



Black-Tailed Prairie Dog Monitoring at Scotts Bluff National Monument

A Comprehensive Report 1995-2009

Natural Resource Technical Report NPS/HTLN/NRTR—2010/309



ON THE COVER

Black-tailed prairie dog (*Cynomys ludovicianus*)

Photo from The Heartland Inventory and Monitoring Network and Prairie Cluster Prototype

Black-Tailed Prairie Dog Monitoring at Scotts Bluff National Monument

A Comprehensive Report 1995-2009

Natural Resource Technical Report NPS/HTLN/NRTR—2010/309

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Executive Summary

Three black-tailed prairie dog (*Cynomys ludovicianus*) colonies have been in existence at Scotts Bluff National Monument, Nebraska, for some period since 1981: (1) The Main Colony was initially established in the northwest corner of the monument in 1981 by dispersers from outside the monument, and has persisted continuously. (2) The North Colony, first observed in 2002 and still in existence, is near the Main Colony, but separated by an irrigation canal. (3) The Saddle Rock Colony, located in the east-central area of the park, was first observed in 2002 and disappeared between the 2007 and 2008 visits. The Main Colony was monitored for 15 consecutive years (1995-2009) using consistent methodologies outlined by Plumb et al. (2001), to measure area occupied and to estimate density and total population size. The North and Saddle Rock Colonies have been monitored since 2004. Additional estimates of these population parameters obtained by other techniques between 1983 and 1995 for the Main Colony are also included here, although the estimates may not be directly comparable. From colonization in 1981, the Main Colony grew to 303 individuals by 1987, despite treatments with reproduction-inhibiting drugs and removal of individuals. The Main Colony declined rapidly from 1987 to 1989, and then declined generally more slowly to 1995. The Main Colony grew at an exponential rate from 1995 to 2003, increasing from 17 to almost 800 individuals. From 2003 to 2009, the Main Colony was highly variable, declining to 147 individuals in 2007, before rebounding to almost 700 individuals in 2009. Area occupied by the Main Colony revealed patterns similar to total estimated population size. The North Colony, surrounded on all sides by barriers to expansion, grew rapidly from 2002 to 2004, occupying a large proportion of the entire habitable area and reaching an estimated population size of >160 by 2004. The colony has varied in area occupied and population size since 2004. In 2008 and 2009, several individuals and active burrows were observed on neighboring private lands. The Saddle Rock Colony generally increased in area occupied and estimated population size from discovery in 2002 until 2007, before mysteriously disappearing between the 2007 and 2008 surveys. Illegal poisoning is the most likely reason for its sudden disappearance. Density varied greatly over time for all colonies. The overall prairie dog population at Scotts Bluff National Monument is relatively small and occupies only a small portion of the monument (i.e., 1.45% of the monument's 698-ha of grassland). Although the prairie dog is known as a keystone species of grassland ecosystems, the Scotts Bluff population is not large enough to produce this aspect of community structure and function. Moreover, small population sizes generally increase susceptibility to random demographic events that may result in inbreeding depression or extinction. Mowing and burning treatments have been shown to have significant positive effects on colony expansion and could be employed to increase area occupied and total population size. Prairie dog colonies may also be re-established through translocations. The North Colony, surrounded by obstacles to expansion, represents an excellent source of colonists for such translocations.

Acknowledgments

We would like to thank the staff at Scotts Bluff National Monument for assisting us with this monitoring, especially Bob Manasek for setting up observation stands and monitoring for the presence of sylvatic plague throughout the year. We would also like to thank the Northern Great Plains Network, especially John Wrede for assisting us with setting up observation stands and counting prairie dog numbers, and in general supporting this methodology and monitoring protocol. Special thanks to Glenn Plumb for helpful comments on this report.

Introduction

Background

Black-tailed prairie dogs (*Cynomys ludovicianus*)—hereafter simply “prairie dogs”—once inhabited hundreds of thousands of km² of the Great Plains from Canada to Mexico, and may have numbered close to 5 billion (Sidle et al. 2001, Knowles et al. 2002, Hoogland 2006a). Contention exists over the historical numbers, largely due to politics concerned with agricultural interests (Miller et al. 2007). Regardless of which figures are accepted, it is clear that prairie dogs now inhabit only a small fraction of their original range, possibly <0.5% (Proctor et al. 2006).

The dramatic decline in prairie dog habitat and abundance is the result of changing land use patterns, habitat fragmentation, disease, shooting, and poisoning (U.S. Fish and Wildlife Service 2000). Sylvatic plague (*Yersinia pestis*), introduced from Europe and first identified in prairie dog populations in the mid-1930's (Hubbard 1947), is capable of causing massive die-offs (Barnes 1993, Cully 1993). In addition, eradication of prairie dogs on both private and public lands at the expense of the landowner has been required at times in most states (Desmond et al. 2000). This requirement for eradication of prairie dogs was relaxed in some states in 2000, when the United States Fish and Wildlife Service ruled the species warranted listing as threatened under the Endangered Species Act (U.S. Fish and Wildlife Service 2000). Prairie dogs have since been removed as a candidate for protection (U.S. Fish and Wildlife Service 2004), and widespread shooting and poisoning of prairie dogs continues. During the 4 ½ years that prairie dogs were listed as a threatened species, however, considerable effort and resources were invested by federal, state and tribal agencies, private landowners, and conservation organizations to better understand the status of the species and design and implement conservation strategies to reduce threats.

Prairie dogs have many ecological interactions with both vertebrates and invertebrates, and have been documented as keystone species (Miller et al. 1994, 2007, Kotliar et al. 2006, Davidson and Lightfoot 2007). Species dependent on the prairie dog for food or habitat include the burrowing owl (*Athene cunicularia*), mountain plover (*Charadrius montana*), swift fox (*Vulpes velox*) and ferruginous hawk (*Buteo regalis*) (National Wildlife Federation 2000, Aschwandten 2001). These species are candidates or potential candidates for listing as threatened under the Endangered Species Act. Once believed to be the most endangered mammal in North America, the black-footed ferret (*Mustela nigripes*) is completely dependent on the prairie dog for survival (National Wildlife Federation 2000, Aschwandten 2001). Prairie dogs have additionally been termed a “foundation” species, which is a species that infers significant and unique effects on an ecosystem due to mere abundance (such as effects on nutrient cycling and soil chemistry; Kotliar et al. 2006). Conservation and restoration of Great Plains ecosystems are not possible without the preservation of prairie dogs.

Federal lands offer much potential for the conservation of prairie dogs, and many of the largest colonies now in existence are located on federal property (Sidle et al. 2006). Concerns for the recovery of the black-footed ferret have prompted state and federal agencies, including the National Park Service, to identify lands within the historic range of the prairie dog that still host prairie dog populations, and to monitor these populations as potential reintroduction sites for the

ferret. Eight of the 30 national parks or monuments within the historic range of the prairie dog still have active colonies (Badlands National Park, SD; Bent's Old Fort National Historic Site, CO; Devil's Tower National Monument, WY; Fort Larned National Historic Site, KS; Sand Creek Massacre National Historic Site, CO; Scotts Bluff National Monument, NE; Theodore Roosevelt National Park, ND; and Wind Cave National Park, SD). Concern for the recovery of the prairie dog has given an even greater impetus to monitoring their populations.

Objectives

Here we document the dynamics of the prairie dog population at Scotts Bluff National Monument, Nebraska, (hereafter SCBL) spanning a period of 29 years beginning with colonization of the monument in 1981. The objectives of this monitoring have been: 1) to estimate prairie dog population abundance; 2) to map the size and location of prairie dog colonies; and 3) to determine through observation if sylvatic plague is present in any of the prairie dog colonies.

Methods

History of Prairie Dogs at Scotts Bluff National Monument

Prairie dogs, native to SCBL, were exterminated from the monument in 1944. Prairie dogs naturally recolonized the northwest corner of the monument in 1981. Nebraska state law at the time required that prairie dogs be controlled, and in 1984 the colony was treated with diethylstilbestrol (a synthetic estrogen that reduces reproduction). Individuals were “removed” from the colony in 1985, 1986, 1987, and 1988 (Franklin 1984, Cox and Franklin 1989). The last documented control efforts occurred in 1988, and the state law requiring control was repealed in 1995.

Estimates of population parameters (area occupied, density, and total population size) were obtained from 1983 to 1993 by a variety of techniques and investigators (Franklin 1983, 1984; Cox and Franklin 1989; Scotts Bluff National Monument personnel, unpublished data). (Estimates of area occupied and density were not obtained in all years; no data were obtained in 1992.) Although methods were not well documented, mark-recapture techniques were employed in 1983 and 1984 (Franklin 1984), and in 1986 “a census was conducted by live-trapping nearly all individuals from July through August” (Cox and Franklin 1989, p. 3-4).

From 1995-1999, prairie dog populations were monitored through a joint effort of the Heartland Inventory and Monitoring Network (formerly the Prairie Cluster Prototype Long-Term Ecological Monitoring Program) and the Northern Prairie Wildlife Research Center, Biological Resources Division of the United States Geological Survey. A peer-reviewed monitoring protocol was the result of this endeavor (Plumb et al. 2001). From 2000-2009, prairie dog populations were monitored by the Heartland Inventory and Monitoring Network with the assistance of monument personnel. Although the data collected prior to 1995 may not be directly comparable to that collected from 1995 onward, the pre-1995 population estimates are informative for describing relatively robust changes over time.

Estimating Prairie Dog Density and Population Size

Three prairie dog colonies are or have been in existence at SCBL since 1981 (Fig. 1): (1) The Main Colony was initially established in the northwest corner of the monument in 1981 and has persisted continuously. (2) The North Colony, first observed in 2002 and still in existence, is near the Main Colony, but separated by an irrigation canal. (3) The Saddle Rock Colony, located in the east-central area of the park, was first observed in 2002 and disappeared between the 2007 and 2008 visits.

The methods of measuring area occupied and estimating prairie dog density and total population size are detailed in Plumb et al. (2001), with modifications described. Briefly, visual counts were made of individuals across each colony, regardless of colony size. Plumb et al. (2001) detail counting prairie dogs on plots 4 ha or smaller. However, the shape of the colonies at SCBL prohibited us from obtaining representative population counts on fixed 4 ha plots. Therefore, visual counts were taken of individuals across entire colonies, even if a colony was >4

ha. Eight replicate counts, with 15-minute intervals between the start of each replicate, were made from each observation point. Counts were conducted on three consecutive days when possible, always between the end of June and the first of August. Using landscape features, sections of the colony were defined for survey from each observation point in an effort to minimize counting individuals twice during a replicate. Observation points were located in eastern, central, and southern locations of the colony to best facilitate the observation of prairie dogs (see Fig 1). Counts from each observation point were synchronized so that a colony-wide estimate could be derived. Daily replicate counts from each observation point were combined to calculate estimates of population density and population size. Surveys were conducted between 6:30am – 9:00am on mornings with little or no precipitation. Population surveys of the North and Saddle Rock Colonies were conducted concurrently with the Main Colony counts. Visual counts of the North and Saddle Rock Colonies were begun in 2004.

Using combined visual count data, prairie dog density and population size were estimated for each colony. Estimated density (P) was derived from the linear transformation described by Severson and Plumb (1998), who determined in a study in the Conata Basin in South Dakota that a linear model using the maximum visual count gave the most precise estimate of prairie dog densities as determined by mark-recapture techniques:

$$Y = 0.40X + 3.04; F = 40.18, r^2 = 64.6, P < 0.0001, n = 24.$$

Where Y is the estimated prairie dog density determined by mark-recapture, and X is the maximum visual count (maximum number counted in any one trial over a 3-day period).

Severson and Plumb (1998) state that the inverse of this model, $X = (Y - 3.04)/(0.40)$, could be used to index prairie dog densities under conditions similar to those encountered in their study. They calculated a 95% confidence band around their linear model to indicate the uncertainty involved with this linear transformation.

The official protocol (Plumb et al. 2001) used this relationship obtained from Severson and Plumb (1998) to estimate density and total population size:

$$\text{Density (P)} = [(Y / Sp) - 3.04] / 0.40,$$

where Y is the maximum count of individuals in a replicate over the three day survey period and Sp is the total area sampled.

$$\text{Population size (T)} = (Sc)(P),$$

where Sc is the total colony size in hectares and P the estimated density per hectare.

In addition to these point estimates, Plumb et al. (2001) also provided estimates of variance for density and population size, and formulas to estimate 95% confidence intervals, based on the variability in the data in Severson and Plumb (1998). The inference is that years with overlapping confidence limits are not considered significantly different.

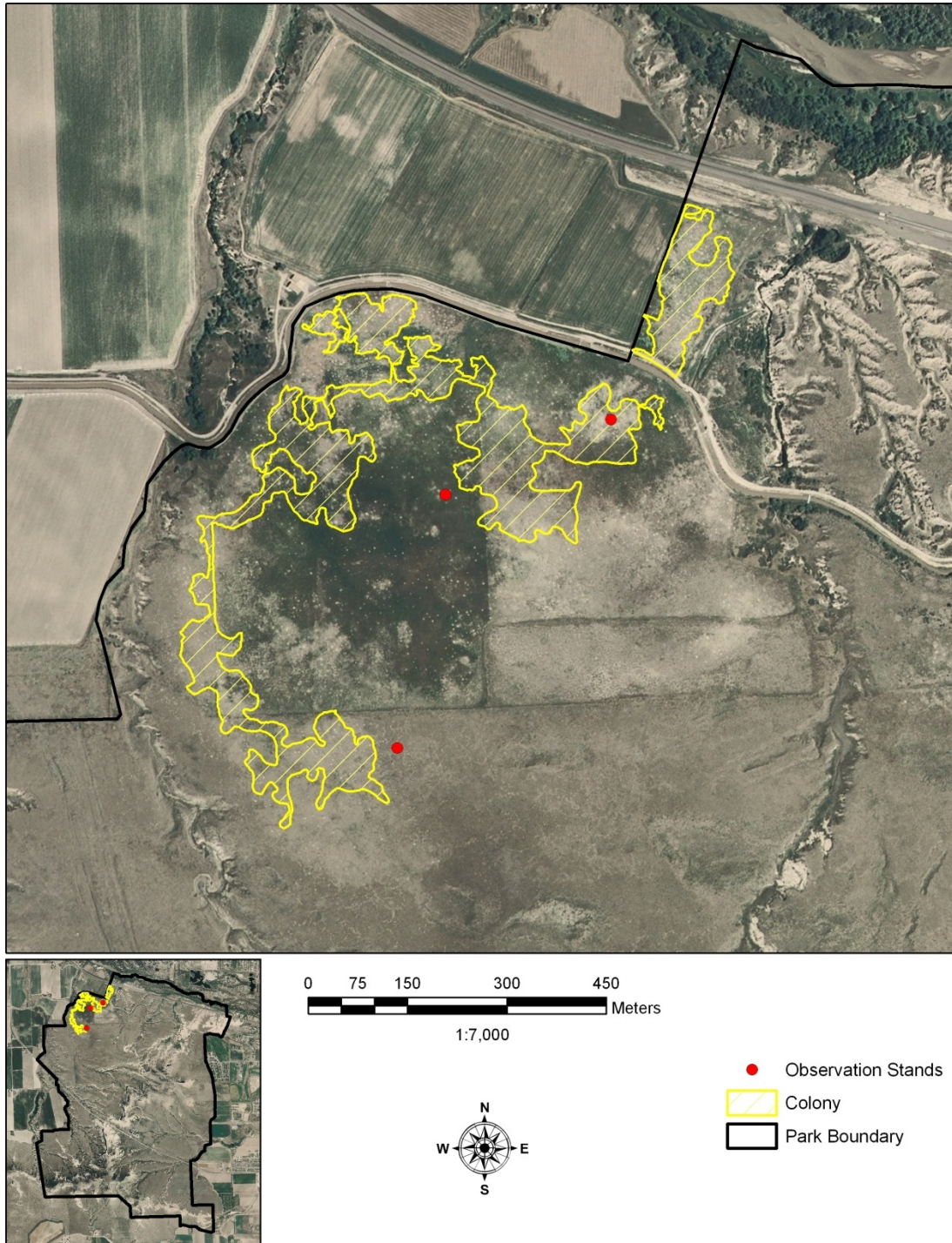


Figure 1. Area occupied by black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument in 2009.

Prairie Dog Colony Mapping

Boundaries of prairie dog colonies were delineated using a Global Positioning System (GPS) in conjunction with a PC-based Geographic Information System, ArcGISv.9TM. Colony boundaries were determined by following active clip lines when discernable or mapping the area within five meters of active burrows when it was not. Burrows were classified as active if burrow openings were greater than 7 cm in diameter and fresh scat was observed within 0.5 m of the opening. Burrows were not classified as active if there were spider webs across an opening or unclipped vegetation growing in or around the opening (Biggins et. al. 1993, Desmond et. al. 2000). Colored pin flags were used to mark the perimeter of each colony prior to GPS mapping. Boundaries were walked in their entirety to close each colony polygon.

Sylvatic Plague Surveillance

Park personnel monitored for sylvatic plague within the prairie dog colonies at SCBL throughout each year from 1995-2009 using a low intensity surveillance approach. Prairie dogs are highly susceptible to plague, and mortality in infected colonies usually approaches 100% (Cully et al. 2006 and references therein). Park staff visited each colony several times throughout the year to determine if significant die-offs had occurred. A population die-off between 2007 and 2008 in the Saddle Rock colony was the only one judged to be suspicious, and subsequent testing of fleas (carriers of the bacterium responsible for sylvatic plague) was undertaken on this colony and the main colony. Fleas were collected from prairie dog burrows by NPS personnel, and sent to South Dakota State University for analysis.

Environmental Correlates of Population Parameters

An exploratory analysis was conducted to evaluate the potential effects of precipitation and temperature on area occupied, estimated density, and estimated population size. Four predictor variables were used: (1) cumulative precipitation in the growing season immediately preceding sampling (April 1 – June 30), (2) cumulative precipitation in the summer of the preceding year (June 1- Sept 30), (3) cumulative growing degree days in the growing season immediately preceding sampling (April 1 – June 30), and (4) cumulative growing degree days in the late spring and summer of the preceding year (May 1- Sept 30). Simple linear regressions were employed for each pair of predictor and response variables listed above.

Data were obtained from the National Weather Service station 257665 at the Scotts Bluff, Nebraska regional airport. Growing degree days were determined in relation to temperatures for generalized growth of plants on which the prairie dogs may be feeding. The minimum temperature for this growth was chosen to be 41°F, and the maximum temperature 86°F. The growing degree days for a 24-hour period were calculated based on the following formula:

Growing degree days (GDD) = ((maximum temperature + minimum temperature)/2) -base temperature (41°F)

Minimum temperatures less than 41°F were set to 41°F, and maximum temperatures greater than 86°F were set to 86°F; this assumes that no appreciable growth occurred at temperatures <41°F or >86°F. If the average temperature was ≤ the base temperature, no degree days were accumulated.

Analyses were not conducted for the whole data series. Attempts were made to cull the population up until 1988. The sharp decline from 1987 to 1989 and the period of very low population abundance extending to 1995 may have been due to the sylvatic plague. At the least, an unusually dry or cold year would not be responsible for such prolonged effects. The very close fit of an exponential growth function to area occupied and estimated population size documented from 1995 to 2003 (see results) indicates the colony was growing at a rate proportional to the previous year's size, with little variability that could be due to inter-annual climatic changes. Thus, only the years 2003-2009 were evaluated for the response variables area occupied and estimated population size for the Main Colony. It is possible that climate affected density during the period of exponential increase in area occupied and population size. Thus, separate analyses were conducted for the response variable density in the Main Colony, for the years 2003-2009, and for the years 1995-2009. Density estimates were not usually available prior to 1995 (Table 1). Similar analyses using the same predictor and response variables were conducted for the North colony for the years 2004-2009.

Results

Prairie Dog Density and Population Size

Main Colony

The area occupied, estimated density, and estimated population size of the Main Colony from 1983-1994 are given in Table 1 and incorporated into Figures 2-4. The Main Colony was the only colony in existence during this period, although it was fragmented in the early 1980s and then coalesced (Franklin 1984, Franklin and Cox 1989).

Table 1. Area occupied, estimated density, and estimated population size of prairie dogs at Scotts Bluff National Monument – Main Colony, between colony reestablishment in 1981 and 1994. Sources of annual data are indicated.

Year	Area (ha)	Density (individuals/ha)	Population Size	Source
1981			Colony Reestablishment in Scotts Bluff National Monument	
1982	--	--	--	None
1983	1.0	76.5	75	Franklin 1984
1984	1.3	30.5	40	Franklin 1984
1985	--	--	107	Cox and Franklin 1989
1986	5.8	34.7	200	Cox and Franklin 1989
1987	5.1	58.9	303	Cox and Franklin 1989
1988	3.4	64.6	219	Cox and Franklin 1989
1989	--	--	62	Monument Personnel unpub.
1990	--	--	62	Monument Personnel unpub.
1991	--	--	27	Monument Personnel unpub.
1992	--	--	--	None
1993	--	--	45	Monument Personnel unpub.
1994	--	--	--	None

Results of monitoring the Main Colony at SCBL between 1995 and 2009 are given in Table 2 and Figures 2-4. Estimates of population size reveal four periods of changing dynamics (Fig. 2): (1) From colonization in 1981, the colony grew to 303 individuals in 1987. (2) The population declined rapidly from 1987 to 1989, and then declined generally more slowly to 1995. (3) The population grew at an exponential rate from 1995 to 2003, increasing from 17 to almost 800 individuals. (This represents a doubling time of almost 1.5 years.) An exponential function fit the data very closely, and better than a linear one ($R^2 = 0.91$, $F = 70.33$, $P < 0.001$; $R^2 = 0.71$, $F = 17.44$, $P = 0.004$; respectively). (4) From 2003 to 2009, the population was highly variable, declining to 147 individuals in 2007, before rebounding to almost 700 individuals in 2009.

The area occupied exhibited similar overall patterns to those of estimated population size (Fig. 3). Although fewer data points are available before 1995, an increase in area is evident from colonization to 1986, and then a decrease through the implementation of the current monitoring protocol. The area occupied increased dramatically from 1995 to 2004, and an exponential function fit the data (slightly) better than a linear one ($R^2 = 0.93$, $F = 112.98$, $P < 0.001$; $R^2 = 0.87$, $F = 54.07$, $P < 0.001$; respectively). The area occupied declined after 2004. Area occupied was positively correlated with estimated population size from 1995–2009 ($R^2 = 0.37$, $F = 7.50$, $P = 0.017$).

Table 2. Area occupied, estimated density (95% CI) and estimated population size (95% CI) of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument - Main Colony.

Year	Area (ha)	Density (individuals/ha)	Population Size
1995	1.4	12.0 (-4.0/28.1)	16.9 (0.9/32.8)
1996	1.4	53.1 (33.9/72.3)	74.4 (50.8/98)
1997	2.6	28.9 (12.7/45.2)	75.2 (51.5/99)
1998	3.3	22.7 (6.7/38.7)	74.9 (51.2/98.6)
1999	10.5	16.7 (0.8/32.6)	175.2 (124.1/226.3)
2000	16.2	9.2 (-7.0/25.4)	149.4 (105.8/193)
2001	10.9	23.4 (7.4/39.3)	254.7 (179.7/329.6)
2002	20	19.0 (3.1-35)	380.5 (267.2/493.8)
2003	25.2	31.1 (14.7/47.5)	783.4 (545.8/1020.1)
2004	36.2	14.1 (-1.9/30.1)	517.4 (362/673)
2005	14.9	45 (27/62.8)	671.2 (468.3/874.1)
2006	20.6	20.31 (4.4/36.2)	418.4 (29.4/543.4)
2007	18.1	8.1 (-8.1/24.4)	147.2 (104.2/190.2)
2008	9.3	44.5 (26.6/62.3)	412.1 (289/535.1)
2009	10.1	68.9 (46.5/91.2)	693.5 (483.7/903.3)

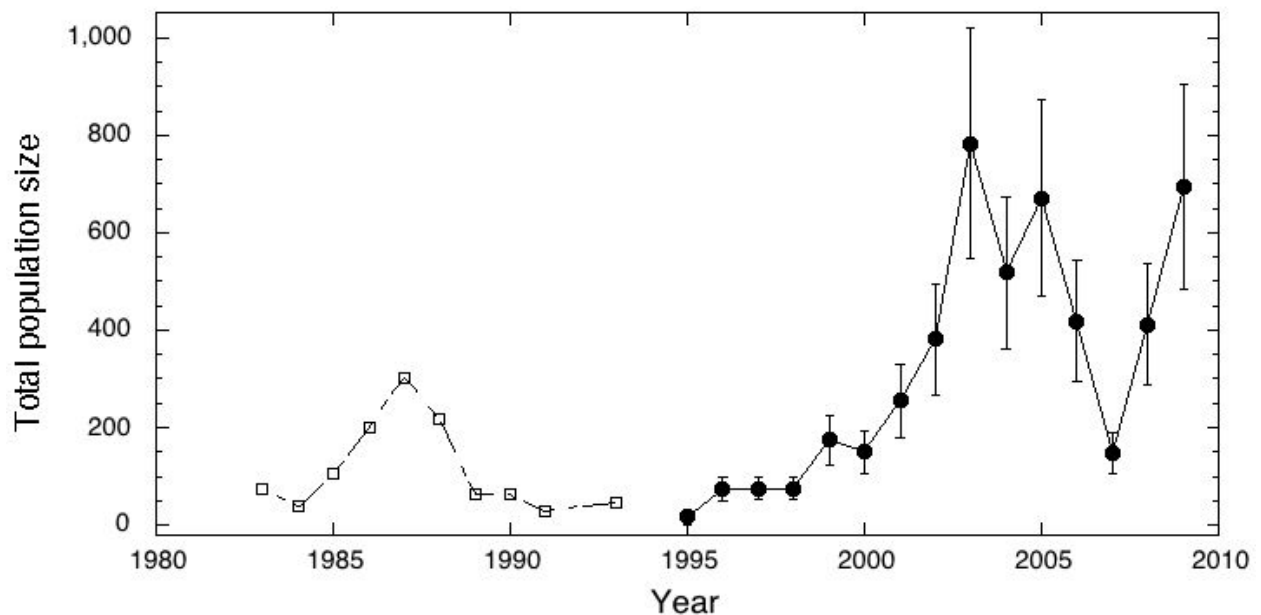


Figure 2. Estimated total population size of the Main Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Open squares represent estimates obtained before establishment of the current monitoring protocol; closed circles represent estimates obtained by that protocol. Bars represent 95% confidence intervals surrounding the point estimate.

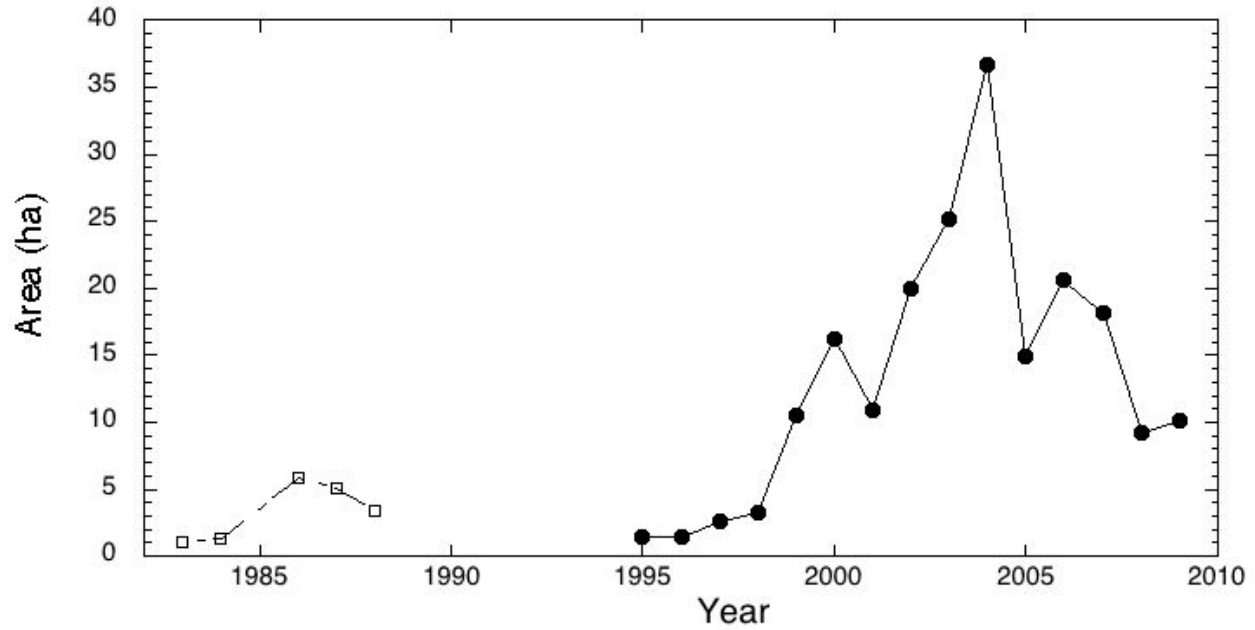


Figure 3. Area occupied by the Main Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Open squares represent estimates obtained before establishment of the current monitoring protocol; closed circles represent estimates obtained by that protocol.

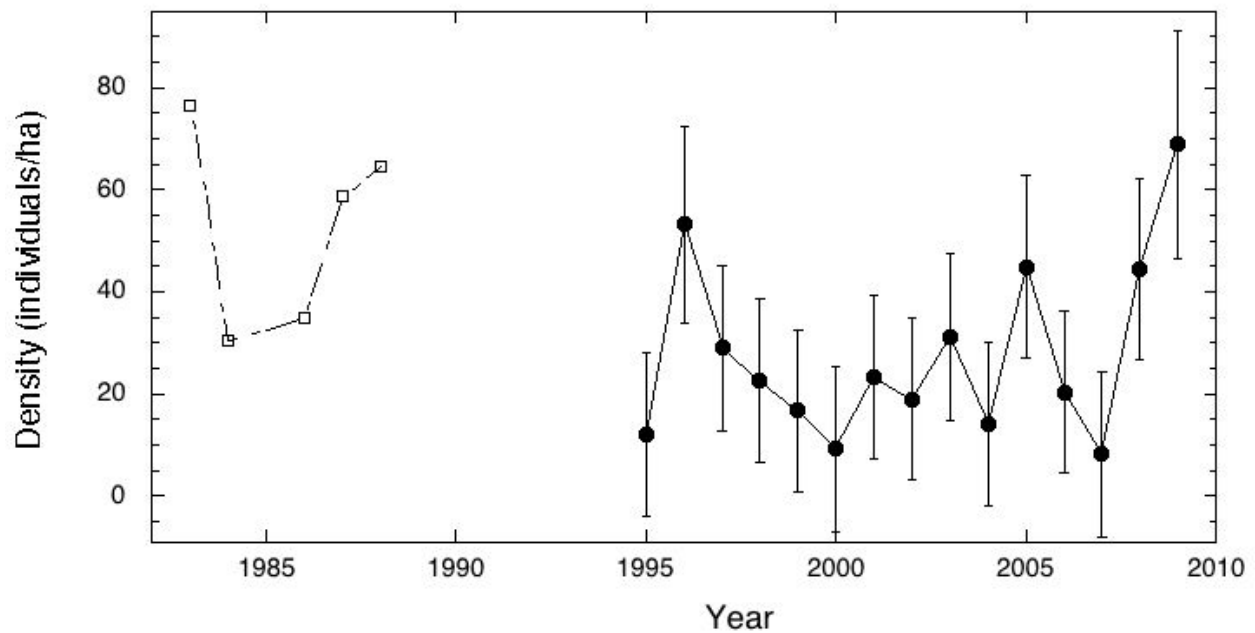


Figure 4. Estimated density of the Main Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Open squares represent estimates obtained before establishment of the current monitoring protocol; closed circles represent estimates obtained by that protocol. Bars represent 95% confidence intervals surrounding the point estimate.

Densities of prairie dogs at the Main Colony varied from 8 to almost 80 individuals per ha (Fig. 4). The magnitude of uncertainties associated with densities (when available) relative to the differences in point estimates make it difficult to distinguish systematic patterns among years, although some years clearly had higher densities than others. The peaks and troughs of patterns in estimated population size and area occupied do not match exactly due to variability in density among years. Density was not significantly correlated with either area occupied or population size for the period 1995-2009 ($P > 0.05$).

North Colony

Results of monitoring the North Colony are presented in Table 3 and Figures 5-7. The North Colony, first observed in 2002, is located across an irrigation ditch from the Main Colony, and is surrounded by obstacles to expansion. It is bordered by the irrigation ditch to the south, private cultivated land to the west, a railroad to the north, and a smaller irrigation ditch and an eroded drainage system to the east (Fig. 1). The colony when first discovered in 2002 occupied <0.1 ha, but expanded to 2.1 ha by 2004, occupying a large proportion of the entire habitable area (Fig. 5). The colony has varied greatly in area occupied since 2004, reaching a peak size of 2.5 ha in 2007 and a low of 1 ha in 2005. In 2008 and 2009, several individuals and active burrows were observed on neighboring private lands. (Individuals outside the park boundaries were not counted, nor were their burrows mapped.)

Density in the North Colony varied between 35 and 95 individuals/ha (Fig. 6), and estimated population size varied between 72 and 174 (Fig. 7) between 2004 and 2009, when these parameters were measured. These data suggest that the relatively small and restricted area available to this colony (~2.5 ha) limits the maximum population size to ~175 individuals (both observed in 2007).

Table 3. Area occupied, estimated density (95% CI), and estimated population size (95% CI) of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument - North Colony. Density and population size were not estimated in 2002 or 2003

Year	Area (ha)	Density (individuals/ha)	Population Size
2002	0.096	--	--
2003	1.716	--	--
2004	2.1	78.1 (53.7/102.5)	163 (115.4/210.6)
2005	1.0	80.9 (55.9/106.0)	77.7 (53.4/102)
2006	2.1	34.9 (18.2/51.6)	71.5 (48.6/94.4)
2007	2.5	69.4 (47/91.8)	174 (123.2/224.8)
2008	1.92	83.5 (57.8/109.3)	160.4 (113.6/207.2)
2009	1.61	94.9 (66.3/ 123.4)	152.8 (108.2/197.3)

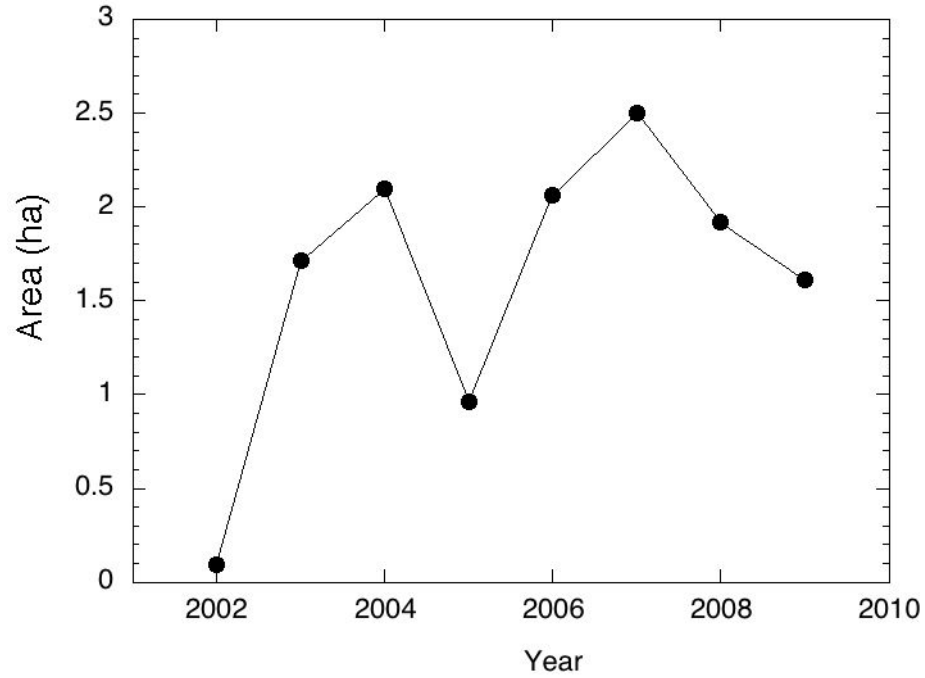


Figure 5. Area occupied by the North Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument.

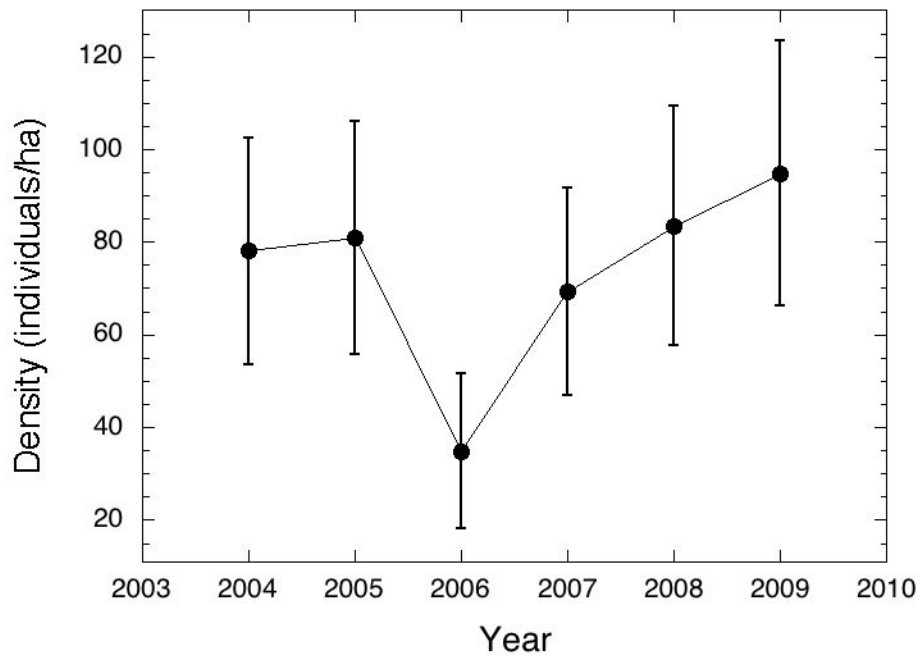


Figure 6. Estimated density of the North Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Bars represent 95% confidence intervals surrounding the point estimate.

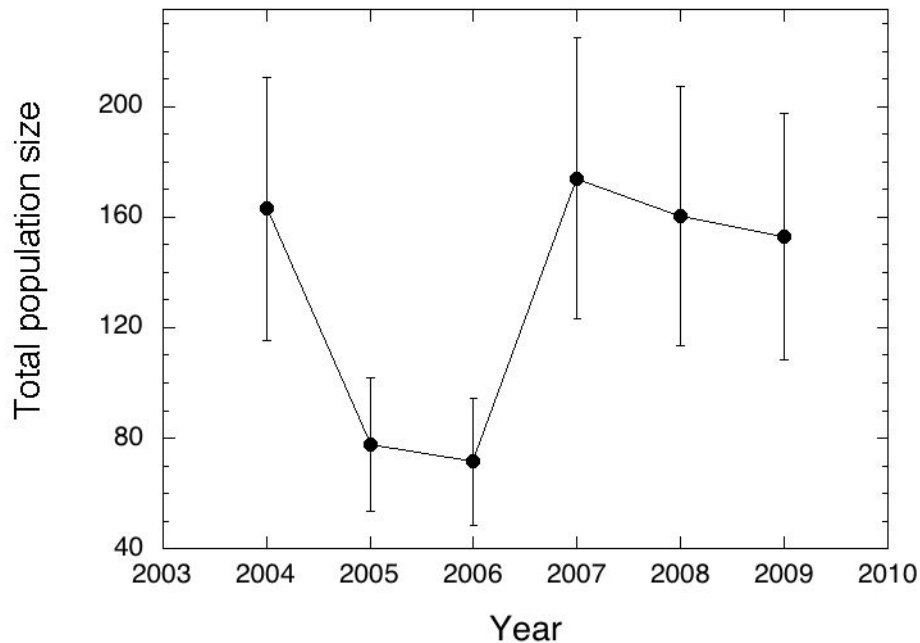


Figure 7. Estimated total population size of the North Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Bars represent 95% confidence intervals surrounding the point estimate.

Saddle Rock Colony

Results of monitoring the Saddle Rock Colony are presented in Table 4 and Figures 8-10. The Saddle Rock Colony, located near the northeastern boundary of the park, was first observed in 2002. Its distance from the Main Colony (~1 mile) and proximity to the park boundary suggest it may have been colonized by prairie dogs migrating from outside the park, although this distance is less than the average prairie dog dispersal distance of 2.4 km (Knowles 1985, Garrett and Franklin 1988). The Saddle Rock Colony grew in area occupied (Fig. 8) and estimated population size (Fig. 9) from colonization to 2007, when it reached a maximum of 3.3 ha, and 58 individuals. Although it bordered private land to the east, additional expansion was possible to the north, west, and south. Densities ranged between 13 and 109 individuals (Fig. 10), a greater range than either the Main or North Colonies, even though densities for the Saddle Rock Colony were only measured in three years (from 2004 to 2006). The Saddle Rock Colony mysteriously disappeared between the 2007 and 2008 surveys. Illegal poisoning is the most likely reason for its sudden disappearance. Boxes of rodenticide were found on the colony in the fall of 2007 (Bob Manasek, personal communication). Testing for sylvatic plague in the summer of 2008 found no evidence of the disease as a causative agent in the disappearance of this prairie dog colony.

Prairie Dog Colony Mapping

The changes in area of the Main Colony reveal interesting patterns (Fig. 11). From 1995 to 2004, during the exponential increase, the colony generally grew by expansion of the outer

boundaries. From 2004 to 2009, however, during the decrease in areal extent, prairie dogs disappeared from what had been the interior regions of the largest area occupied, resulting in multiple, fragmented sub-colonies. Maps of the Main Colony were also constructed for 1983, 1984, and 1988 (see Franklin 1984, Cox and Franklin 1989). For maps of the North Colony and Saddle Rock Colonies in previous years, see Cribbs and Peitz 2003, 2005a, 2005b, Hummel et al. 2006, Peitz and Cribbs 2007, 2008).

Table 4. Area occupied, estimated density (95% CI), and estimated population size (95% CI) of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument - Saddle Rock Colony. Density and population size were not estimated in 2002 or 2003.

Year	Area (ha)	Density (individuals/ha)	Population Size
2002	0.865	--	--
2003	1.224	--	--
2004	1.1	13.2 (-2.8 - 29.2)	14 (-1.7 - 30.3)
2005	0.3	108.7 (76.5 - 140.9)	30 (14.0 - 46.7)
2006	1.7	17.4 (1.47 - 33.3)	30 (13.3 - 45.9)
2007	3.3	17.6 (1.6 - 33.5)	58 (37.5 - 77.6)

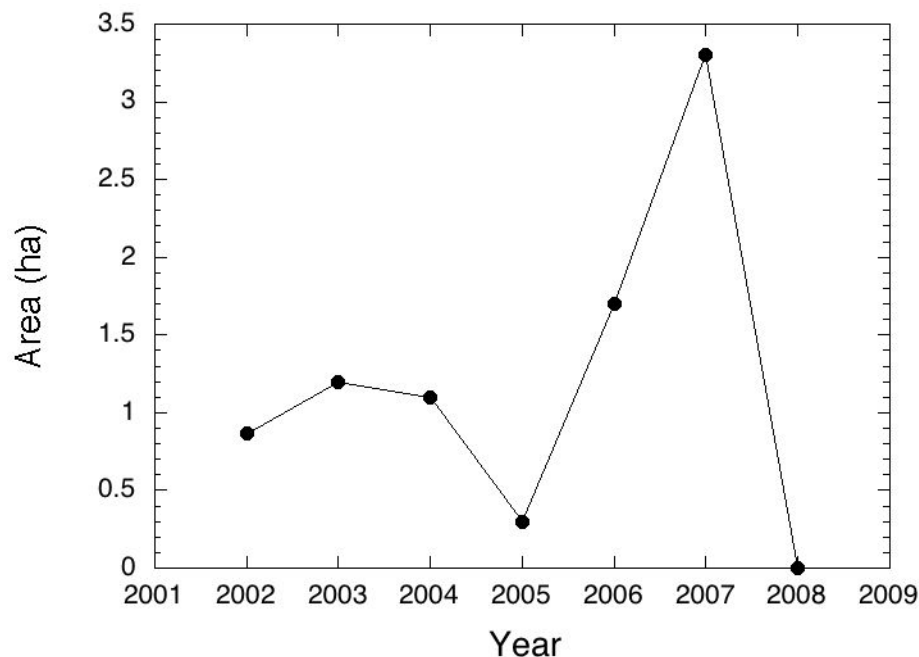


Figure 8. Area occupied by the Saddle Rock Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument.

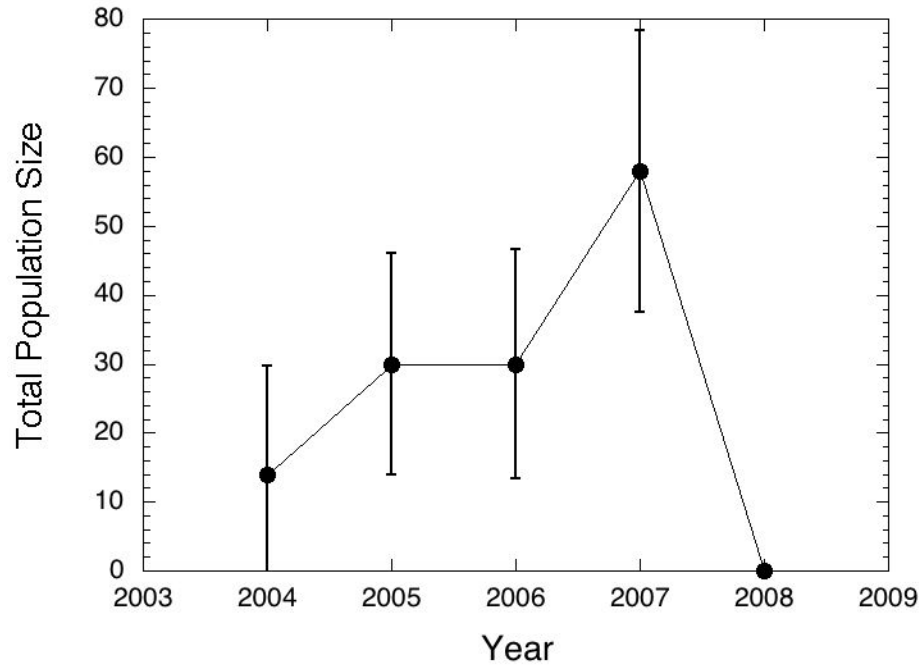


Figure 9. Estimated total population size of the Saddle Rock Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Bars represent 95% confidence intervals surrounding the point estimate.

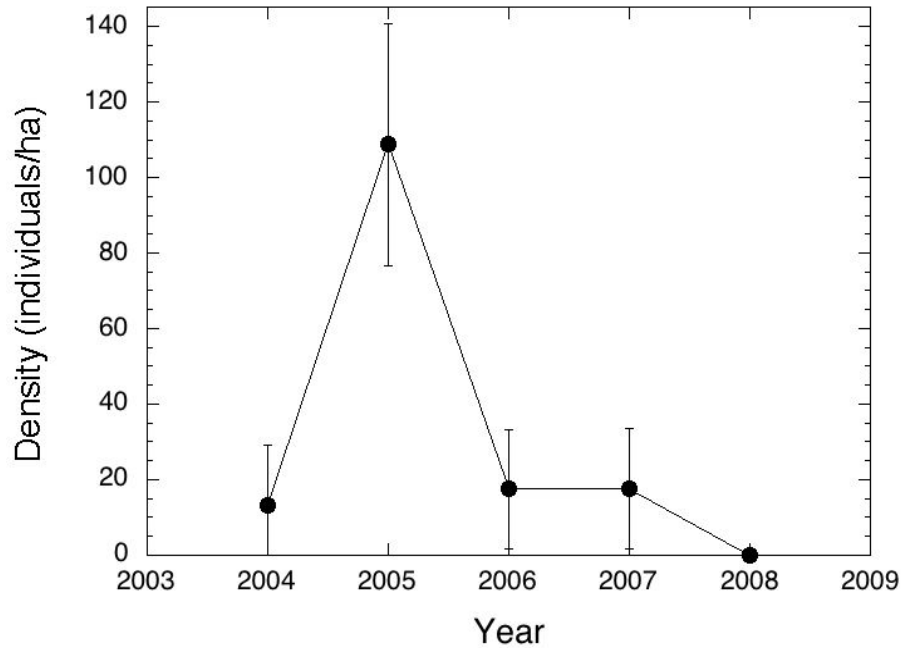


Figure 10. Estimated density of the Saddle Rock Colony of black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument. Bars represent 95% confidence intervals surrounding the point estimate.

Sylvatic Plague Surveillance

No confirmed cases of sylvatic plague were observed in any prairie dog colonies at SCBL from 1995-2009. A population die-off between 2007 and 2008 at the Saddle Rock colony suggested that sylvatic plague may have been present. Subsequent testing of fleas, however, found no evidence of plague.

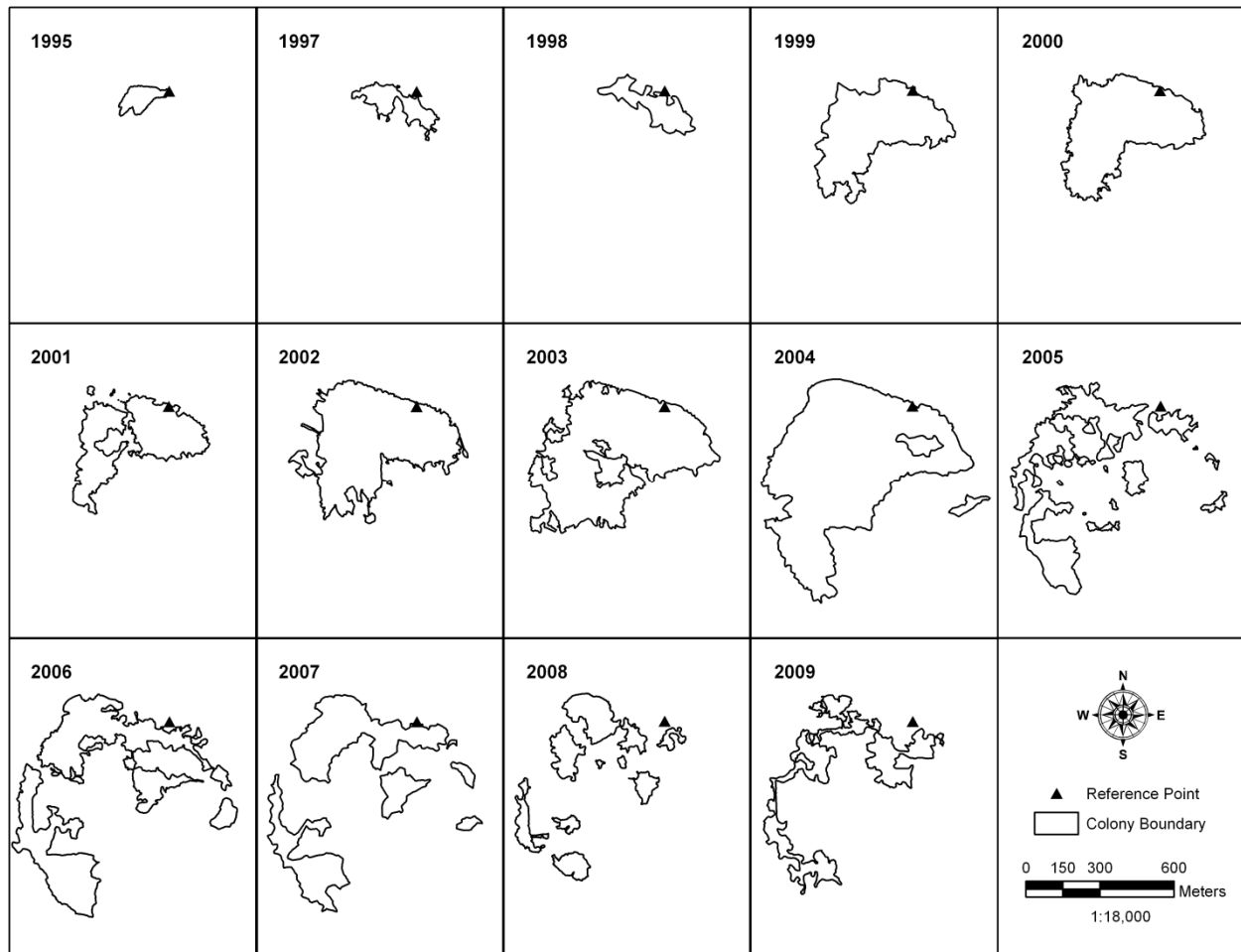


Figure 11. Area occupied by black-tailed prairie dogs (*Cynomys ludovicianus*) at Scotts Bluff National Monument – Main Colony from 1995 to 2009 (except 1996; the colony size and shape was roughly the same for 1995 and 1996.)

Environmental Correlates of Population Parameters

For the Main Colony, density was positively correlated with cumulative precipitation in the growing season immediately preceding sampling (April 1 – June 30) for the 2003-2009 period ($F = 12.9$, $P = 0.016$, $R^2 = 0.72$). For the North Colony, area occupied was negatively correlated with cumulative precipitation in the growing season immediately preceding sampling (April 1 – June 30) ($F = 20.7$, $P = 0.010$, $R^2 = 0.84$). Density was negatively correlated with cumulative

growing degree days in the growing season immediately preceding sampling (April 1 – June 30) ($F = 32.3$, $P = 0.005$, $R^2 = 0.89$). No other regressions were significant (all $P > 0.05$).

None of the population parameters were significantly correlated between the Main and the North colony (area occupied: $R^2 = 0.12$, $F = 0.57$, $P = 0.49$; density: $R^2 = 0.38$, $F = 2.42$, $P = 0.20$; population size: $R^2 = 0.13$, $F = 0.62$, $P = 0.48$).

Other Observations

Anecdotal observations of animals associated with prairie dogs were recorded from 2000-2009. A few burrowing owls (*Athene cunicularia*) were usually observed at the Main Colony (Table 5). Burrowing owls do not prey on prairie dogs; they benefit from nesting and foraging at prairie dogs colonies, but can survive elsewhere. Thus they are facultatively dependent on prairie dogs for survival, and prefer large prairie dog colonies to smaller ones (Kotliar et al. 2006). A few predators (i.e., coyotes, hawks, and badgers) were also observed (Table 6), although our methods were not well suited to detect predators, and their impacts on the colony were not directly evaluated.

Table 5. Observations of burrowing owls (*Athene cunicularia*) at the Main Colony (2000-2009). Observations on different days may have been of the same, or different, individuals.

Year	Day one	Day two	Day three
2000	0	0	1
2001	0	0	0
2002	4	5	7
2003	3	2	4
2004	0	2	0
2005	2	2	3
2006	2	4	3
2007	0	0	0
2008	1	1	1
2009	7	4	7

Additional anecdotal observations or details of the monitoring for specific years may be found in the annual status reports (Rizzo 2001, Peitz 2001, 2002, Cribbs and Peitz 2002, 2003, 2005a, 2005b, Hummel et al. 2006, Peitz and Cribbs 2007, 2008).

Table 6. Observations of predators at the Main Colony (2000-2009).

Year	Coyote	Hawk	Badger
2000	1	1	0
2001	0	0	0
2002	1	0	0
2003	0	1	0
2004	1	0	1
2005	1	0	0
2006	0	1	0
2007	0	1	1
2008	0	0	0
2009	0	0	0

Discussion

Data quality

A number of different methodologies for estimating the abundance of prairie dogs (both black-tailed and white-tailed, *Cynomys leucurus*) exist, including burrow or mound counts, aerial photography or satellite imagery, visual counts of active individuals, and mark-recapture or mark-resight techniques (Fagerstone and Biggins 1986, Menkens et al. 1990, Biggins et al. 1993, Severson and Plumb 1998, Johnson and Collinge 2004, Magle et al. 2006, Biggins et al. 2006, McClintock et al. 2009). Burrow or mound counts have often been found to yield inaccurate or biased results (Powell et al. 1994, Severson and Plumb 1998, Biggins et al. 2006). Techniques involving aerial photography or satellite imagery are most efficient over relatively large scales; the major drawback of these techniques is that they cannot distinguish between active colony areas and recently deserted colony areas (Biggins et al. 2006). Visual count methods as employed here represent a cost-effective procedure for tracking prairie dog populations over time. Mark-recapture methods, although generally more accurate, are much more labor intensive and costly, and are not free of bias. Mark-recapture sampling at SCBL was found to underestimate the actual population size because of behavioral differences among individuals that influenced capture probabilities (Cox and Franklin 1989). The mark-resight technique is less labor intensive than mark-recapture methodologies, and may avoid the bias of trap happy or trap shy individuals. Magle et al. (2006) reported a mark-resight technique to provide more precise estimates than linear transformations of visual counts.

Thus, the linear transformation of visual counts used here is not as precise as other methods, although it can be employed at low cost. The linear transformation used was developed at another site, and may not characterize the relationship at SCBL. Differences in detectability of prairie dogs at SCBL relative to another site could change the slope of the linear transformation, or increase or decrease the variability surrounding this relationship. This would in turn lead to different point estimates or different confidence intervals, respectively.

Severson and Plumb (1998) admitted that their point estimates were not very precise, due to the relatively large 95% confidence band surrounding their regression. Yet they state that the method was “still better than any of the others we tested for monitoring prairie dog populations”, and that only more costly methods (e.g., mark-recapture) would yield more precise data. They suggest that correction factors that modify counts based on visual obstructions may be useful, although such corrections did not improve correlations in their study. In a study of white-tailed prairie dogs, Menkens et al. (1990) evaluated correction factors and found that they did not significantly improve correlations between mark-recapture and visual count density estimates, even though visual obstruction ranged from 0-40%.

The official protocol (Plumb et al. 1990) is mute on the ramifications of the application of the Severson and Plumb (1998) linear transformation derived from prairie dog colonies at Conata Basin in South Dakota to prairie dog colonies at SCBL. Variability in detectability and correction factors is likewise not mentioned. No attempts have been made to examine the relationship between maximum visual counts and density determined by any other method at SCBL, and no correction factors related to detectability have been evaluated.

The sources of sampling error and potential site bias described above apply to estimates of density. There was much uncertainty in the obtained density estimates (i.e., broad confidence intervals), and few inferences can be made based on density alone. The obvious, robust patterns are seen in area occupied and total population size. Total population size is the product of area occupied and density, and the changes observed in this parameter are obviously driven by changes in area occupied. No analogous sources of error or site bias are known to be associated with the measurement of area occupied. Thus, the point estimates and confidence regions for density and total population size should be interpreted as approximate, rather than exact, and focus should lie on the relative changes of the target parameters over time, as any site bias should be constant over time. The relatively large changes in population size—spanning almost two magnitudes—in the Main Colony at SCBL over the long term are simply too robust to be attributed entirely to sampling error or bias.

Why has the population declined at times?

Prairie dogs have potentially high reproductive rates (Hoogland 2006b). The exponential growth rate of the Main Colony from 1995 to 2003 (doubling on average every 1.5 years), and the rapid growth of the North Colony for two years after founding, demonstrate this potential.

Additionally, the Main Colony displayed dramatic increases in size and area occupied over the first 6 years after colonization in 1981, despite treatments with reproduction-inhibiting drugs and removal of individuals. These removals decreased the colony size by as much as 50% in some years (Cox and Franklin 1989).

Thus the sharp declines observed, along with prolonged reductions in population size, are somewhat puzzling. For example, beginning in 1988 (the last year of any known population control efforts) the Main Colony began to decline. By 1991 only 27 individuals remained, and in 1995 the lowest estimate of 20 individuals was recorded. The rapid decline and sustained depression in population size from 1987 to 1995 could have been the result of unofficial shooting or poisoning. Alternatively, even though sylvatic plague has never been documented from SCBL, it has been reported from western Nebraska (Cully et al. 2006), and it is possible the colony may have been infected with this disease, although there is no direct evidence of plague.

Predators may have been partially responsible for some of the declines. A badger was observed at the Main Colony in 2004 and in 2007. Short-term declines in the population size of the Main Colony were observed from 2003 to 2004, and from 2005 to 2007. Badgers are possibly the most significant predator of prairie dogs (Campbell and Clark 1981, Lindzey 1982). Even a single badger may have a relatively large impact on a small prairie dog colony. Cox and Franklin (1989) reported “high mortality” due to a badger that excavated 39 burrows at the Main Colony between 1987 and 1988, which corresponds to the documented decline in population size from 1987-1989. Predation may also have important indirect, as well as direct effects on colony size: Predation on lactating females may cause coterie collapse, which can lead to increased intraspecific mortality due to cannibalism, decreasing pup survival and resulting in negative population growth (G. Plumb, personal communication).

The complete disappearance of the Saddle Rock Colony between 2007 and 2008 is even more puzzling. Even though there is evidence that illegal poisoning occurred, elimination of every resident within a prairie dog colony by poisoning is usually difficult (Hoogland 2006b). The

relatively small population size of this colony, however, would have facilitated any eradication attempts.

Environmental Correlates of Population Parameters

It is assumed that population parameters of prairie dogs are affected by interannual climatic variability, although this has rarely been the subject of study (Hoogland 2006b). The environmental variables evaluated here may be indicative of two different types of effects: (1) Responses to precipitation or temperature in the same year would be primarily behavioral. Such effects would result primarily in changes in area occupied or density. (2) Responses to precipitation or temperature in the previous year would be manifested largely in differential reproduction. Such effects could result in changes in all three parameters.

Density of the main colony was higher in wetter years, and area occupied by the North Colony was less in wetter years. Precipitation increases the amount of forage produced, which in turn reduces the amount of area required by prairie dogs for foraging, and increases density of individuals. Thus larger foraging areas are required in dry years compared to wet years (and result in less dense colonies). This is a behavioral effect. An increase in growing degree days, which would lead to higher net primary productivity and standing cover, could result in higher predation risk. Higher net primary productivity could also lead to higher intraspecific competition in a smaller area, resulting in greater intra-specific mortality or cannibalism and a decline in pup survival (G. Plumb, personal communication).

If interannual variability in climate has biologically important effects on prairie dogs, it might be hypothesized that population parameters should be positively correlated between the North and Main Colonies, as both colonies should react in a similar manner to changes in climate. No such positive correlations were observed, however. Because the North Colony exists in a relatively small area surrounded by barriers, it may not have been able to respond to climate in the same way as a less restricted colony (i.e., the Main Colony) could. In this case, however, the Main Colony would be more likely to reveal significant relationships with climate than the North Colony.

This analysis of environmental correlates was exploratory rather than confirmatory in nature, because it evaluated all possible simple linear models, rather than select models representing specific hypotheses. Often such analyses, evaluating many variables in individual comparisons, yield a relatively large number of “significant” results, many of which are likely spurious (i.e., without a functional relationship). Thus the finding of relatively few significant results is somewhat puzzling. This should not necessarily be interpreted that this population is not affected by climate, only that we found little evidence of it given the data available. Most of the analyses consisted of only a few years of observations, and thus had low statistical power. The effects of predators (or unofficial shooting or poisoning attempts) could result in dramatic changes to small prairie dog colonies, but could not be taken into account in such analyses. Density (and to a lesser degree population size) often varied relatively little in relation to the uncertainty associated with its measurement, and thus provided little resolution to observe a pattern. The reproductive effect of climate may be most directly observed through litter size, or size of the juvenile population, which was not quantified. For example, Knowles (1987) found

that average yearly litter size was positively correlated with summer (June-September) precipitation prior to the breeding season. Future attempts to evaluate the reproductive effects of climate should focus on estimates of reproductive success, such as litter size, and any attempts should ideally use methodology with less uncertainty associated with population parameter estimates.

Implications

The overall prairie dog population at SCBL is relatively small and occupies a tiny fraction of the monument (i.e., 1.45% of the monument's 698-ha of grassland). It has been estimated that for a colony or complex of colonies to be large enough to provide suitable habitat for black-footed ferrets and other species that depend upon prairie dogs for survival, an occupied area of 4,000 ha is necessary for a "fully functional grassland ecosystem" (Conservation Breeding Specialist Group 2004, Proctor et al. 2006). Given the relatively small size of the monument, this means that prairie dogs would have to colonize surrounding areas. Even if such a fully functional ecosystem is not a realistic possibility, an increase in the size of the prairie dog population would reduce its susceptibility to random demographic events that in small populations can result in inbreeding depression or perhaps even extinction (Soule 1987). Manipulative studies indicate mowing and burning treatments have significant positive effects on colony expansion (Milne-Laux and Switzer 2006, Northcott et al. 2008).

Monument staff should continue to monitor for new occurrences of prairie dog colonies in other areas of the monument. Dispersal from colonies outside the monument (possibly the source of the Saddle Rock Colony) and from colonies within (most likely the source of the North Colony) may produce new colonies. One such colony did appear to have established east of the Main Colony in 2007, but subsequently it was abandoned. Colony sites lacking prairie dogs are attractive to dispersers, and often do not remain without prairie dogs for long (Hoogland 2006b). Thus the Saddle Rock colony site should be monitored for potential recolonization. Dispersal usually begins in late winter and is complete by the end of June (Garrett and Franklin 1988; Hoogland 1995). Experimental work has shown that prairie dog colonies may also be re-established through translocations (Dullum et al. 2005, Long et al. 2006). The North Colony at SCBL, surrounded by obstacles to expansion, represents an excellent source of colonists for such translocations.

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