spatial autocorrelation with a Moran's *I* statistic. If predictors in the final model were categorical, one-way analysis of variance (ANOVA) and subsequent Tukey's HSD tests were performed. Spatially-explicit ANOVAs were accomplished via spatial autoregressive models with dummy variables. Residuals were checked for normality and homoscedasticity.

RESULTS

PRE-TRANSLOCATION FERRET LOCATIONS

There were 46 locations obtained for 16 ferrets (Figure 2), resulting in 985 total mapped prairie dog burrows in the pre-translocation data set (range = 38.9 – 102.6 burrows/ha at ferret-used locations, mean = 75.9 burrows/ha ± 2.2 Standard Error (SE)). The average number of nights in the wild at the time locations were obtained from pre-translocation, or never translocated, independent kits was 27.6 nights ± 2.8 SE (range = 5
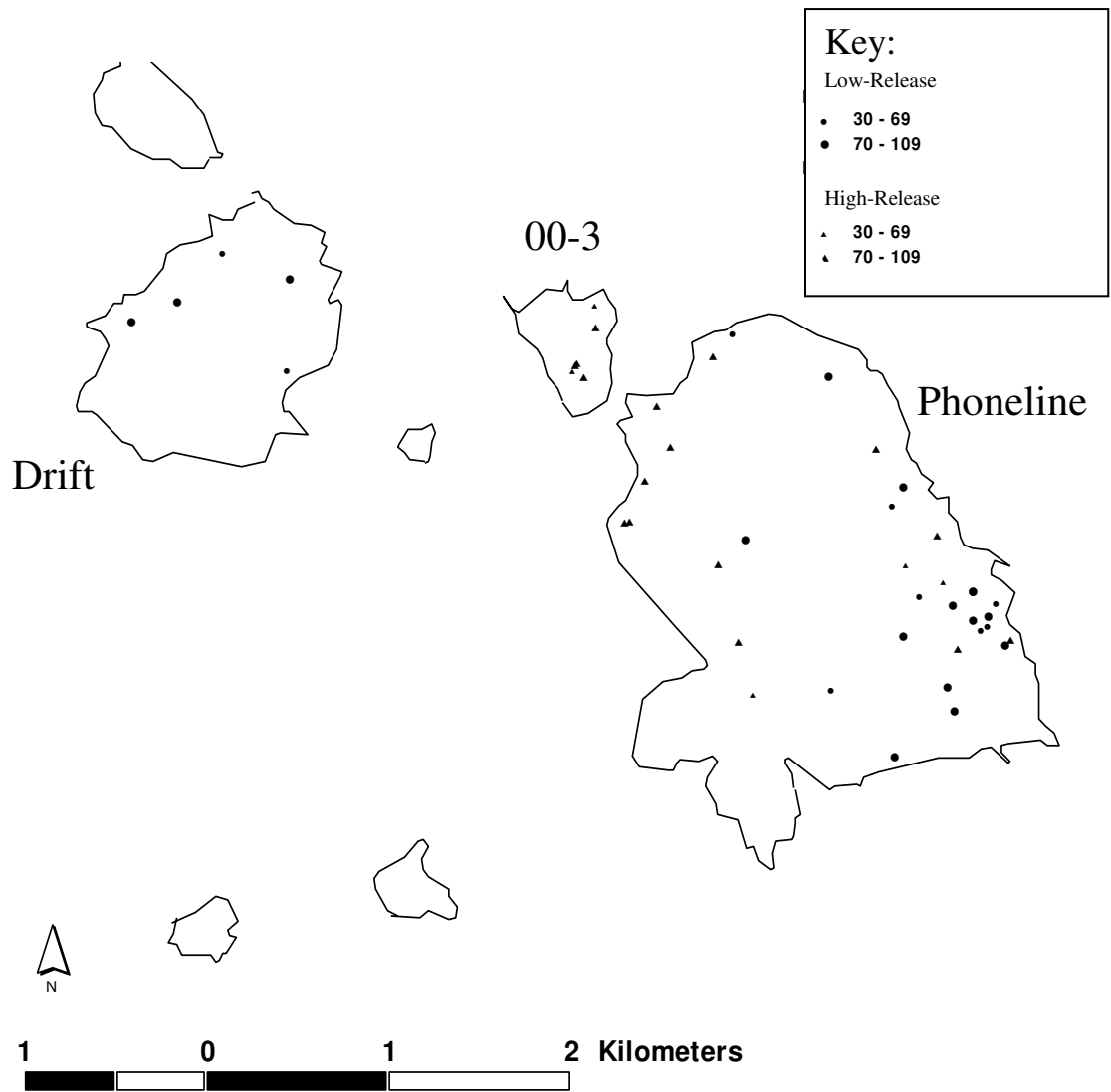
Figure 2. Three black-tailed prairie dog (*Cynomys ludovicianus*) colonies (Drift, 00-3, and Phoneline) inhabited by pre-(or never)-translocated black-footed ferret (*Mustela nigripes*) kits at Vermejo Park Ranch, New Mexico, 2007. Size of symbol represents the ferret-used localized burrow densities (burrows/ha) based on 0.28 ha circular plots.

– 63 nights). Sex (Males: $n = 23$; Females: $n = 23$) was not found to be a predictor of

used burrow densities ($P \geq 0.50$). Therefore, treatment groups were not separated by sex

for further analyses. Locations on the Drift and 00-3 colonies were included in this data

set because two ferrets that were released on the Phoneline colony subsequently dispersed

to these colonies. Spatial autocorrelation in used burrow densities was not significant for

the data set as a whole, nor for the treatment groups separately (Moran's *I*, Low-Release:

$n = 25$; High-Release: $n = 21$, $P \geq 0.39$).

Hypothesis Testing

Within the high-release group, the negative trend between burrow densities

(release and used) and nights in the wild was better modeled with a quadratic predictor

(ordinary least squares model, $n = 29$, $F_{2,26} = 18.19$, $P < 0.0001$) than a linear predictor,

and there was no trend detected within the low-release group ($n = 33$, $P \geq 0.18$) (Figure

3). There was an interaction between the release site burrow density category and the

number of nights in the wild in both linear and quadratic ordinary least squares models (n

$= 62$, Linear: $P = 0.001$; Quadratic: $P = 0.02$, Figure 3). Release burrow densities ($n =$

46, $P = 0.24$) and the interaction between nights in the wild and release burrow densities

($n = 46$, $P = 0.14$) were not found to be predictive of used densities.

Further Analysis

The change from release burrow densities to ferret-used densities, which involves

a conversion of the number of nights in the wild into categories of release burrow

densities (0 nights in the wild) and used burrow densities (> 0 nights in the wild), was

significant for both treatment groups (paired t-tests, Low-Release: $n = 25$, mean of the

Low-Release Site Burrow Density:
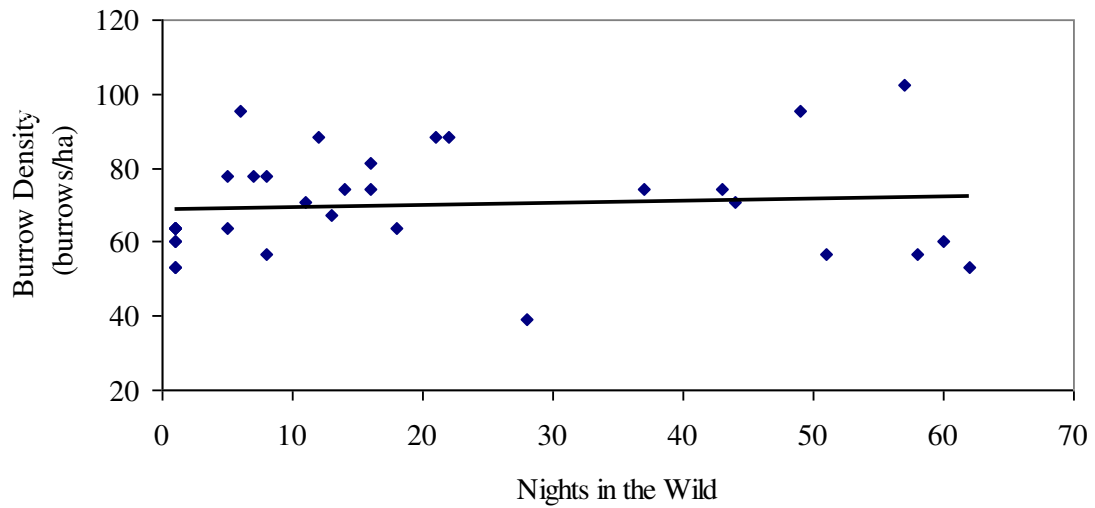
High-Release Site Burrow Density:
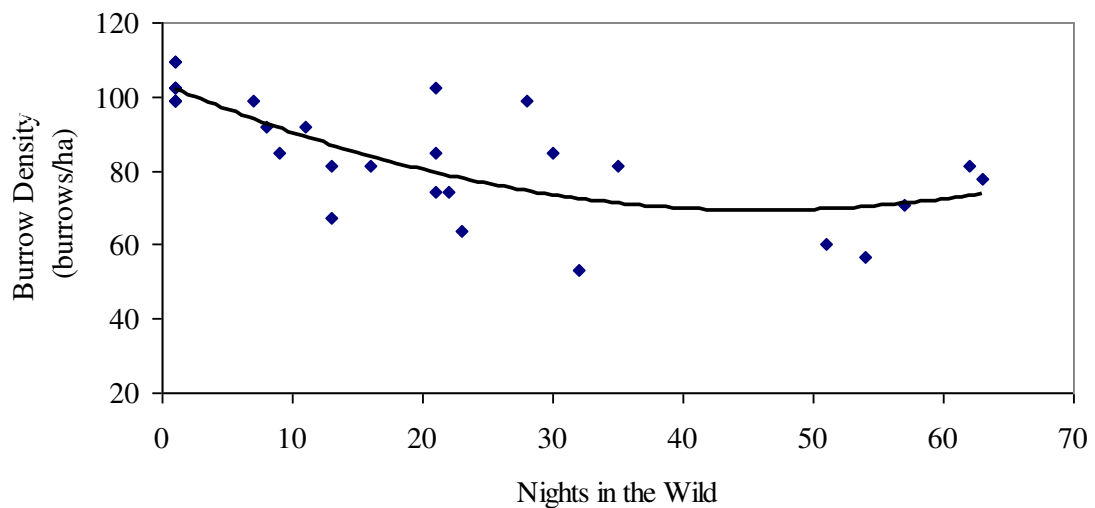
Figure 3. Relationships between the nights spent in the wild and prairie dog burrow densities of release and ferret-used locations from pre-translocation black-footed ferrets at Vermejo Park Ranch, New Mexico, 2007 (High-release site burrow density locations: ordinary least squares model, $n = 29$, $R^2 = 0.58$, Residual SE = 10.79, $\beta_0 = 103.61 \pm 3.72$ SE, $\beta_1 = -1.49 \pm 0.35$ SE, $\beta_2 = 0.02 \pm 0.01$ SE, $P < 0.0001$).

differences = 13.3 burrows/ha ± 3.1 SE, t = -4.25, P = 0.0003; High-Release: n = 21,

mean of the differences = -25.4 burrows/ha ± 3.5 SE, t = 7.30, P < 0.0001, Figure 4). A

difference in the used burrow densities of high- and low-release ferrets was not detected

(P = 0.17, Figure 4).
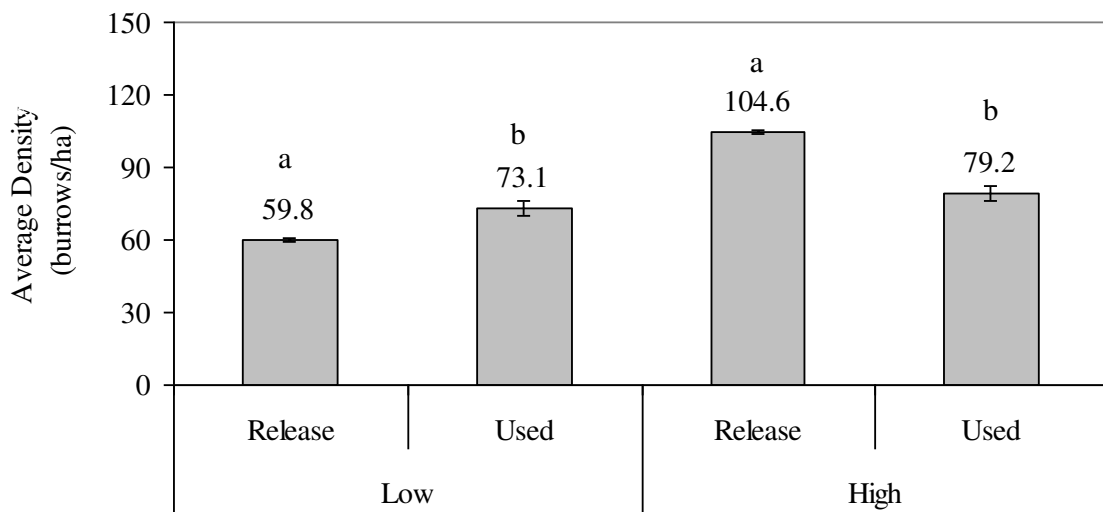
Figure 4. Average prairie dog burrow densities (mean ± SE) at release sites for black-
footed ferrets released in "Low" (n = 25) and "High" (n = 21) burrow densities compared
to average used densities for those same ferrets, Vermejo Park Ranch, New Mexico.
2007. Within either the low or high burrow density category, different letters above bars
indicate significant differences ($P \leq 0.0003$). The same letters above "Used" bars
indicate similarities in densities (P = 0.17).

Differences in used and available burrow densities were not detected for locations

on the Drift and 00-3 colonies (Drift: n = 5, P = 0.98; 00-3: n = 6, P = 0.12), but used

densities were slightly lower than densities available on the Phoneline colony (paired t-

test, n = 35, mean of the differences = -8.6 burrows/ha ± 2.5 SE, t = -3.47, P = 0.001)

(Figure 5).
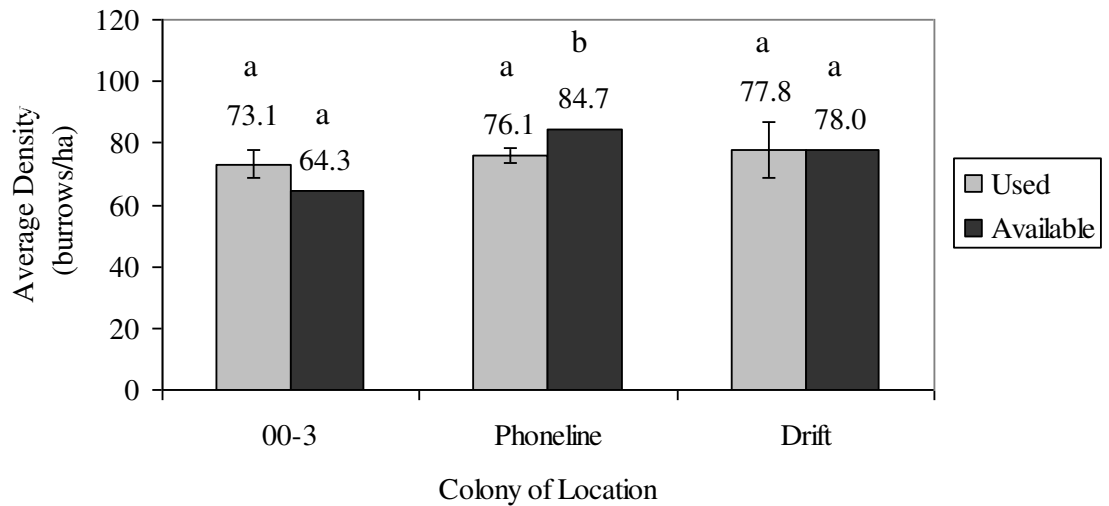
Figure 5. Average used prairie dog burrow densities (mean ± SE) for each colony on which black-footed ferrets were observed pre-translocation, and the available densities at those colonies, Vermejo Park Ranch, New Mexico, 2007. Within each colony, different letters above bars indicate significant differences ($P = 0.001$).

Because the predictions were not supported, an extended list of possible predictors (Table 2) was assessed in an attempt to gain more insight into behavior patterns (i.e., use of areas with varied prairie dog burrow densities) of newly released ferrets. The final model for all (low- and high-release combined) pre-translocation ferret-used burrow densities included only the minutes since sunset at the time of the observations (ordinary least squares model, $n = 46$, $F_{1,44} = 5.30$, $P = 0.03$, Figure 6). No other variables significantly improved the linear model of Used Burrow Densities ~ Minutes Since Sunset. Consistent with the linear model, there was a small difference in used densities before ($n = 26$, 79.6 burrows/ha ± 2.9 SE) and after ($n = 20$, 71.1 burrows/ha ± 3.1 SE) midnight (two-sample t-test, $t = 2.00$, $P = 0.05$).

No linear or quadratic predictors (Table 2) were significant for low-release ferret used burrow densities ($n = 25$, $P \geq 0.16$). The number of nights in the wild predicted

high-release ferret used burrow densities (Figure 3), but the minutes since sunset was also a significant predictor within this data set (ordinary least squares model, $n = 21$, $F_{1,19} = 5.57$, $P = 0.03$, Figure 6), although multiple variables in the same model were not mutually significant.
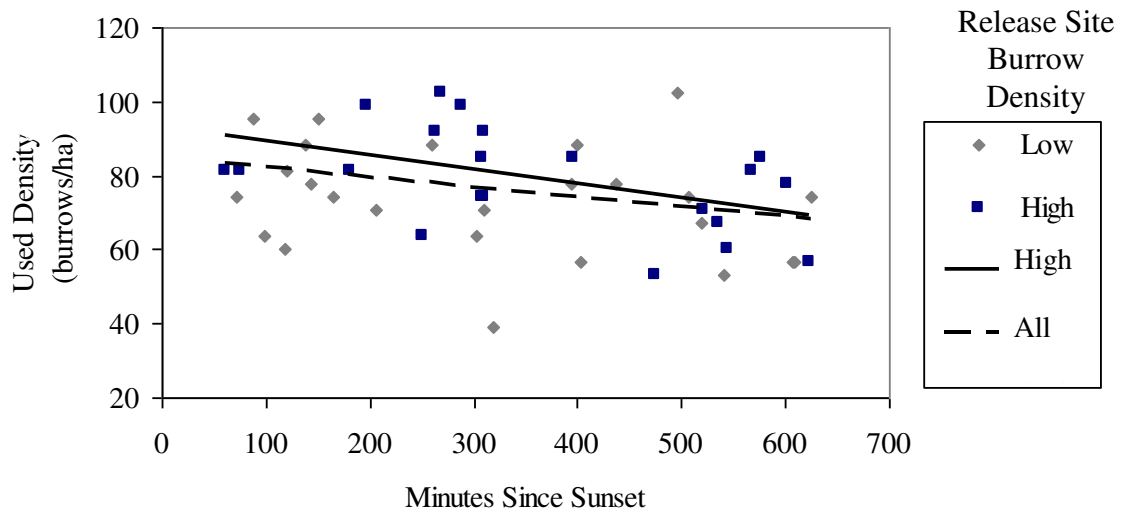
Figure 6. Relationship between the minutes since sunset of black-footed observations and used prairie dog burrow densities at locations, Vermejo Park Ranch, New Mexico, 2007 (High-release site burrow density locations: ordinary least squares model, $n = 21$, $R^2 = 0.23$, Residual SE = 12.50, $\beta_0 = 93.07 \pm 6.50$ SE, $\beta_1 = -0.04 \pm 0.02$ SE, $P = 0.03$; All locations: ordinary least squares model, $n = 46$, $R^2 = 0.11$, Residual SE = 14.06, $\beta_0 = 85.07 \pm 4.49$ SE, $\beta_1 = -0.03 \pm 0.01$ SE, $P = 0.03$).

POST-TRANSLOCATION FERRET LOCATIONS

There were 53 locations obtained for 10 ferret kits subsequent to their translocation to other colonies (Figure 7), resulting in 1,501 total mapped prairie dog burrows in the post-translocation data set (range = 35.4 – 187.5 burrows/ha at ferret-used locations, mean = 100.2 burrows/ha ± 4.3 SE). The average number of nights in the wild since the 4 September release at the time locations were obtained from post-translocation
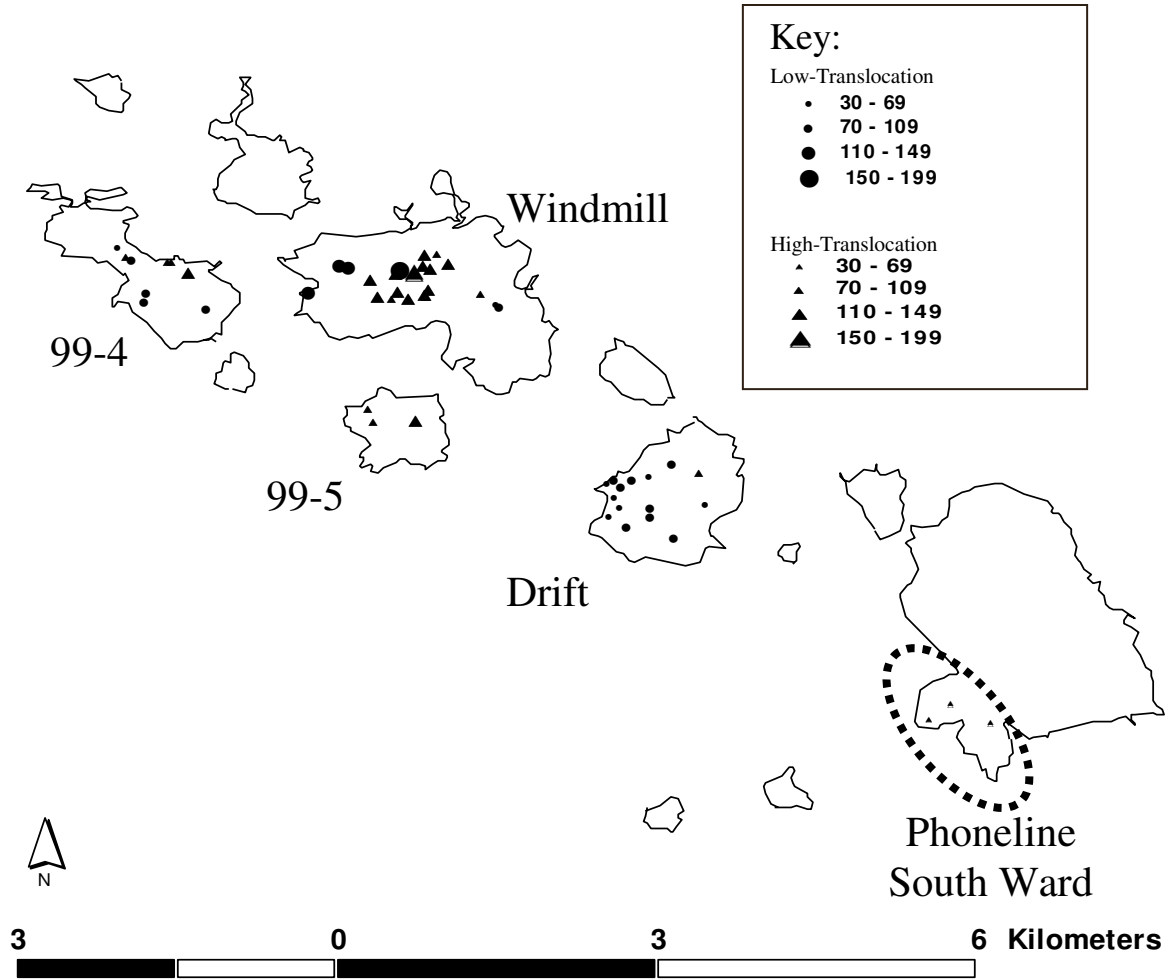
Figure 7. Five black-tailed prairie dog (*Cynomys ludovicianus*) colonies that post-translocated black-footed ferret (*Mustela nigripes*) kits inhabited, Vermejo Park Ranch, New Mexico, 2007. Phoneline South Ward is encircled with a dashed oval. Size of symbol represents the ferret-used localized burrow densities (burrows/ha) based on 0.28 ha circular plots.

kits was 47.8 nights ± 1.6 SE (range = 23 – 64 nights). Sex (Males: $n = 31$; Females: $n = 22$) was not found to be a predictor of used burrow densities ($P \geq 0.58$). Therefore, treatment groups were not separated by sex for further analyses. Locations on Phoneline South Ward were included in this data set because a ferret that was translocated to the Drift colony later dispersed to that ward.

Used burrow densities for low-translocation ferrets were inverse transformed to normalize the data and residuals, as well as enhance the ability to detect spatial autocorrelation (Czaplewski et al. 1994). Spatial autocorrelation in used burrow densities was significant for the post-translocation data set as a whole (Moran's I, $I = 0.41$, $z = 9.18$, $P < 0.0001$), as well as for both treatment groups separately (Low-Translocation: $n = 25$, $I = 0.18$, $z = 2.43$, $P = 0.02$; High-Translocation: $n = 28$, $I = 0.33$, $z = 4.82$, $P < 0.0001$). Gaussian spatial autoregressive models with only intercepts revealed that spatial dependency explained 4.5% of the variation in the used burrow densities for the data set as a whole, and 76.8% and 37.3% for low and high-translocation data, respectively, indicating that spatial autocorrelation was stronger within the data subsets than within the post-translocation data set as a whole (Lichstein et al. 2002).

Hypothesis Testing

There was no trend detected between burrow densities (translocation and used) and nights spent in the wild for the high-translocation treatment group ($n = 33$, $P = 0.67$, Figure 8). A quadratic fit was better than a linear fit within the low-translocation group, but the spatial autoregressive model was still not significant ($n = 30$, $P = 0.14$, Figure 8). The interaction between the translocation site burrow density category and the number of nights in the wild was not significant in a spatial autoregressive model ($n = 63$, Linear: P

Low-Translocation Site Burrow Density:
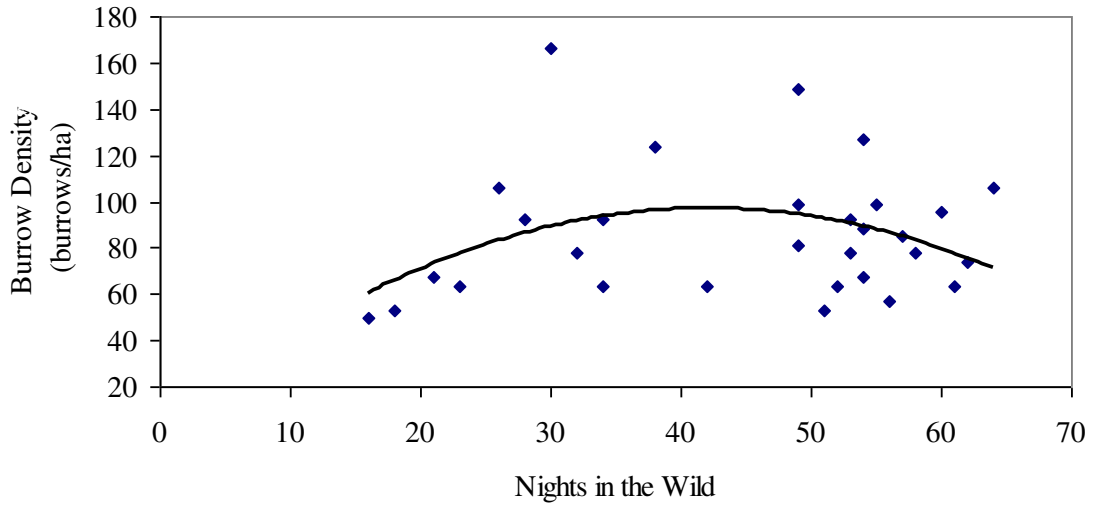
High-Translocation Site Burrow Density:
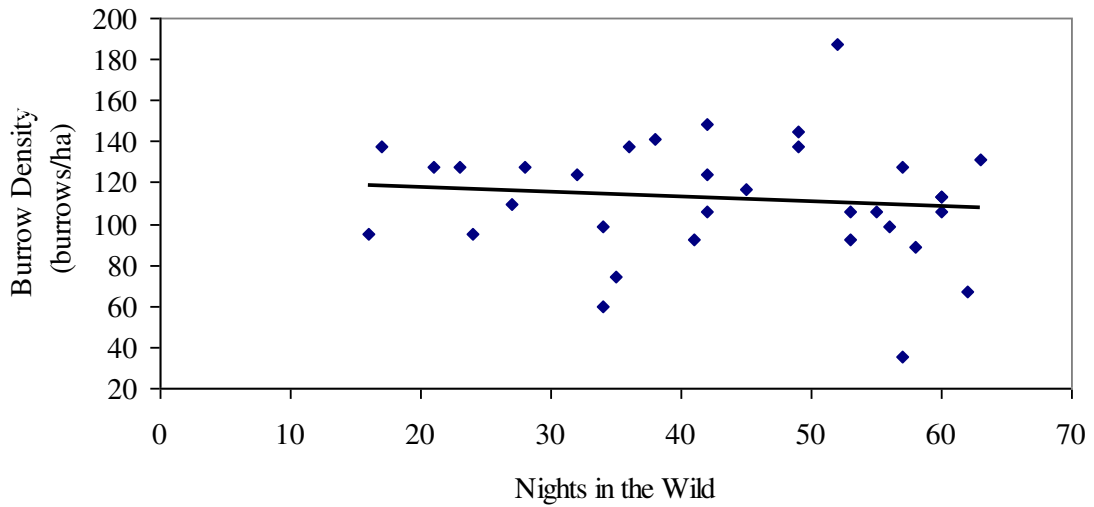
Figure 8. Relationships between the nights spent in the wild and prairie dog burrow densities of release and ferret-used locations from post-translocation black-footed ferrets at Vermejo Park Ranch, New Mexico, 2007.

= 0.07; Quadratic: $P = 0.88$, Figure 8). Neither translocation burrow densities ($n = 53$, P

= 0.12) nor the interaction between nights in the wild and translocation burrow densities

($n = 53$, $P = 0.35$) were found to be predictive of used burrow densities.

Further Analysis

The change from translocation burrow densities to ferret-used densities, which is

a conversion of the number nights in the wild into categories (0 nights in the wild vs. > 0

nights in the wild), was significant for both treatment groups (spatial paired t-tests, Low-

Translocation: $n = 25$, mean of the differences = 20.3 burrows/ha ± 5.8 SE, $t = 3.18$, $P =$

0.004; High-Translocation: $n = 28$, mean of the differences = -13.9 burrows/ha ± 4.6 SE,

$t = -2.86$, $P = 0.008$, Figure 9). The used burrow densities of high-translocation ferrets

appear higher than the used densities of low-translocation ferrets, but after accounting for

spatial autocorrelation by performing a Wilcoxon rank sum test on the residuals from a

spatial autoregressive model with intercept only, a difference was not found between

treatment groups ($n = 53$, $P = 0.86$, Figure 9). Unlike the pre-translocation data set,

minutes after sunset of observations for post-translocation ferrets did not appear to

predict post-translocation used burrow densities ($n = 53$, $P \geq 0.49$). Furthermore, time

since sunset was not found to predict used densities when pre- and post-translocation data

sets were combined ($n = 99$, $P = 0.29$).

Used and available burrow densities did not appear to differ on any colony

(colony 99-4: $n = 9$, $P = 0.08$; 99-5: $n = 3$, $P = 0.17$; Drift: $n = 15$, $P = 0.75$; Phoneline

South Ward: $n = 3$, $P = 0.20$; Windmill: $n = 23$, $P = 0.26$, Figure 10). Available prairie

dog burrow densities at the colony level predicted fine-scale used burrow densities of

post-translocation ferrets (spatial autoregressive model, $n = 53$, $F_{2,50} = 47.67$, $P = 0.0003$,

Figure 11). No other variables significantly improved the spatially-explicit linear model of Used Burrow Density ~ Available Burrow Density. The same trends were observed within low- and high-translocation treatment groups; therefore, only one model is presented.

Used burrow densities differed among colonies when tested with a spatial autoregressive model with colonies as categories ($n = 53$, $F_{5,47} = 30.07$, $P < 0.0001$); the Windmill colony ($n = 23$) had significantly higher used densities than the Phoneline South Ward ($n = 3$) (Tukey's HSD test, $P < 0.0001$), Drift ($n = 15$) ($P < 0.0001$), and 99-4 ($n = 9$) ($P = 0.0008$), while 99-5 ($n = 3$) had higher used densities than the Phoneline South Ward ($P = 0.04$) (Figure 10). Spatial autocorrelation of used burrow densities was significant within the Windmill colony (Moran's I, $n = 23$, $I = 0.21$, $z = 4.00$, $P < 0.0001$), but not within the other four colonies ($P \geq 0.16$).
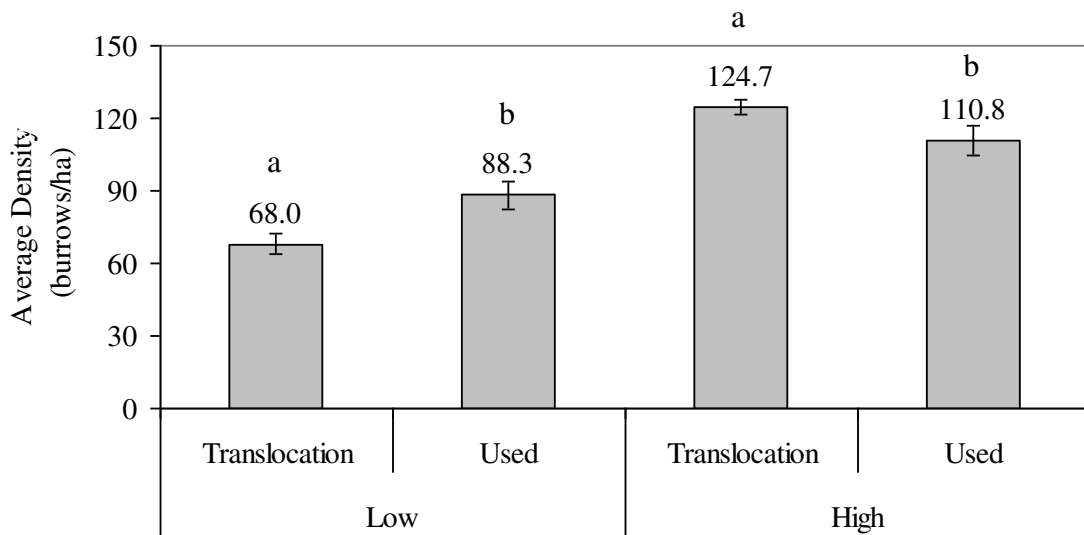
Figure 9. Average prairie dog burrow densities (mean ± SE) of the translocation sites for black-footed ferrets translocated to "Low" ($n = 25$) and "High" ($n = 28$) densities compared to average used densities for those ferrets, Vermejo Park Ranch, New Mexico, 2007. Within either the low or high burrow density category, different letters above bars indicate significant differences ($P \leq 0.008$). The same letters above "Used" bars indicate similarities in densities ($P = 0.86$).
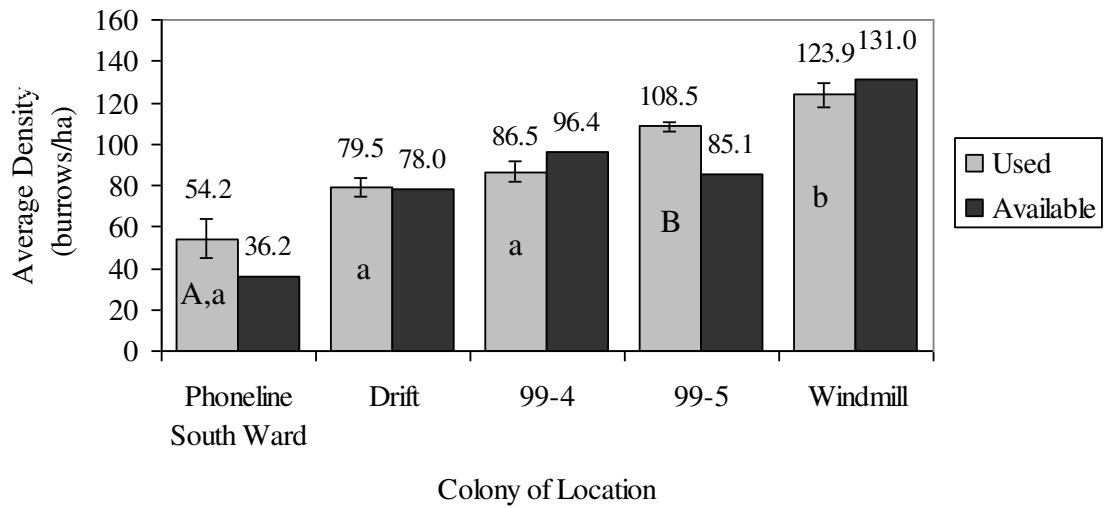
Figure 10. Average used prairie dog burrow densities (mean ± SE) for each colony on which black-footed ferrets were observed post-translocation, and the available densities at those colonies, Vermejo Park Ranch, New Mexico, 2007. There were no significant differences within colonies ($P \geq 0.08$). Among colonies, different letters within grey bars indicate significant differences in used densities, with capital and lower-case letters representing different comparisons ($P \leq 0.04$).
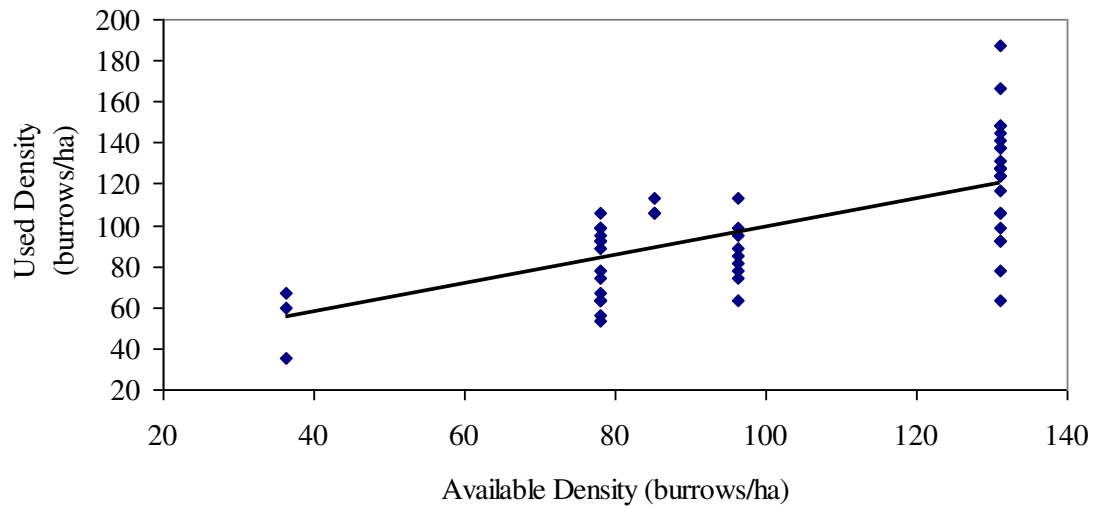
Figure 11. Relationship between available prairie dog burrow densities and used burrow densities for locations obtained from post-translocation black-footed ferrets, Vermejo Park Ranch, New Mexico, 2007 (spatial autoregressive model, $n = 53$, FIT = 0.57, Residual SE = 21.08, $\beta_0 = 30.54 \pm 18.62$ SE, $\beta_1 = 0.66 \pm 0.17$ SE, $\lambda = 0.72 \pm 0.16$ SE, $P < 0.0001$).

DISCUSSION

AVAILABLE BURROW DENSITIES AS PREDICTOR OF USED DENSITIES

Contrary to the hypotheses, captive-born black-footed ferret kits released in areas of high and low burrow densities at Vermejo Park Ranch did not appear to select the densest areas of black-tailed prairie dog burrows within a colony during two months of experience in the wild in the autumn of 2007. This is illustrated by used burrow densities declining over time for high-release ferrets (Figure 3). There was no significant trend detected over time for the used burrow densities of high-translocation ferrets, which would appear to support the hypothesis that ferrets released in high density areas would maintain high used densities. However, there was a decrease in burrow densities used, compared to release or translocation densities, for both high-release and high-translocation ferret locations when patterns over time were converted to merely release or translocation densities vs. ferret-used densities (Figures 4 and 9). While low-release and low-translocation ferret locations did not show significant patterns of increasing used burrow densities as ferrets spent more nights in the wild, used burrow densities did increase on average compared to release or translocation burrow densities when the element of time was converted to categories (Figures 4 and 9). Instead of selecting high burrow density areas, the Vermejo kits in 2007 used areas with burrow densities approximating those available on the colony that they inhabited (Figures 5 and 10). For post-translocation ferrets, every 1 burrow/ha increase in available densities resulted in an increase of 2/3 burrow/ha in used densities (Figure 11).

The one colony where used burrow densities were significantly less than available (Phoneline; Figure 5), might have had an inflated correction factor for calculating the

available density because plots used to establish the correction were on the perimeter of this 50+ year old colony, where burrow densities would be expected to change more between 2005 and 2007 than in the interior of the colony (Garrett et al. 1982, Truett et al. 2006, Yeaton and Flores-Flores 2006). Nevertheless, it is unlikely that the correction factor was exaggerated by an amount that would have masked used burrow densities higher than available densities.

It is possible that use of average burrow densities is due to available densities being greater than some threshold of prey or refugia required by ferrets (e.g., 12 active burrows/ha based on ferret energy requirements, Biggins et al. 1993; 10 burrows/ha based on observations, Forrest et al. 1985). Perhaps selection of high localized burrow densities by captive-born kits released into habitat free of conspecifics in a previous study in Montana (Biggins et al. 2006a) can be explained, at least in part, by available densities in that study being lower than those at Vermejo. However, Carlson (1993) reported captive-born ferrets using average burrow densities on white-tailed prairie dog colonies with available densities less than those at Vermejo. Furthermore, wild-born ferrets showed selection for dense burrows even within colonies of relatively high available densities (Biggins et al. 1985, Biggins et al. 2006a, Eads 2009, Jachowski 2007a, Livieri 2007) and other members of genus *Mustela* have shown selection for areas of dense prey in the wild (e.g., stoat (*M. erminea*), Cuthbert and Sommer 2002; long-tailed weasel (*M. frenata*), Gehring and Swihart 2004; European polecat (*M. putorius*), Lode 1996; least weasel (*M. nivalis*), Zub et al. 2008).

Conclusions on habitat use could be affected by the scale used for assessment (Gough and Rushton 2000, Kotliar and Wiens 1990, Wiens 1989). In this study, in which

0.28 ha plots were used to determine burrow densities, the scale seems appropriate because ferret selection for high burrow density areas has been found at 0.07 ha (Biggins et al. 2006a) and 0.64 ha (Eads 2009) scales. Selection of dense areas of white-tailed prairie dog by newly released ferrets was not found at the 1 ha scale (Carlson 1993).

There was, however, an observation of litter mixing that might suggest kit abandonment of low density release sites. After five nights in the wild, a male (5792, Table 1) and female (5793, Table 1) kit dispersed from their low burrow density release site (E, Figure 1) and were observed interacting with ferret families in the two highest density release areas (A and C, Figure 1); the male kit was following the dam at a high-release site in single file (Henderson et al. 1974). These were independent dispersals of ~1,200 and ~1,600 m, respectively, and the kits were only 83 days old, younger than the normal ~120 days of age at dispersal (Biggins et al. 1985, Vargas and Anderson 1998a). Perhaps the kits were seeking high burrow density areas. However, this speculation is confounded by the fact that their biological mother disappeared immediately after the release; it is possible that the kits left their release area seeking another adult female rather than better habitat.

A possible explanation for the use of average burrow densities by the 2007 Vermejo kits might be a need by captive-born ferrets for an adjustment period longer than two months to establish habitat preferences in the wild, or to learn their new habitat and apply innate preferences. The localized burrow densities where ferrets were observed might have trended toward average available densities by chance as ferrets explored their novel surroundings (Biggins 2006a). Perhaps monitoring this cohort of ferrets for a longer period of time would have revealed the hypothesized selection of high burrow

density areas within colonies. Furthermore, early autumn might not be the time of year in which young ferrets need high quality habitat; the breeding season has not commenced (Biggins et al. 2006e, Clark et al. 1986, Richardson et al. 1987) and, due to their age, female kits do not have dependent young. Perhaps ferret kits were adjusting to the wild throughout preconditioning at Vermejo and procuring and defending quality habitat was not vital enough during this period to override exploratory behavior (Carlson 1993). A radio-tracked female kit from a relic population displayed similar behaviors; "In October and November her behavior may have differed from that of adult females with established home ranges and presumably better hunting skills" (Biggins et al. 1986, p. 136). The Vermejo kits might have been preoccupied with performing random search patterns, as seen in other mustelids (Svendsen 2003), instead of habitat selection based on prior knowledge of their environment.

Wild preconditioning on a prairie dog colony, as performed at Vermejo, is intended to give naïve, captive-born kits time to learn wild behaviors. The 2007 kits were released at an average of 85.4 days of age; therefore, due to a presumably innate tendency to disperse shortly after release, kits did not have much time with their dams in the wild setting to learn normal behavior patterns before independence from the family unit (Vargas and Anderson 1998b). Time with dams was further reduced because most dams (5/6) at Vermejo disappeared within 11 nights of release (Appendix II).

In addition to the lack of guidance by dams during wild preconditioning, being held in cages during potentially critical stages in development (< 60 days old, Biggins et al. 1998; ~60 – 90 days for prey preference, Vargas and Anderson 1996) might have made it more difficult for kits to adjust to the prairie. Newly-released ferret kits without

38

conspecific competitors were found to select high burrow density habitats during

September – November in Montana (Biggins et al. 2006a), but 55 of the 71 ferrets in that

study had been preconditioned in quasi-natural environments before release at ~120 days

of age (Biggins et al. 1998). Only 18 of the 139 released ferrets determined by Carlson

(1993) to have used available burrow densities in the wild had been preconditioned in

outdoor pens before their release at ~120 days old (Biggins et al. 1999). The

unpredictable pattern of habitat use by Vermejo ferrets could have been due, in part, to

releasing kits that did not have prior experience in outdoor conditioning pens, thus

decreasing their chances of successful hunts (Vargas and Anderson 1998b, Vargas and

Anderson 1999), predator avoidance (Miller et al. 1990b), and survival in the wild

(Biggins et al. 1998, Biggins et al. 1999). One male kit at Vermejo was observed

attempting to capture a prairie dog by the leg (Eads et al. in press) and Vermejo ferrets

repeatedly approached idling ATVs (pers. obs.). If the kits released at Vermejo had

developed at an early age in a quasi-natural environment, perhaps the trends over time in

habitat use that were expected would have been observed. Ferret kits destined for wild

preconditioning should be placed in those closely-managed wild environments as family

groups when kits are ~60 days of age or they should have prior experience beginning at

~60 days of age in quasi-natural pen environments before their extended preconditioning

in the wild setting.

Exposure of ferrets to natural environs at an early age is optimal; however, the

constraints on time, money, and space within the black-footed ferret captive-breeding

program are genuine (Biggins et al. 2003, Biggins et al. 2006f, Clark 1994, Line 1997,

Lockhart et al. 2006) and placing ferrets in preconditioning (wild or pen) at ~90 days of

age is probably superior to no preconditioning (Biggins et al. 1998, Vargas et al. 1998). Releasing wild-born animals has been promising for ferret recovery (Biggins 2000, Biggins and Godbey 2003, Biggins et al. 2006a) and for other reintroduced species (Griffith et al. 1989), but there are currently only two populations from which excess wild-born ferrets are removed. Therefore, captive-born ferrets account for ~80% of the ferrets reintroduced each year (T.M. Livieri, Prairie Wildlife Research, pers. comm.). It may not be appropriate to classify the ferret behaviors seen at Vermejo in 2007 as "normal," especially because Vermejo kits were released at ~85 days of age whereas most kits are released into the wild at ~120 days of age, but observations at Vermejo might represent how other newly-released ferrets (often young-of-the-year and often released in autumn) with a similar history of captivity (often indoor cages until ~90 days of age) would respond to the wild.

The seven colonies and wards inhabited by ferrets in this study were within one prairie dog complex (Biggins et al. 1993) and had a range of available prairie dog burrow densities of 36.2 – 131.0 burrows/ha (Figure 10), which correlates with prairie dog densities (Appendix I). This wide range of refuge and prey densities might have implications for population dynamics of newly released ferrets. Colonies with high burrow densities could have energetic benefits for ferrets, potentially increasing survival and productivity. For example, in this study, proportionately more ferrets released in high burrow density areas were recaptured at the end of the preconditioning period than those released in low density areas (Appendix II). Unpublished data suggest a positive correlation between ferret productivity and burrow density (mentioned in Biggins et al. 2006b). Ferrets might maintain small home ranges in high quality habitat (e.g., Cuthbert

and Sommer 2002, Gehring and Swihart 2004, Jachowski 2007a). Furthermore, releasing ferrets on colonies with high burrow densities might encourage fidelity; if ferrets travel between colonies, the chance of survival likely decreases because food and refugia are scarce off-colony (Biggins et al. 1998, Biggins et al. 2006e, Forrest et al. 1988). Thus, the release of ferrets onto colonies with high available densities might increase reintroduction success.

TIME OF NIGHT AS PREDICTOR OF USED BURROW DENSITIES

Activity levels of ferrets during different diel periods have been documented, but this is the first report of differences in used burrow densities for varied times of the night. For every half-hour past sunset, burrow densities used by pre-translocation ferrets decreased by roughly one burrow/ha (Figure 6). Other studies found bimodal activity patterns, with ferret activity concentrated shortly after dark and again in the early morning hours (Biggins et al. 1986, Hillman 1968, Paunovich and Forrest 1987), while some findings emphasize only the increase in detections in the early morning (Biggins et al. 1986, Biggins 2000, Clark et al. 1986, D.A. Eads et al. unpublished data, Jachowski 2007b). It is possible that Vermejo ferrets were detected in areas of less dense burrow openings in mornings compared to evenings because they were making exploratory moves during morning hours. Also, coyotes are more active two hours after sunset than two hours before sunrise, so exploratory movement by ferrets into areas with fewer escape options in the mornings, and selection of dense refugia in the evenings, might be behaviors that decrease intraguild predation (Biggins 2000, Marcum 2003).

The pattern of decreasing used burrow densities following sunset did not hold for post-translocation ferrets at Vermejo. Perhaps exploratory moves were less important to

older kits more familiar with prairie dog colonies. Many post-translocation observations

were later in the year than pre-translocation observations; thus, it is also possible that

there is a seasonal shift away from using different densities of burrows within a night. A

wild female ferret displayed less within-night variation in activity levels as autumn

proceeded (Biggins et al. 1986); perhaps trends of within-night burrow density use of

captive-born ferrets at Vermejo mimic annual activity patterns of ferrets before the

commencement of the captive breeding program. Future studies on ferret habitat use,

especially those during late summer and early autumn, should consider Vermejo findings

when determining spotlight survey protocol, as some recommend monitoring ferrets

during peak activity times in the early morning hours (Biggins et al. 1986). Early

morning monitoring is probably still optimal for assessing ferret population sizes, but

monitoring during this time period may not detect selection of the highest quality habitat

by ferrets. Nevertheless, Eads (2009) documented within-colony selection of high

burrow density areas using data collected only after midnight. Surveys for that study

spanned June – October so within-night burrow density use in the summer might be

expected to vary from patterns seen in autumn at Vermejo. Also, Eads (2009) monitored

adult females caring for young and high quality habitat should be more essential for a

dam with a litter than for independent kits (Powell et al. 1985).

Additional studies on ferret habitat use during different periods of night are

needed. Knowledge of time ferrets allot to use of different parts of activity areas and

habitat attributes ferrets use for varied purposes (e.g., densely burrowed areas for hunting,

shrubs for scent marking, etc.) could guide when and where to study ferrets in the wild

(Barraquand and Benhamou 2008, Bright and Smithson 1997, North and Reynolds 1996).

It was not possible to determine if burrow densities where ferrets were observed reflected densities used for hunting or if they were densities in habitat that a ferret was merely traversing to reach another destination. This study might suggest hunting areas are visited earlier in the night, but, given the semi-fossorial nature of ferrets, many questions about habitat function will probably have to wait for technological advancements.

STATISTICAL CONSIDERATIONS

Spatial statistics (Cliff and Ord 1981) proved imperative for this relatively small sampling of spatially dependent data. Trends in Vermejo data that would have been deemed significant via classic statistical tests were found unconvincing after accounting for spatial autocorrelation. For example, burrow densities at translocation sites were significant predictors of used densities via an ordinary least squares model ($P < 0.0001$); however, a spatial autoregressive model revealed that much of that pattern could be attributed to spatial relationships ($P = 0.12$). Thus, standard errors were underestimated in classical models (Bonham and Reich 1999, Hoeting 2009). When geographically close locations had similar ferret-used burrow densities, each location carried less information than would truly independent locations. In this study, spatial statistics helped account for underlying trends in burrow distributions on prairie dog colonies (Jachowski et al. 2008), as well as for habits of individual ferrets so that a suite of locations from one ferret did not unduly influence the statistical outcome. Because many studies on imperiled species have small sample sizes and spatially explicit data, spatial statistics should be used to gain information while reducing Type I errors.

Some of the findings presented herein are the result of *post hoc* analyses performed after determining that the hypotheses on captive-born ferret habitat use were

not supported. Therefore, ferret use of average burrow densities by colony and the decrease in used densities over the course of a night should be interpreted with care and regarded as prompts for studies designed to explicitly test these variables of available burrow densities and time since sunset (Anderson et al. 2001). A larger sample of both ferrets and locations would also give more generality to findings.

MANAGEMENT IMPLICATIONS

Generalizations based on a single study should be limited, but because little is known about post-release habitat use by ferrets, even tentative management guidelines may be valuable. At Vermejo, newly released black-footed ferret kits without prior conditioning used average available burrow densities at the colony level during a two month period in the wild. While not negating known ferret habitat suitability models (e.g., Bevers et al. 1997, Biggins et al. 1993, Biggins et al. 2006b, Miller et al. 1988), the results of this study suggest that the colonies within a prairie dog complex on which ferrets are released might affect the success of reintroductions. If there is time and personnel, estimates of available burrow densities at the colony level should be made prior to releasing ferrets (Biggins et al. 1993). A more general assessment of colonies might involve identifying as ferret release colonies those without extensive bare ground between burrow openings because graminoids available for prairie dog consumption might be positively related to prairie dog densities (Detling 2006b, Jachowski et al. 2008). Also, younger prairie dog colonies (Detling 2006a) and colonies with potential for expansion (Garrett et al. 1982, Reading et al. 1989) tend to have a greater abundance of palatable grasses available. To manage extant colonies for greater burrow densities, supplemental prairie dogs can be translocated to colonies slated for ferret release and/or

forage can be supplied (Dullum et al. 2005, Long et al. 2006, Snell and Hlavachick 1980, Truett and Savage 1998, Truett et al. 2001, Truett et al. 2006).

Competition among ferrets for high burrow density areas was not apparent in this study, but it was a factor in other ferret releases (Biggins et al. 2006a); perhaps the technique of dispersing release sites on Vermejo colonies decreased competitive interactions. Because burrow densities at ferret release sites were not found to predict used densities, it might be more important to separate individual ferret release sites than to release many ferrets together in particularly high burrow density areas. However, releasing ferrets in areas with high localized burrow densities is still recommended whenever possible because survival tended to be greater for Vermejo ferrets released in such areas (Appendix II). Captive-born animals should be given as many advantages as possible while they acclimate to the wild and it is clear that more studies are necessary to understand the process of adjustment for reintroduced black-footed ferrets.

CONCLUSION

The process of habitat selection might be different for captive-born individuals adjusting to a natural environment than for wild-born animals (Morell 2008). It is important in all reintroduction efforts to determine how animals behave upon release into native habitat and establish ways to facilitate the transition to maximize survival and productivity. While it is inappropriate to generalize the specific results from this study of one cohort of ferrets in one year at one site, it is apparent that monitoring the behavior of animals that are being returned to the wild, during the time of year that releases typically happen and with the stock of animals typically released, is relevant to the recovery of all

reintroduced species. Learning how to ease the process of reintroduction for endangered

animals should be considered a recovery goal (Biggins et al. 2006f).

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APPENDIX I: ASSUMPTIONS

Several assumptions had to be considered to appropriately analyze and interpret ferret burrow density use. Program R version 2.8.1 (Ihaka and Gentleman 1996) was used for analyses of these assumptions.

PATCHINESS OF BURROWS

In order for habitat selection to occur, resources must be patchy (Biggins et al. 2006a). An index of dispersion (ID = variance/mean; Cliff and Ord 1981) was calculated to verify that burrows were aggregated at the scale of the response variable (0.28 ha). For the 99 ferret-used locations collectively, ID = 8.71 and the confidence interval, with a probability of committing a Type I error (α) set at 0.05, was (0.74, 1.30). Because the ID was greater than the upper confidence limit (UCL), burrows were judged to be aggregated.

Separate indices were calculated for each colony or ward inhabited by ferrets to ensure that varied burrow densities on different colonies was not the only reason for the significance of the universal ID. By colony, the ID was significant for colony 99-4 *(n =* 9, ID = 2.50, UCL = 2.19), Drift (*n* = 20, ID = 3.99, UCL = 1.73), Phoneline (*n* = 35, ID = 2.84, UCL = 1.53), Phoneline South Ward (*n* = 3, ID = 5.15, UCL = 3.69, and Windmill (*n* = 23, ID = 6.37, UCL = 1.67). Colonies 99-5 (*n* = 3 from one ferret translocated to this colony, ID = 0.15, confidence interval (CI) = (0.03, 3.69)) and 00-3 (*n*

= 6 from one ferret that dispersed to this colony from the Phoneline, ID = 1.76, CI = (0.17, 2.57)) did not have significant burrow clumping, but also had few ferret-used locations; it is assumed that resources were patchily distributed on these colonies based on results for other colonies, many with larger sample sizes.

STATIC BURROW DENSITY OVER SHORT TIME SPANS

To check the assumption that the density of prairie dog burrows on the colonies in this study did not change over the duration of the ferret monitoring season, burrows within seven 1-ha control plots were mapped during 5 – 8 September and 7 – 9 November 2008, near the beginning and end of the 4 September – 6 November 2007 season. Plots were distributed over five prairie dog colonies occupied by ferrets with the two colonies > 400 ha in size assigned two control plots each (Figure 12). Random GPS coordinates were generated to designate the northwest corner of each plot. Plots were delineated in the field with pin flags. Burrows within each plot were mapped using the GPS. Corners of plots were also mapped. Densities of burrows from the two mapping sessions did not appear to differ (paired t-test, $P = 0.78$), suggesting that change in ferret-used densities over time would not be due to a change in available burrow densities.

CORRELATION BETWEEN BURROWS AND PRAIRIE DOGS

While the correlation between burrow densities and prairie dog populations may not be exact or universal (Menkens et al. 1988, Powell et al. 1994, Severson and Plumb 1998), it has been found to be statistically significant in some cases (Biggins et al. 1993, Biggins et al. 2006b, Johnson and Collinge 2004). It is intuitive that careful application of methodology should give a correlation between the abundance of burrows and prairie
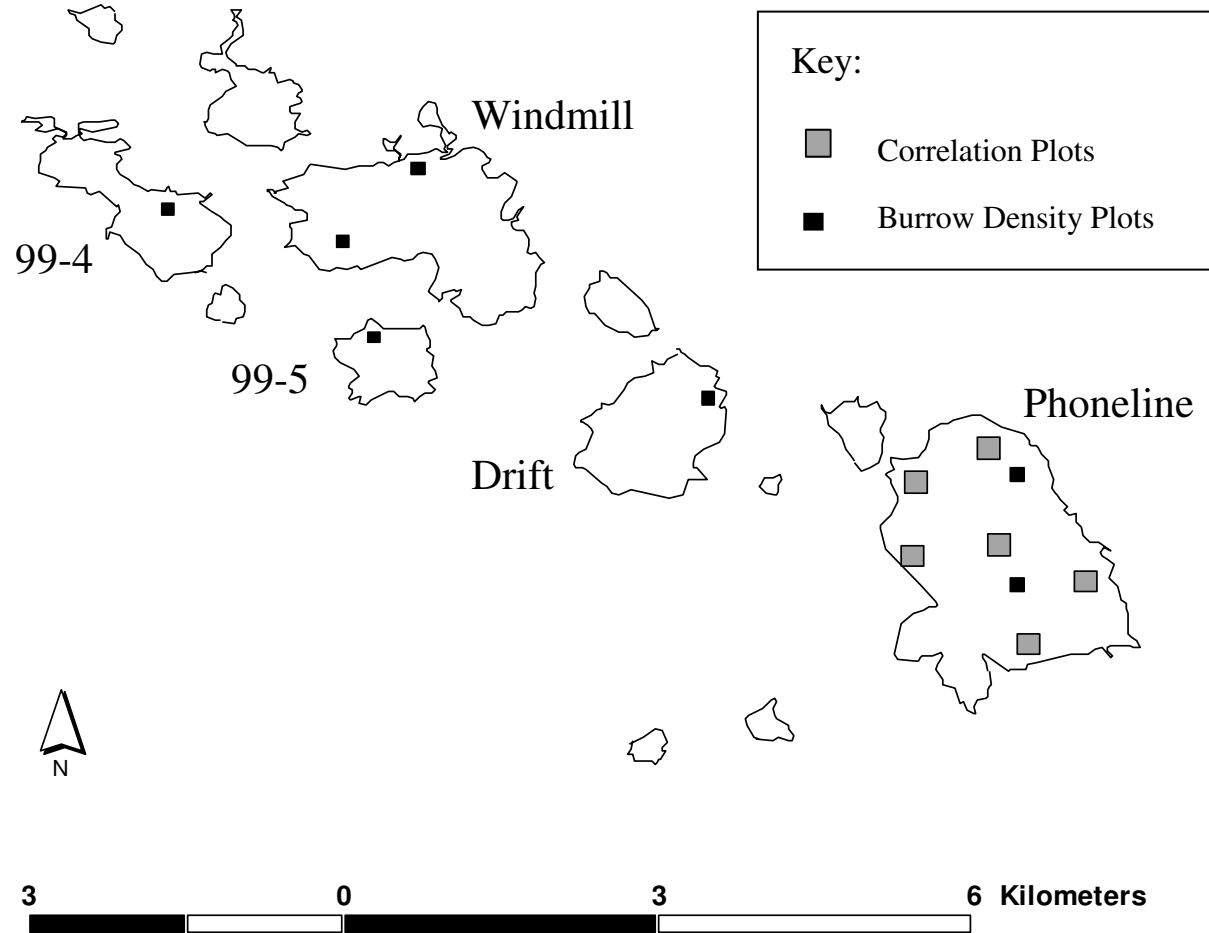
Figure 12. Plots to assess assumptions of correlation between black-tailed prairie dogs (*Cynoymys ludovicianus*) and their burrows (6 4-ha plots on Phoneline colony, counted in 2007) and static burrow density over time (7 1-ha plots on 99-4, 99-5, Drift, Phoneline, and Windmill colonies, counted in 2008), Vermejo Park Ranch, New Mexico.

dogs. However, this intuition is countered by the knowledge that prairie dogs use

multiple burrows, burrows have multiple entrances, and burrows can be shared between

family members (Biggins et al. 2006d, Hoogland 1995, Merriam 1902). Furthermore,

prairie dog populations vary seasonally and annually (e.g., Biggins et al. 2006d, Forrest et

al. 1985, Menkens et al. 1988), while total burrow densities tend to be relatively static

(Biggins et al. 2006d, Jachowski et al. 2008). Therefore, it is preferable to assess each

site for relationships based on local factors. The assumption that burrow densities are a

surrogate for prey (i.e., prairie dog) densities at Vermejo was checked by computing the

correlation between mapped prairie dog burrows and aboveground prairie dogs counted

at six 4-ha plots on the Phoneline colony (Figure 12).

The six plots used in this analysis were described in "Pre-Translocation Ferret

Locations," above. Burrow mapping at the 4-ha scale was conducted 4 – 8 August for

five plots and on 2 September for plot E. Aboveground prairie dogs were counted 23 –

24 and 27 – 31 August. Plots were marked with pin flags and mapped.

Visual counts of aboveground prairie dogs were performed in morning hours

under conditions of low wind and no precipitation. The observer arrived ~0700 h and

waited 30 minutes before commencing counts (Powell et al. 1994, Severson and Plumb

1998). To further minimize disturbance, observation locations were a minimum of 59 m

(mean = 64.1 m ± 1.9 SE) from the nearest plot boundary (Adams et al. 1987, Magle et

al. 2005). Counts were conducted from the bed of a mini-truck using a tripod and 9x

binocular (Leupold® RXB™ IV digital laser rangefinder). Each plot was counted 5 – 6

times in increments of 30 minutes for one morning by slowly scanning the plot from one

side to the other. Maximum counts (Fagerstone and Biggins 1986, Knowles 1986,

Severson and Plumb 1998), with an observability correction of + 33% (Biggins et al. 2006d), were used. A positive relationship between densities of burrows and prairie dogs was found (ordinary least squares model, $n = 6$, $F_{1,4} = 18.77$, $P = 0.01$, Figure 13) and, given the connection between robust measures of population size and counts of aboveground prairie dogs (Facka et al. 2008, Fagerstone and Biggins 1986, Knowles 1986, Menkens et al. 1990, Severson and Plumb 1998), burrow densities seem a reasonable surrogate for prey densities at Vermejo in 2007.
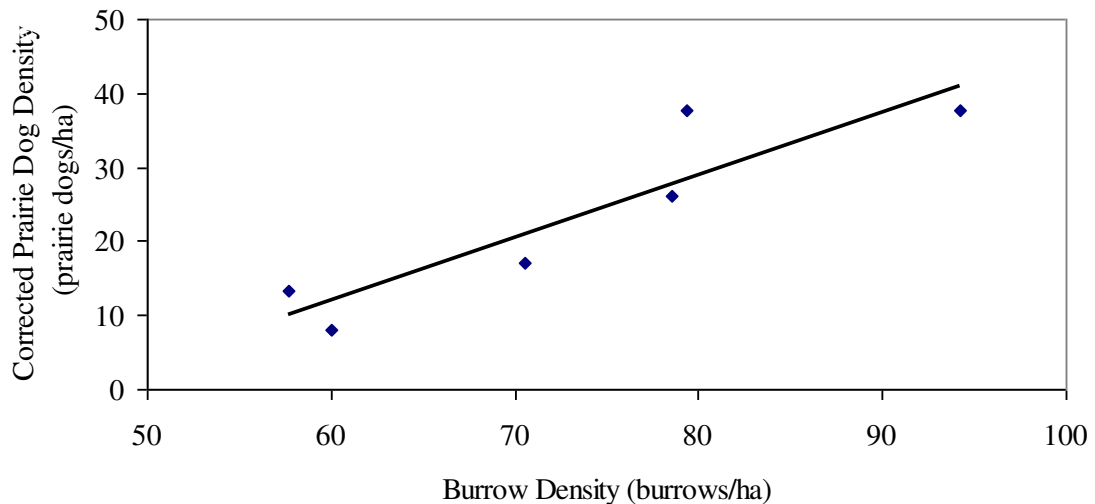

Figure 13. Correlation between black-tailed prairie dog (*Cynomys ludovicianus*) burrows and aboveground prairie dogs counted on six 4-ha plots on the Phoneline colony at the Vermejo Park Ranch, New Mexico, 2007 (ordinary least squares model, $n = 6$, $R^2 = 0.82$, Residual SE = 4.45, $\beta_0 = -28.81 \pm 10.84$ SE, $\beta_1 = 0.63 \pm 0.15$ SE, $P = 0.01$).

INDEPENDENCE OF FERRET LOCATIONS

Because of the small numbers of ferrets released during reintroductions (Biggins et al. 2006e, Breck et al. 2006; 26 in this study), and the even smaller numbers that survive beyond the first few weeks in the wild (Biggins et al. 2006e, Breck et al. 2006, Vargas et al. 1998; 15 in this study), sample sizes in studies of newly released ferrets are

minimal. Furthermore, it is difficult to obtain adequate re-sampling on semi-fossorial ferrets when they do not have predictable home ranges. Repeated measures mixed models require large data sets to be reliable. However, further knowledge about ferret ecology post-release is needed; therefore, to learn more about trends in habitat use, the number of ferret-used locations rather than the number of ferrets was used as the sample size in this study. Reasoning for this approach, and safeguards employed, are below.

Biological Independence

It is appropriate to acknowledge that two locations obtained from the same animal are inherently related (e.g., Aebischer et al. 1993, Baghli and Verhagen 2005, Goodrich and Buskirk 1998, Powell 1987, Tracey et al. 2005), but some researchers classify locations from an animal that has gone through an activity cycle between observations as independent (Lair 1987, Minta 1992, Swihart and Slade 1985). Because only one location per ferret was collected per night, ferrets were certain to have gone through a day-night activity cycle between consecutive logged locations.

Furthermore, two locations can be considered biologically independent if an animal is theoretically able to move the length of its home range (Burt 1943) between observations (Lair 1987, Powell 1987, Swihart and Slade 1985, White and Garrot 1990). Liberal estimates of ferret home ranges are ~75 and ~150 ha for females and males, respectively (Biggins et al. 1985, Forrest et al. 1985, Jachowski 2007a, Livieri 2007, Richardson 1986), and Biggins et al. (1999) observed 19 ferrets travel > 7 km, and eight travel > 15 km, in a single night; thus ferrets can easily traverse their entire home range between nightly observations.

Temporal Independence

An equation for time to independence (TTI) for carnivores (Swihart et al. 1988; TTI=196*m$^{0.49}$, where "m" indicates mass in kg) was utilized to estimate a reasonable time separation between locations that could be assumed to be independent. A ferret mass of 1 kg was assumed (Anderson et al. 1986, Fortenbery 1972), resulting in a minimum of 196 minutes (3.3 hours) between independent locations. Because ferrets are nocturnal, 196 minutes of darkness (based on sunset and sunrise times determined for Maxwell, New Mexico by U.S. Naval Observatory) between observation times were required for temporal independence. There were no sequential locations within a data set that were obtained from the same ferret that were not separated by at least 3.3 hours of darkness (minimum = 5.0 hours, mean = 81.9 hours ± 9.1 SE).

APPENDIX II: SURVIVAL

A Fisher's exact test compared survival of ferret kits initially released in high vs. low burrow density areas (Table 1). Survival was indicated by a ferret being recaptured at the end of the two month preconditioning period (4 September – 6 November 2007) (Table 1), and the probability of detecting ferrets that are present is < 1.0 (Biggins et al. 2006c).

Of the 20 ferret kits released, 9/10 released with their families in high burrow density areas survived the two-month preconditioning period, while only 5/10 released in low burrow density areas survived (one-sided Fischer's exact test, $n = 20$, odds ratio = 0.13, $P = 0.07$). The high-release kit that disappeared (Table 1) did so after 13 nights in the wild. The five low-release kits that were not recovered (Table 1) disappeared after 4 – 17 nights in the wild. As in other ferret releases (Biggins et al. 2006e), adults at Vermejo disappeared sooner and in higher proportions than kits; 5/6 dams had disappeared within 11 nights. The only dam that survived the preconditioning period was the one released in the highest localized burrow density.

APPENDIX III: FERRET USE OF PRAIRIE DOG DENSITIES

Black-footed ferrets have a similar body mass as their prey; therefore, it was hypothesized that hunting of smaller juvenile prairie dogs would be advantageous and might be evolutionarily selected for in ferret populations. To address this hypothesis, two questions were asked: (1) Do captive-born ferret kits use areas of higher than average densities of juvenile prairie dogs? (2) Do captive-born ferret kits use areas with relatively high densities of prairie dogs regardless of prairie dog age class?

A small subset ($n = 10$ locations from seven kits, 8 – 25 September 2007) of ferret locations in the pre-translocation data set were within three plots where prairie dog locations had been mapped 29 June – 2 July 2007. These plots, all on the Phoneline colony, ranged in size from 9.1 – 15.4 ha (mean = 12.1 ha ± 1.8 SE). Methods for counting aboveground prairie dogs are described in "Correlation Between Burrows and Prairie Dogs" in Appendix I. In addition to counting the prairie dogs, 9x binoculars with a digital rangefinder and compass were used to map locations of individual prairie dogs via distance and angle measurements combined with trigonometric formulas (D.A. Eads, J.G. Chipault, D.E. Biggins, J.J. Millspaugh, in prep). Also, age class (juvenile or adult) of prairie dogs was noted. In GIS, the juvenile and adult prairie dogs located within a 30 m radius of ferret-used locations were counted. Available juvenile and adult prairie dog densities were obtained by locating five random points within corresponding count plots for each ferret location; a plot with a 30-m radius was created around each random

point and the adult and juvenile prairie dogs within resulting 0.28 ha plots were counted. Because of biases associated with prairie dog count data (e.g., observer disturbance causing prairie dogs near the observer to remain underground and observer visual limitations resulting in prairie dogs at greater distances from the observer to be undetected), the number of prairie dogs counted was adjusted using a new technique in which the distance between the observer and a prairie dog counted indicates the adjustment factor (D.A. Eads, J.G. Chipault, D.E. Biggins, J.J. Millspaugh, in prep) (Table 3). Because 0.28 ha circular plots without any prairie dogs could not be adjusted, six such available plots were removed from the data set. Portions of plots beyond 300 m from the observer were also removed from the data set because adjustment factors at great distances were large. Paired Student's t-tests and Wilcoxon signed rank tests were used to compare ferret-used densities of juvenile, adult and total prairie dogs to average densities available on the count plot.

Prairie dogs of both age classes separately, and collectively, were significantly clumped at the 0.28 ha scale used for assessment ($n = 44$, ID > 25.8, CI with $\alpha = 0.05$ is (0.62, 1.46), Appendix I). Prairie dog productivity was high in 2007 (J.G. Chipault, unpublished data) and available juvenile prairie dog densities were greater than available adult densities ($n = 44$, $W = 1586.5$, $P < 0.0001$, Figure 14). There were no significant differences detected between ferret-used densities and available densities of total prairie dogs ($n = 10$, $P = 0.06$), adult prairie dogs ($P = 0.41$), nor juvenile prairie dogs ($P = 0.09$) (Figure 14). However, when only prairie dogs within 270 m of the observer (Table 3) were included in analyses in order to avoid the use of adjustment factors ≥ 20, there were significant differences in used and available adult ($n = 10$, mean of the differences = 21.9

prairie dogs/ha ± 8.4 SE, $t = 2.59$, $P = 0.03$) and total ($n = 10$, mean of the differences = 47.8 prairie dogs/ha ± 19.0 SE, $t = 2.51$, $P = 0.04$) prairie dog densities (Figure 14).

The assessment of the use of prairie dog densities by ferrets at Vermejo in 2007 was not a *post hoc* idea, but should be considered a pilot study to prompt further research because the data set is not sufficient and the adjustment factors (Table 3) based on data collected in South Dakota might not be accurate for Vermejo data. Furthermore, prairie dogs were mapped in late June and early July, while ferrets selected locations in September; it is not certain that the distribution of prairie dogs at the 0.28 ha level remained static during this 2 – 3 month lapse. Distributions of prairie dogs change more rapidly than burrow distributions (Hoogland 1995, Martin et al. 1984), and burrow densities used in the main text of this thesis were mapped within four days of ferret occupation. The lack of selection for juvenile prairie dogs specifically is not surprising because ferrets were released in September, thus prairie dogs born the previous spring would be close to adult mass. However, because selection of high densities of prairie dogs was suggested in this pilot study, it is possible that the use of prairie dog densities, instead of burrow densities, provides a stronger evaluation of ferret habitat selection. Further assessment of newly-released ferret use of prairie dog densities and age classes is necessary. In future studies, ferrets should be released closer to the time of juvenile prairie dog emergence and the mapping of prairie dogs, and prairie dog count adjustment factors should be determined at the site at which they are being applied.

Table 3. Adjustment factors used for prairie dogs (*Cynomys ludovicianus*) counted at varied distances from the observer in order to adjust for observer disturbance to nearby prairie dogs within the count plot and observer visual limitations at longer distances. Adjustments were calculated by D.E. Biggins (U.S. Geological Survey) from unpublished data obtained by D.A. Eads (Colorado State University) at Conata Basin, South Dakota.

Distance from Observer (m)	Adjustment Factor
0-10	19.35
10-20	17.41
20-30	9.67
30-40	6.66
40-50	3.79
50-60	3.29
60-70	2.39
70-80	1.87
80-90	1.45
90-100	1.49
100-110	1.13
110-120	1.20
120-130	1.00
130-140	1.09
140-150	1.11
150-160	1.25
160-170	1.33
170-180	1.43
180-190	1.70
190-200	1.85
200-210	2.36
210-220	3.12
220-230	3.45
230-240	5.39
240-250	6.20
250-260	8.04
260-270	12.40
270-280	20.46
280-290	23.46
290-300	32.31

(A)
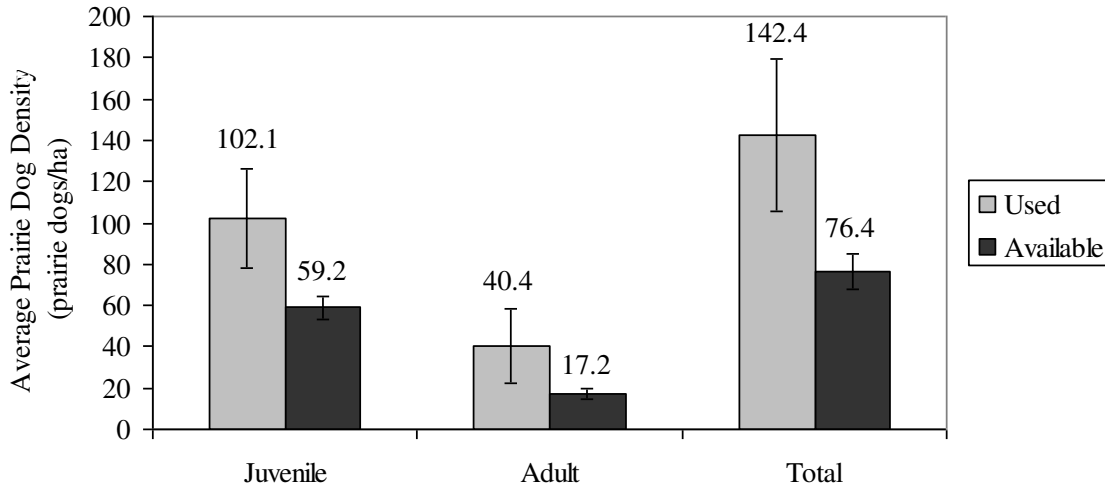
(B)
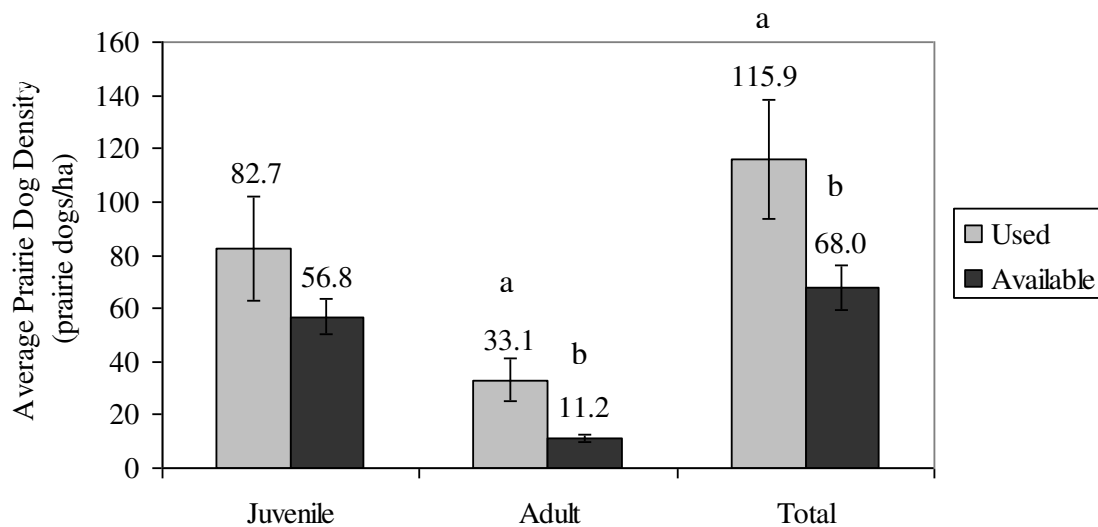

Figure 14. Average used prairie dog (*Cynomys ludovicianus*) densities (mean ± SE) obtained from prairie dog count plots on which black-footed ferret kits (*Mustela nigripes*) were observed pre-translocation, and the available prairie dog densities on those plots, Vermejo Park Ranch, New Mexico, 2007. There were no significant differences ($P \geq$ 0.06) in used and available prairie dog densities within prairie dog categories when prairie dogs within 300 m of the observer were included in analyses (A), however significant differences ($P \leq 0.04$) were found when only prairie dogs within 270 m of the observer were included (B). Different letters above bars indicate significant differences.