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The Influence of Landscape Factors on Black-Tailed Prairie Dog (Cynomys ludovicianus) Colony Persistence in Northwest Kansas

Jamie Oriez
Fort Hays State University, jamie.oriez@gmail.com

THE INFLUENCE OF LANDSCAPE FACTORS ON BLACK- TAILED PRAIRIE DOG (CYNOMYS LUDOVICIANUS) COLONY PERSISTENCE IN NORTHWEST KANSAS

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Jamie A. Oriez
B.A., DePauw University

Date 12 November 2020 Approved ______________________
Major Professor

Approved ______________________
Graduate Dean

This thesis for

The Master of Science Degree

By

Jamie A. Oriez

has been approved by

[signature]

Chair, Supervisory Committee

[signature]

Supervisory Committee

[signature]

Supervisory Committee

[signature]

Supervisory Committee

[signature]

Chair, Department of Biological Sciences

PREFACE

This thesis is written in the style of the Journal of Mammalogy. Keywords: black-tailed prairie dogs, mammals, metapopulation theory, conservation biology, wildlife management

ABSTRACT

The black-tailed prairie dog (*Cynomys ludovicianus*) is a colonial and fossorial rodent species that serves as an ecosystem engineer and keystone species in North America's grasslands. Black-tailed prairie dogs historically ranged from northern Mexico to southern Canada, and from eastern Nebraska to the foothills of the Rocky Mountains. However, with the loss and fragmentation of grasslands, introduction of Sylvatic plague (*Yersinia pestis*), and control measures such as poisoning and shooting, black-tailed prairie dogs are limited to less than 5 percent of their historical range.

In this study, I examined how colony area, location, isolation, and surrounding land cover affected the persistence of black-tailed prairie dog colonies in northwest Kansas from 2005-2015. Using aerial imagery from the National Agricultural Imagery Program (NAIP), I attempted to map every black-tailed prairie dog colony in northwest Kansas from 2005-2015. I used generalized linear models and Akaike's information criterion (AIC) to determine which factors influenced colony persistence.

I found that the number of black-tailed prairie dog colonies and total area occupied by colonies varied from 2005-2015, with both experiencing a sharp decline from 2014-2015. While the number of colony extinctions per year also varied, the number of new colonies established steadily decreased over the study period. The logarithmic transformation of colony area was the most important variable to colony persistence, occurring in all of the best 25 models. The longitude of the colony was the second most important factor, occurring in 24 of the best 25 models. Determining which factors have the greatest impact on black-tailed prairie dog colony persistence is crucial for the development of conservation management plans for this declining species.

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INTRODUCTION

The black-tailed prairie dog (*Cynomys ludovicianus*) is a highly social and fossorial colonial rodent species. Black-tailed prairie dogs are the most abundant and widespread of the five species of prairie dog (Hoogland 1996). They derive their name from their long (71-115 mm) tails with a black distal tip (Hoogland 1996). Black-tailed prairie dogs are brown in color, approximately 12 inches in length, and weigh 1-3 pounds (Hoogland 1996). Their geographic range stretches across the short and mid-grass prairies of northern Mexico to southern Canada, and from eastern Nebraska west to the foothills of the Rocky Mountains. Black-tailed prairie dogs once ranged across approximately 40 million hectares of the Great Plains of North America and might have been the most abundant mammal in North America at the time of early western exploration (Lomolino and Smith 2003b, Mulhern and Knowles 1997, Wuerthner 1997). However, black-tailed prairie dog populations experienced a severe decline in the 20^{th} century, and were estimated to occupy only 2% of their former geographic range (Mulhern and Knowles 1997).

Because of these population declines, in 1998, black-tailed prairie dogs were added to the Candidate Species List for the Endangered Species Act (ESA). However, they were removed in 2004 after the U.S. Fish and Wildlife Service determined they did not meet the ESA’s definition of threatened (USFWS 2004). More recently, prairie dog populations are estimated to be stable to upward, and while there is debate surrounding the accuracy of some population estimates, there is little doubt that they are well above the estimates from the previous century (WAFWA 2014).

Black-tailed prairie dogs are social rodents, living in colonies or towns that range in size from one hectare to thousands of hectares (Kansas Black-Tailed Prairie Dog Working Group 2002). This colonial behavior aids in the detection of predators, deters predators through mobbing behavior, and increases reproductive success through cooperative rearing (Hoogland 1996, USFWS 2008). Colonies are comprised of coteries, most containing a single breeding adult male, two or three adult females, and several non-breeding juveniles (Hoogland 1996). Colonies probably function as a metapopulation, a population whose persistence largely depends on dispersal and re-colonization across several interconnected but distinct populations (Lomolino and Smith 2001, Magle et al. 2009, 2010). If populations become too small or isolated, the decrease in connectivity might affect the long-term persistence of colonies (Lomolino and Smith 2001, Magle et al. 2009). Movement between populations is essential to the persistence of the metapopulation and the species as a whole (Lomolino and Smith 2001, Magle et al. 2010).

Black-tailed prairie dogs work as ecosystem engineers: physically creating, maintaining, and modifying their environment (Johnson and Collinge 2004, Jones et al. 1994, Lomolino and Smith 2003a). They are also often cited as a keystone species, a species that has an irreplaceable ecological impact relative to its abundance, whether directly through interspecific interactions or indirectly through ecosystem engineering. (Magle et al. 2010, Power et al. 1996, Wuerthner 1997). Black-tailed prairie dogs perform several functions to help maintain grassland ecosystems. Prairie dogs prevent shrub invasion of grasslands by consuming shrub seeds and seedlings (Ceballos et al. 2010, Hale et al. 2020, Lomolino and Smith 2003a, Miller and Reading 2012, Sierra-

Corona et al. 2015). Soil mixing from burrow construction and fecal deposition around mounds increases the amount of nutrients in the system and enhances soil structure, water infiltration, and primary productivity (Davidson et al. 2012, Magle et al. 2010, Miller and Reading 2012).

Black-tailed prairie dog colonies create important habitat for many species, increasing biodiversity in grassland ecosystems (Ceballos et al. 2010, Davidson et al. 2012, Lomolino and Smith 2003b). Over 100 vertebrate species reportedly use black-tailed prairie dog colonies as habitat, and over 150 species are associated with or depend upon colonies (Clark 1989, Mulhern and Knowles 1997). Burrows may serve as shelter for many species of arthropods, amphibians, reptiles, and mammals (Davidson et al. 2012, Johnson and Collinge 2004, Lomolino and Smith 2003b, Miller and Reading 2012). The increased abundance of forbs and dwarf shrubs associated with colonies attracts ungulates such as pronghorn (*Antilocapra americana*), and the burrow mounds themselves attract lizards and bison (*Bison bison*) (Davidson et al. 2012, Field et al. 2016, Hoogland 1996). Higher bird densities and diversity in black-tailed prairie dog colonies have been observed (Davidson et al. 2012, Lomolino and Smith 2001, Mulhern and Knowles 1997). The list of species associated with black-tailed prairie dog colonies varies by region but includes numerous species of concern to conservation biologists (Lomolino et al. 2003, Mulhern and Knowles 1997). Black-tailed prairie dogs are prey for many species, including the federally endangered black-footed ferret (*Mustela nigripes*), coyotes (*Canis latrans*), badgers (*Taxidea taxus*), swift foxes (*Vulpes velox*), and several species of raptors (Ceballos et al. 2010, Johnson and Collinge 2004, Lomolino and Smith 2003a, Wuerthner 1997).

Black-tailed prairie dog colonies increase heterogeneity in ecosystems by providing unique habitat that supports distinctive plant and animal assemblages (Davidson et al. 2012, Field et al. 2016, Hendrickson et al. 2016, Lomolino and Smith 2003a, Magle et al. 2009). The decline of black-tailed prairie dog populations may have accelerated the decline of species that depend upon colonies, evidenced by the declines of burrowing owls (*Athene cunicularia*), ferruginous hawks (*Buteo regalis*), mountain plovers (*Charadrius montanus*), swift foxes, and the near extinction of the black-footed ferret (Lomolino and Smith 2001, Wuerthner 1997).

Black-tailed prairie dogs feed on a variety of vegetation including grasses, forbs, and their seeds (Kansas Black-Tailed Prairie Dog Working Group 2002, Koford 1958). Because of the similarities in their diet, ranchers often only view black-tailed prairie dogs as competing with livestock for forage (Connell et al. 2019, Stoltenburg et al. 2004, Vermeire et al. 2004). In addition to consumption, prairie dogs can further reduce plant biomass by clipping standing forge as a strategy to enhance their ability to see predators (Connell et al. 2019, Hale et al. 2020, Hendrickson et al. 2016, Stoltenberg et al. 2004). The livestock industry has often cited one study in particular to support the negative effects of black-tailed prairie dogs on cattle foraging. In 1902, Merriam estimated that prairie dogs cause a 50-75% reduction in range productivity (Merriam 1902). Another early-20th century study stated that the prairie dog is “one of the most injurious rodents of the southwest and plains regions,” and results in “the removal of vegetation in its entirety from the vicinity” (Taylor and Loftfield 1924).

However, while black-tailed prairie dog herbivory and burrowing activities can reduce overall plant biomass in an area, the higher levels of nutrients in the soil and increased water infiltration often results in increased forage quality and elevated nutrient content in forage surrounding the burrows (Connell et al. 2019, Davidson et al. 2012). Cattle have been found to preferentially graze on black-tailed prairie dog colonies rather than areas without prairie dogs (Lomolino and Smith 2003b, O'Meilia et al. 1982, Sierra-Corona et al. 2015). Studies have found that prairie dog foraging does not significantly affect the weight gain of cattle (O'Meilia et al. 1982, Sierra-Corona et al. 2015). However, it is important to note that the magnitude of black-tailed prairie dogs' effect on cattle weight is highly dependent on colony scale, site-specific grass species, soil type, and precipitation (Connell et al. 2019, Hendrickson et al. 2016). Despite findings that the relationship between prairie dogs and cattle may be mutualistic, conflict with the livestock industry and the negative sentiment toward the black-tailed prairie dog continues.

Black-tailed prairie dog populations have experienced a severe decline, and the species went locally extinct in Arizona by 1960, although successful reintroduction efforts began in 2008 (Hale et al. 2020, WAFWA 2011). Black-tailed prairie dog colonies, which once covered some 40 million hectares, experienced an extreme population decline in the 20th century to less than 600,000 hectares (Lomolino and Smith 2003a, Miller and Reading 2012, Mulhern and Knowles 1997). Range-wide and statewide trends for black-tailed prairie dog populations appear to be increasing from their severe low in 1961, and have been holding steady to slightly increasing in the past decade at just under 900,000 hectares (USFWS 2008, WAFWA 2014, WAFWA 2015). Several factors have led to population declines, including disease, the loss and fragmentation of the grassland ecosystem, and human control measures such as shooting and poisoning.

Sylvatic plague (*Yersinia pestis*) is a factor in the decline of black-tailed prairie dogs. Since its introduction to North America, Sylvatic plague, caused by the bacterium *Yersinia pestis* and carried by fleas, has devastated rodent populations that lack immunity, such as black-tailed prairie dogs (Davidson et al. 2012, Miller and Reading 2012, Mulhern and Knowles 1997). The high rates of social contact within black-tailed prairie dog colonies makes this species more susceptible to Sylvatic plague (Miller and Reading 2012, Stapp et al. 2004). Sylvatic plague has the potential to eradicate or severely bottleneck colonies with a single outbreak (Miller and Reading 2012, Tripp et al. 2017). During an outbreak, black-tailed prairie dog populations on even the largest colonies can suffer nearly 100% mortality (Lomolino and Smith 2003a, Miller and Reading 2012, Wuerthner 1997, Tripp et al. 2017). Sylvatic plague persists in a colony even after the initial outbreak, resulting in prolonged population recovery times (Mulhern and Knowles 1997). Sylvatic plague is present in the western two-thirds of the black-tailed prairie dog range, but has been moving eastwards with climate change (Davidson et al. 2012, Liccioli et al. 2020, USFWS 2008). Plague on prairie dog populations is most often managed with a reactive use of insecticides such as deltamethrin to control fleas, although newly developed oral vaccinations are becoming more popular (Liccioli et al. 2020, Salkeld 2017, Tripp et al. 2017). Neither treatment provides complete protection, and treatment is generally only efficient logistically and financially on a small-scale (Salkeld 2017, Tripp et al. 2017).

Another cause of black-tailed prairie dog decline is the loss and fragmentation of the grassland ecosystem in central and western North America. Black-tailed prairie dog population declines can be traced to the conversion of grasslands to cropland, shrubland, or urban landscapes (Kansas Black-Tailed Prairie Dog Working Group 2002, USFWS 2000). Most of the decline in habitat occurred during the first half of the 20^{th} century with the westward expansion of European settlement and the advancement of agricultural practices (Lomolino and Smith 2001). Because grasslands have been converted to agriculture and livestock production, black-tailed prairie dogs are often in conflict with human activities (Davidson et al. 2012). In landscapes where colonies are limited by agriculture or urbanization, inter-colony movement may be inhibited, disrupting the metapopulation dynamics and leading to inbreeding, loss of genetic diversity, and the inability to re-colonize extinct colonies (Sackett et al. 2012, USFWS 2000).

There have been extensive control measures taken against black-tailed prairie dogs throughout the past century (Davidson et al. 2012). In 2000, the US Fish & Wildlife Service estimated that 10-20% of area occupied by prairie dog colonies was poisoned annually (Miller and Reading 2012). Prairie dog poisoning still occurs on local government, state, federal, tribal, and private lands (Miller and Reading 2012). While fragmentation from poisoning still occurs throughout the black-tailed prairie dog range, it does not occur in the same degree or intensity of past efforts (Van Pelt 1999, WAFWA 2014). However, some state and local governments, including areas of Kansas and Nebraska, do require eradication measures to be taken against colonies; otherwise, the landowners face fines (Kansas Black-Tailed Prairie Dog Working Group 2002, Miller and Reading 2012, Mulhern and Knowles 1997). In 2007, the EPA approved the use of

Rozol (chlorophacinone) for prairie dog control in several states despite protests from state agencies (WAFWA 2008, WAFWA 2014). Unlike traditionally used zinc phosphide, Rozol does not require pre-baiting (WAFWA 2014). Concerns have arisen regarding the potential impacts of secondary poisoning on other grassland species, as mortality from Rozol application on prairie dog towns has been documented in a badger and a bald eagle (WAFWA 2008, WAFWA 2014).

The shooting of black-tailed prairie dogs contributes to population fragmentation and reduction in colony productivity and health (Kansas Black-Tailed Prairie Dog Working Group 2002). Shooting can significantly impact local populations in areas where the practice is intense or persistent (Kansas Black-Tailed Prairie Dog Working Group 2002, Mulhern and Knowles 1997, Van Pelt 1999). Shooting may preclude or delay the recovery of colonies reduced by other factors (Kansas Black-Tailed Prairie Dog Working Group 2002). However, many landowners and some tribal lands are able to maintain prairie dog populations and generate revenue from charging people for recreational shooting, which creates an additional incentive to maintain prairie dog populations (USFWS 2008, Van Pelt 1999).

The specific causes of black-tailed prairie dog decline do not operate in isolation, because they often affect populations simultaneously (Miller and Reading 2012). Due to the severe decline in population as a result of the combination of all these factors, black-tailed prairie dogs may once have been threatened with extinction across their entire range (Wuerthner 1997). More recently populations seem to be stable to slightly increasing, although the accuracy of some estimates remain in question (WAFWA 2014, WAFWA 2015).

Black-tailed prairie dogs have historically inhabited the western two-thirds of the state of Kansas (Kansas Black-Tailed Prairie Dog Working Group 2002, Peek and Houts 2008). In 1903, black-tailed prairie dogs reportedly occupied an estimated 800,000 ha of habitat in Kansas (Lantz 1903). Nearly two-thirds of the estimated 13.5-million hectares of rangeland within Kansas's black-tailed prairie dog range were converted to cropland or other uses after European settlement in the region, resulting in the destruction or fragmentation of large colonies (Kansas Black-Tailed Prairie Dog Working Group 2002). Some counties have had population reductions of up to 84% (Mulhern and Knowles 1997). A 1992 survey estimated 18,845 hectares of colonies remained in Kansas, approximately 2% of estimates from the previous century (Lantz 1903, Vanderhoof et al. 1994).

In 2009, there was estimated to be 59,800-62,700 hectares of black-tailed prairie dog colonies in Kansas, however there are conflicting reports and the reliability of estimates are unknown (McDonald et al. 2015, Peek and Houts 2009, WAFWA 2014). The first sylvatic plague epizootic in Kansas was verified on the Cimmaron National Grassland in southwestern Kansas in 1996, but its impact in other areas of the state is unknown (Kansas Black-Tailed Prairie Dog Working Group 2002, USFWS 2000). Poisoning is widespread across the state, with some counties requiring eradication efforts. Control permits (KAR 115-16-2) are required to use any poisonous gas or smoke to control prairie dogs, except toxicants labeled and registered for aboveground use (Van Pelt 1999). A hunting license is required for non-residents to shoot black-tailed prairie dogs in Kansas, but the season is open year-round with no limit on number harvested (KDWPT 2020).

In this study, I examine the persistence of black-tailed prairie dog colonies in northwestern Kansas over a ten-year period. My first objective was to identify the number of colonies and the total area occupied by colonies in each year. My second objective was to build a model that, using several landscape factors, will be able to predict colony persistence. This information can be useful to the management of black-tailed prairie dog colonies in the state of Kansas, and potentially several other states in the species' geographic range.

The factors that I examined were: colony area, location (latitude and longitude), isolation, and surrounding land cover. I hypothesize that surrounding land cover will have the greatest impact on colony persistence, followed by colony area, isolation, and location, respectively. I believe surrounding land cover will have the largest effect on colony persistence due to the potential conversion of grassland to other land cover types (e.g., agriculture), the increased use of control measures by farmers and ranchers, and by limiting movement between colonies. Specifically, I hypothesize that colonies surrounded by cultivated crops will have a greater chance of going extinct, either from land conversion or limited immigration. I also hypothesize that smaller colonies are more likely to become extinct than larger colonies, as human control measures and stochastic factors will have a greater impact on smaller colonies. Finally, I hypothesize that more isolated colonies will have a higher rate of extinction, because they are less likely to benefit from metapopulation dynamics and less likely to be re-colonized after an extinction event.

METHODS AND MATERIALS

My study focused on the 17 counties comprising the northwest corner of Kansas, including Cheyenne, Rawlins, Decatur, Norton, Sherman, Thomas, Sheridan, Graham, Wallace, Logan, Gove, Trego, Greeley, Wichita, Scott, Lane, and Ness counties (Fig. 1). This northwest region has been reported to have the highest density of black-tailed prairie dogs in Kansas (Pontius 2002). This region is comprised of a combination of mixed-grass prairie typically characterized by big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), western wheatgrass (*Pascopyrum smithii*), and blue grama (*Bouteloua gracilis*), and shortgrass typically characterized by blue grama and buffalo grass (*Buchloe dactyloides*) (KNPS 2019). The climate of northwestern Kansas can be described as a cold semi-arid climate, with an average annual precipitation of 474 mm, warm summer temperatures, and relatively long growing seasons (Ricketts el al. 1999).

Data Collection

Aerial imagery was obtained from the Farm Service Agency's National Agricultural Imagery Program (NAIP) and accessed through the State of Kansas GIS Data Access and Support Center (DASC) on kansasgis.org on September 1, 2017. National Agricultural Imagery Program imagery is 1-meter resolution and is collected at the beginning of the summer across the state generally every 2-3 years (Peek and Houts 2008). Imagery from the years 2005, 2006, 2010, 2012, 2014, and 2015 were available for this study. 2005 was chosen as the beginning year, as it was the first year with higher resolution imagery. 2015 was the most recent year available at the beginning of this study.

Land cover data were obtained from the National Land Cover Database (NLCD) and accessed from the State of Kansas GIS DASC on kansasgis.org on September 1, 2017. National Land Cover Database rasters were available for the years 2006 and 2011 at 30-meter resolution. The 2006 raster was used for 2005 and 2006 persistence analysis, and the 2011 raster was used for 2010, 2012, and 2014 persistence analysis. National Land Cover Database data are separated into 20 land cover attributes, 15 of which were present in the study area: open water, developed – open space, developed – low intensity, developed – medium intensity, developed – high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, and emergent herbaceous wetlands (USGS 2011) (APPENDIX A).

To determine the number of black-tailed prairie dog colonies and total area occupied by colonies in northwest Kansas, I searched the NAIP imagery to find and delineate colonies using ArcGIS version 10.5.1 (ESRI 2017). Black-tailed prairie dog colonies are easily visible on the high-resolution NAIP imagery, except in years of extreme drought (McDonald et al. 2015). The imagery was systematically searched by county at a scale of 1:8000, using a 1- by 1-mile grid system. Each county was searched twice with at least one week between searches to ensure detection of colonies and avoid delineation of null features (e.g. ant colonies). Key features that distinguish a black-tailed prairie dog colony from its surrounding landscape include burrow openings, mounds, trails between burrows, and a clip line from prairie dog herbivory in the surrounding vegetation. When a potential colony was located, I digitized the perimeter at my discretion. The definition of colony perimeter was taken from Peek and Houts 2008, and defined as "...the area just beyond the outermost burrows, often consisting of the distinct area in which black-tailed prairie dog impacts on vegetation were visible" (Peek and Houts 2008) (Fig. 2). The estimated total area occupied by prairie dog colonies detected during this study is likely to be positively biased, because some features delineated may not be prairie dog colonies (null features) and colonies may only be partially occupied (McDonald et al. 2011).

In order to assess the accuracy of colony delineations, ground truthing surveys were conducted between June 2-September 30, 2017 after young prairie dogs were aboveground (McDonald et al. 2011). Five colonies of differing sizes were chosen from each county to visit. Colonies were visually examined from a distance using binoculars, and classified as "active" if prairie dogs were seen and "inactive" if no prairie dogs or signs of activity (fresh scat, fresh digging/burrowing, clipping of vegetation) were seen after 10 minutes. It has been argued that the use of imagery-based interpretation alone cannot provide defendable estimates of the proportion of area occupied, and therefore ground surveys must be completed (McDonald et al. 2011).

Persistence Variables

In order to determine colony persistence, each colony was designated a unique identification number in order to track its presence over the study period. To account for changes in a colony size and distribution, a colony was determined to be the same and given the same ID number if any portion of the colony's perimeter overlapped between years. A colony persisted if it was present in the NAIP imagery from one year to the next. For example, the perimeter of colony 739 in 2006 overlapped with a delineated colony in 2010, so the 2010 colony was designated the same identification number (739) and the colony was determined to have persisted from 2006-2010. A colony was considered extinct if it was present in the NAIP imagery one year and absent in the next. A colony was considered newly established if it was not present in the NAIP imagery one year and present the next. Colonies that persisted were coded as ‘1’ and extinct colonies were coded as ‘0’.

Colony area was determined by measuring the area inside of the delineated perimeter and was measured in hectares by using ArcGIS. Colony location was characterized as colony latitude and longitude measured at each colony’s centroid.

Originally, three measures of colony isolation were collected – nearest neighbor distance, the number of colonies within a 10-kilometer buffer of the focal colony, and the proportion of a 10-kilometer buffer around the focal colony comprised of other colonies. Multiple metrics were calculated, because no single isolation metric has gained widespread acceptance (Magle et al. 2009). Nearest neighbor distance was calculated using ArcGIS, measuring nearest edge-to-edge distance between colonies in meters. The number of colonies and proportion of area occupied by colonies in the 10-kilometer buffer were considered an indication of focal colony isolation, with more isolated colonies having a lower number of colonies or less total occupied area in the surrounding landscape. Ten kilometers was chosen as the buffer size as it is the estimated maximum dispersal distance for black-tailed prairie dogs (Lomolino et al. 2003, Stapp et al. 2004).

Two measures of surrounding land cover were collected using the NLCD data. The first was the predominant land cover type of the focal colony. The predominant cover type would indicate which land cover class black-tailed prairie dog colonies were most dominant, and if this affected colony persistence. The second measure taken was the proportion of land cover types within a 2-kilometer buffer around the focal colony. The surrounding land cover of the focal colony would influence the ability of black-tailed prairie dogs to move across the landscape. To reduce the number of variables, Pearson correlations were calculated to test for correlation between each of the 15 cover types, and scatter plots were created to examine the cover type's potential impact on persistence. The proportion of surrounding grassland/herbaceous and proportion of surrounding cultivated crops were correlated. Cultivated crops were chosen to be included in the final analysis as they are man-made and potentially have larger management implications. Proportions of the following land cover types were used in the analysis: cultivated crops, pasture/hay, developed – low intensity space, and barren land. Two kilometers was chosen as the buffer distance, because it is the mean dispersal distance of a black-tailed prairie dog (Johnson and Collinge 2004).

Analysis

Colony area was logarithmically transformed for the final analysis to control model dispersion. Pearson correlations were calculated to avoid multicollinearity. All three measures of isolation were correlated, so nearest-neighbor distance was chosen to be included in analysis as it is the simplest metric able to determine management implications. Predominant colony land cover type was not used, as it did not vary between most colonies. The variables used in the final analysis are as follows: log-transformed colony area, latitude, longitude, nearest neighbor distance, proportion of surrounding cultivated crops, proportion of surrounding pasture/hay, proportion of surrounding developed – low intensity, and proportion of surrounding barren land.

Statistical analyses were performed in R x64 version 3.6.1 (R Development Core Team 2019). To estimate which factor had the greatest affect on colony persistence, I generated generalized linear models (GLMs) using the boot, jtools, and ResourceSelection packages in R (Canty and Ripley 2020, Lele et al. 2019, Long 2020). Models were constructed as binomial generalized linear models with logit link functions. I used a jackknifing resampling method for the models, where subsets of the data were used to create models and the coefficients were averaged to create the final model. Overall, 140 models were constructed. Model variable significance was calculated using t-tests with $\alpha = 0.05$. I calculated Akaike's information criterion (AIC) to determine the most parsimonious model predicting colony persistence. Models with delta AIC < 2 were considered to have equivalent support. The goal of AIC is not to determine model significance, but which of the tested models is best for inference and further exploration (Johnson and Collinge 2004).

RESULTS

Number and Area of Colonies

I identified 3909 individual black-tailed prairie dog colonies in northwest Kansas over the course of the study. The number of colonies each year varied, with 2015 having the lowest number of colonies (1384) and 2006 having the most (2256) (Table 1). In 2010, I saw the most colony extinctions, with 1067 colonies going extinct between 2006 and 2010 (Table 2). This was also the largest interval between NAIP imagery, as the other imagery was separated by only one to two years. Between 2005-2006 I saw the fewest colony extinctions and most colonies established, with 371 colonies going extinct and 733 new colonies being established in that year (Table 2). In 2014-2015 I saw the fewest colonizations, with only 332 new colonies being established. The year 2014 had the largest total area of colonies with 46,825.88 hectares, and 2015 had the smallest total area of colonies with 28,776.22 hectares (Table 1). The smallest colony was 0.055 hectares, located in Sheridan County in 2015. The largest colony was 4,169.4 hectares, located in Logan County in 2012 (Table 1).

Persistence Models

Log-transformed colony area and longitude were the only variables present in each year's best-performing model (Table 3). The proportion of surrounding cultivated crops and the proportion of surrounding barren land were present in 4 of the 5 best-performing models.

The best-supported model for colony persistence from 2005-2006 included log-transformed colony area, latitude, longitude, nearest neighbor distance, the proportion of surrounding cultivated crops, and the proportion of surrounding pasture/hay (Table 4).

Log-transformed colony area and the proportion of surrounding cultivated crops had significant positive relationships with persistence, while colony longitude had a marginally significant positive relationship with persistence. Colony latitude and the proportion of surrounding pasture/hay had significant negative relationships with persistence. Nearest neighbor distance was not related to colony persistence. This model correctly predicted 1251 colony survivals and 19 colony extinctions, with 32 false negative and 259 false positive predictions (Table 4).

The best-supported model for colony persistence from 2006-2010 included log-transformed colony area, latitude, longitude, the proportion of surrounding cultivated crops, and the proportion of surrounding barren land (Table 5). Log-transformed colony area and the proportion of surrounding barren land had significant positive relationships with persistence, while colony latitude, longitude, and the proportion of surrounding cultivated crops had significant negative relationships with persistence. This model correctly predicted 711 colony survivals and 602 colony extinctions, with 271 false negative and 309 false positive predictions (Table 5).

The best-supported model for colony persistence from 2010-2012 included log-transformed colony area, longitude, nearest neighbor distance, the proportion of surrounding developed – low intensity land, and the proportion of surrounding barren land (Table 6). Log-transformed colony area and colony longitude had significant positive relationships with persistence, while nearest neighbor distance had a marginally significant positive relationship. The proportion of surrounding developed – low intensity land had a significant negative relationship with persistence. The proportion of surrounding barren land had a non-significant relationship with colony persistence. This model correctly predicted 1077 colony survivals and 57 colony extinctions, with 45 false negative and 275 false positive predictions (Table 6).

The best-supported model for colony persistence from 2012-2014 included log-transformed colony area, latitude, longitude, the proportion of surrounding cultivated crops, and the proportion of surrounding barren land (Table 7). Log-transformed colony area, longitude, and the proportion of surrounding barren land all had significant positive relationships with persistence. Colony latitude and the proportion of surrounding cultivated crops were not related to colony persistence. This model correctly predicted 1080 colony survivals and 79 colony extinctions, with 59 false negative and 277 false positive predictions (Table 7).

The best-supported model for colony persistence from 2014-2015 included log-transformed colony area, longitude, nearest neighbor distance, the proportion of surrounding cultivated crops, and the proportion of surrounding barren land (Table 8). Log-transformed colony area, longitude, the proportion of surrounding cultivated crops, and the proportion of surrounding barren land all had significant positive relationships with persistence. Nearest neighbor distance had a marginally significant negative relationship with colony persistence. This model correctly predicted 834 colony survivals and 410 colony extinctions, with 218 false negative and 350 false positive predictions (Table 8).

DISCUSSION

Number and Area of Colonies

The number of black-tailed prairie dog colonies in northwest Kansas varied over the study period. The number of colonies peaked in 2006 with 2256 colonies, before dropping off in 2010 to only 1803 colonies (Table 1). Subsequently, the number of colonies remained stable until 2015, when colonies declined to 1384. The longer time lapse between the 2006 and 2010 imagery could explain the large decline in the total number of colonies, and could also explain the large number of extinctions, with 1067 colonies going extinct (Table 2). There was also a sharp decline in the number of colonies between 2014 and 2015, as well as the second-highest number of extinctions, with the loss of 760 colonies.

This decline in the number of colonies between 2014-2015 might be in response to weather variation in my study region. From December 2013 – May 2015, the western portion of my study range experienced a severe drought, which might have led to increased colony extinction in this area (NDMC 2015). A decline in prairie dog populations has been documented during drought periods especially as it relates to plague dynamics (Stephens et al. 2018). As vegetation production is reduced, the availability of moisture and forage for prairie dogs is limited and prairie dogs loose mass (Eads and Hoogland 2016). The poor conditions during drought years may compromise prairie dogs ability to escape or successfully counter attack predators, and prairie dogs may have weaker behavioral and immunological defenses against ectoparasites (Eads and Hoogland 2016, Liccioli et al. 2020, Stephens et al. 2018). It is also possible that the severe drought decreased colony detectability on NAIP imagery from 2014 and 2015, as it has been documented that detectability decreased in NAIP imagery during a severe drought in Wyoming (McDonald et al. 2015).

While the number of colony extinctions varied widely year-to-year, the number of new black-tailed prairie dog colonies established fluctuated slightly, but generally declined from 2005-2015 (Table 2). The greatest number of colonizations occurred between 2005 and 2006. 733 new colonies were established, compared to 371 colony extinctions. The number of colonizations declined throughout the course of the study, and between 2014 and 2015 there were only 332 new colonies established compared to 760 colony extinctions.

The total area occupied by black-tailed prairie dog colonies also varied throughout the course of this study (Table 1). In 2014, I examined the highest total area occupied by black-tailed prairie dog colonies with 46,825 hectares occupied in northwest Kansas. However, there was a large decline between 2014-2015, and 2015 had the lowest total area occupied, with only 28,776 hectares of black-tailed prairie dog colonies – a loss of over 18,000 hectares.

The fluctuation in the total area occupied by black-tailed prairie dog colonies in northwest Kansas followed the same pattern as the fluctuation in the number of colonies. For example, the total occupied area increased by over 10,000 hectares between 2005-2006, mirroring the increase in the number of colonies from 1894 to 2256 over the same timeframe. The decline in total occupied area between 2014 and 2015 mirrored the sizable decrease in the total number of colonies. The total area occupied by colonies was not proportional to the number of colonies, however. For instance, while 2014 had the highest total area occupied by colonies (46,825 ha), it only had the third highest number of colonies (1812). 2005 had the second highest number of colonies (1894), but was second to last in terms of total area occupied (36,662 ha).

One troublesome finding is that while there were similar losses in the overall number of colonies between 2006-2010 and 2014-2015 (453 and 428 fewer colonies respectively), the loss in the amount of area occupied by black-tailed prairie dog colonies was not proportional. While 5,452 hectares of black-tailed prairie dog colonies were lost between 2006-2010, 18,049 hectares were lost between 2014-2015. That is more than three-fold the amount of area lost, despite 2006-2010 losing 25 more colonies.

This study documented a decline in both the number of black-tailed prairie dog colonies and the total area occupied by colonies between 2005-2015. While there was variability in the total number and total area occupied by colonies over the 10-years, the consistent decline in the number of newly established colonies over the study and the severe decline in the total area occupied by black-tailed prairie dog colonies at the end of the study is of ecological concern. It remains to be seen if these decreasing trends have continued, or if the sharp declines in the black-tailed prairie dog populations in 2015 were simply stochastic fluctuations.

Persistence Models

At the onset of this study, I predicted that surrounding land cover type would have the largest effect on colony persistence, followed by colony area, isolation, and location respectively. Colony area was present and had a significant positive relationship with persistence, and was the most important factor in all 25 of the best-performing models (Tables 4-8, Appendix B). Location, specifically longitude, was the second most important variable to colony persistence, occurring in 24 of the 25 models. A measure of surrounding land cover type was present in each of the 25 best-performing models, but these measures were generally not significant or important. Nearest neighbor distance was one of the less important variables, occurring in only 14 of the 25 models.

In this study, colony area was the most important indicator of black-tailed prairie dog colony persistence in northwestern Kansas from 2005-2015. In all of the best 25 models, colony area was positively related with colony persistence, highly significant, and the most important variable (Tables 4-8). At the beginning of this study, I hypothesized that colony area would affect persistence, as smaller colonies would be more likely to go extinct than larger colonies. This hypothesis is supported in these models. Smaller colonies are more subject to extinction from demographic or environmental stochasticity, and the negative effects of poisoning, shooting, and Sylvatic plague are more apparent (Wuerthner 1997). As biogeography and metapopulation theories predict, larger colonies might attract more immigrants than smaller colonies, thus increasing the genetic diversity of that colony, increasing the likelihood of re-colonization after an extinction event, as well as providing increased protection against predators (Lomolino and Smith 2001, Magle et al. 2010).

After colony area, longitude was generally the next most important variable for black-tailed prairie dog colony persistence. In every year except 2006, colony longitude had a positive relationship with colony persistence, meaning that colony persistence increased from the west to the east. In 2006, however, longitude had a significant negative correlation with persistence; so black-tailed prairie dog colonies in the western portion of the study region had a higher likelihood of persistence than in the east. Whether this negative correlation is related to the distribution of black-tailed prairie dogs contracting westward, or potentially due to increased control measures, encroaching urbanization, inhospitable weather, or another mitigating factor in the eastern portion of the study region remains unknown. However, it is alarming to note threats to colony persistence coming from both the eastern and western boundaries of the study region.

At the onset of this study I also hypothesized that colonies surrounded by cultivated crops would have a higher probability of extinction. In areas where black-tailed prairie dog colonies are bounded by agriculture, inter-colony movement is inhibited, disrupting metapopulation dynamics and leading to in-breeding and preventing re-colonization (Sackett et al. 2012). However, the proportion of cultivated crops within two kilometers of the focal colony only had a significant negative correlation with persistence in 2006. In 2005 and 2014, the proportion of surrounding cultivated crops had a significant positive correlation with persistence. It is an interesting note that the proportion of cultivated crops both benefited and harmed the persistence of black-tailed prairie dog colonies in separate years. This may be because the ease of black-tailed prairie dog movement is determined by the type of crop grown. Whereas some crops might inhibit black-tailed prairie dog movement, other crops might allow for easier movement (Magle et al. 2009, Sackett et al. 2012).

I also hypothesized that more isolated colonies would have higher rates of extinction. Because black-tailed prairie dog colonies are thought to function as metapopulations, their persistence depends on dispersal. Patches that are too isolated might not persist, because they will not receive enough immigrants to maintain genetic diversity or re-colonize in the case of an extinction event (Lomolino and Smith 2001, Magle et al. 2009). However, this hypothesis was not supported in my findings. Despite generally being considered one of the most important variables to colony persistence, in this study my chosen isolation metric, nearest neighbor distance, was only present in 14 of the best 25 models, and its relationship with persistence was rarely significant (Lomolino and Smith 2001, Lomolino et al. 2003). In the future, I would recommend testing to determine if a different isolation metric is a better predictor of colony persistence in this region.

In 2006, 2012, and 2014, the proportion of barren land within two-kilometers of black-tailed prairie dog colonies had a significant positive relationship with colony persistence. The NLCD data used for this study defined barren land as "...areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. [Areas where] generally, vegetation accounts for less than 15% of total cover" (USGS 2011) (Appendix A). An increase in the amount of barren land surrounding a black-tailed prairie dog colony could potentially promote dispersal, aid in the detection of predators, and decrease the amount of livestock production in a region, thereby reducing the amount control measures taken against black-tailed prairie dogs.

Overall, the models did an adequate job predicting colony presence, but lacked when attempting to predict extinction (Tables 4-8). In most years, the number of correct positive predictions was high and false negative predictions were low, indicating that the models were good at predicting the colonies that would persist. However, the number of false positive predictions (model predicted colony persistence, but was wrong) each year was high. Only between 2006-2010 (Table 5) and 2014-2015 (Table 8) did the models predict more true extinctions than false positives. These were also the two years with the highest number of extinctions in the dataset. In the future, the models need to be refined and more data needs to be collected, as it is my belief that these models would work better with more data overall, and specifically with more extinction data.

The most important variable or set of variables that is limiting black-tailed prairie dog colony persistence in this region was likely not included in my model. More data needs to be collected to find what variable or set of variables is truly predicting colony extinction. Along with increasing the size of the study region, I would recommend adding predictor variables for weather (especially precipitation) and soil structure, along with adding a set of variables that take into account local government control laws.

Using NAIP imagery for future studies is an efficient way to obtain data on the number, size, and location of black-tailed prairie dog colonies in a region. While it is a time-consuming technique, it is effective and examining the imagery is inexpensive. This technique is easy to learn, readily accessible, and should be used in future studies in conjunction with ground truthing to determine the current status of black-tailed prairie dog populations.

Finally, there needs to be better monitoring of Sylvatic plague epizootics – or lack thereof – throughout the entire black-tailed prairie dog range. The presence of Sylvatic plague in Kansas, especially in northern Kansas, is generally unknown. In order to determine if Sylvatic plague is having an effect on black-tailed prairie dog persistence in this study region, it must first be known if and when plague outbreaks are actually occurring. Constructing these persistence models and determining the true cause of population decline will be ineffective without this information.

MANAGEMENT AND CONSERVATION

Black-tailed prairie dogs have faced a severe population decline over the past century, and are estimated to occupy only 2% of their former range (Mulhern and Knowles 1997). However, black-tailed prairie dogs were removed from the ESA's Candidate Species List in 2004 due to a lack of evidence that they required federal protection (USFWS 2004). At present, black-tailed prairie dog populations are estimated to be stable with slight fluctuations, and approximately 900,000 hectares of occupied colonies are estimated across their range (WAFWA 2015).

In the state of Kansas, reductions in black-tailed prairie dog populations of up to 84% over the past century have been reported (Mulhern and Knowles 1997). In 2002, the Kansas Department of Wildlife and Parks published the Kansas Black-Tailed Prairie Dog Conservation and Management Plan, which laid out the state's goal to maintain at least 130,000 acres (approximately 52,600 hectares) of black-tailed prairie dog colonies by 2012 (Kansas Black-Tailed Prairie Dog Working Group 2002). While this study only examined black-tailed prairie dog colonies in the northern half of the state's range, it seems likely that Kansas was able to reach this goal in each year examined. However, the extreme decline in black-tailed prairie dog colonies witnessed at the end of this study – a loss of over 18,000 hectares within a single year – is alarming. Over this study period, the number of colonizations diminished, from 733 new colonies established between 2005-2006 to only 332 new colonies established between 2014-2015. While the number of colonizations declined, the number of extinctions increased between 2014-2015. If this trend of an increasing number of extinctions and decreasing number of colonizations continues, it will have serious ramifications for the future of the black-tailed prairie dog.

If the decline of black-tailed prairie dogs in Kansas continues, it will not only impact this one species. It will affect over 150 species that use black-tailed prairie dogs and their colonies as a major source of prey or habitat, including many threatened and endangered species (Clark 1989, Lomolino and Smith 2003b). Their loss will allow woody plant invasion, leading to further decline of the North American grassland ecosystem, and an overall decline in biodiversity (Hale et al. 2020, Field et al. 2016, Sierra-Corona et al. 2015).

This study found that colony area was the most important factor predicting black-tailed prairie dog colony persistence between 2005 and 2015. Therefore, when effectively managing this species in northwest Kansas, I recommend that wildlife managers make sure to protect larger colonies (> 16 ha) from habitat degradation, fragmentation, and excessive control measures. Protecting large colonies is essential to the survival of populations in this region. Protecting large and moderate-sized (> 3 ha, < 16 ha) colonies and allowing them to expand can also increase the populations of the associates that rely on these colonies for food and shelter, increasing the heterogeneity of the grassland ecosystem as a whole (Lomolino and Smith 2001, Stapp et al. 2004).

It is not just larger colonies that need to be protected, however. During Sylvatic plague outbreaks, very large and very small colonies suffer disproportionately (Stapp et al. 2004). Colonies smaller than 3-hectares and greater than 16-hectares were more likely to go extinct during an outbreak than the intermediate-sized colonies (Stapp et al. 2004). While the smaller colonies are more vulnerable to demographic and environmental stochasticity, larger colonies can support larger flea populations and have increased immigration (Stapp et al. 2004). Having colonies of several sizes is integral to maintaining metapopulation dynamics and allowing re-colonization after extinction events.

A few black-tailed prairie dog colonies also need to be large enough to support a population of the near-extinct black-footed ferret. Black-footed ferrets occur exclusively on prairie dog colonies, rely on prairie dogs as their primary prey source, and spend most of their lives in underground burrow systems created by prairie dogs (Jachowski et al. 2010). The US Fish and Wildlife Service's black-footed ferret breeding program is running out of suitable reintroduction habitat (Jachowski et al. 2010). Ferrets require extensive black-tailed prairie dog complexes to support them, and these complexes are now extremely rare (Davidson et al. 2012). One such complex in my study region, Smoky Valley Ranch, a Nature Conservancy property in Logan County, has an established black-tailed prairie dog complex and has attempted to reintroduce a population of black-footed ferrets in the past. This complex and others like it must be protected, as they are crucial to the re-establishment of the black-footed ferret population.

An important challenge to black-tailed prairie dog management will be maintaining populations of black-tailed prairie dogs in a way that is compatible with human activities (Davidson et al. 2012). Because grasslands are vital to agriculture and livestock production, the conflict between black-tailed prairie dogs and humans will not end soon. The continued conservation of black-tailed prairie dog ecosystems is unlikely without changes in management policy, but these changes will not be possible as long as agricultural interests dominate management policy (Mulhern and Knowles 1997). Maintaining both prairie dogs and cattle on the landscape is important ecologically, culturally, and economically (Field et al. 2016). In Kansas, where some local and county governments require people to eradicate black-tailed prairie dogs on their land or face fines, a compromise must be made for effective management. I recommend eliminating eradication requirements, increasing the engagement of local communities in the conservation of this species, and increasing funding for economic incentives whereby landowners receive financial benefits for supporting black-tailed prairie dog populations on their lands.

Even if black-tailed prairie dogs are conserved in the future, if those individuals persist in small, isolated colonies scattered across the landscape, their function as a keystone species and ecosystem engineers will diminish, and the species will become ecologically extinct (Lomolino and Smith 2003a). While the conservation and management options for black-tailed prairie dogs may be limited by practice, it is crucial to address these limits and have a full and detailed understanding of the management options.

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Table 1. The number of black-tailed prairie dog (*Cynomys ludovicianus*) colonies identified in northwest Kansas, total area (ha) occupied by the colonies, and the area (ha) of the largest and smallest colonies from 2005-2015

Year	Number of colonies	Total area of colonies (ha)	Smallest colony (ha)	Largest colony (ha)	Average colony area (ha)
2005	1894	36,663	0.104	1,945	19.36
2006	2256	46,783	0.066	3,107	20.74
2010	1803	41,330	0.067	4,140	22.92
2012	1787	39,547	0.077	4,169	22.13
2014	1812	46,826	0.178	4,054	25.84
2015	1384	28,776	0.055	3,896	20.72

Table 2. The number of black-tailed prairie dog (*Cynomys ludovicianus*) colonies that went extinct and were established in northwest Kansas from 2005-2015.

Time Period	Number of colony extinctions	Number of colonies established
2005-2006	371	733
2006-2010	1067	614
2010-2012	457	441
2012-2014	422	447
2014-2015	760	332

Table 3. The best-performing model per year predicting the persistence of black-tailed prairie dog (*Cynomys ludovicianus*) colonies in northwest Kansas. Sign indicates the direction of the relationship. Zeros indicate no significant relationship. A blank cell indicates the predictor variable was not in the best-performing model.

	Model variables							
Time Period	Colony area	Latitude	Longitude	Neighbor distance	Cultivated crops	Pasture/hay	Developed-low intensity	Barren
2005-2006	+	-	0	0	+	-		
2006-2010	+	-	-		-			+
2010-2012	+		+	0			-	0
2012-2014	+	0	+		0			+
2014-2015	+		+	0	+			+

Table 4. The best five models predicting black-tailed prairie dog (*Cynomys ludovicianus*) colony persistence from 2005-2006. A blank cell indicates the predictor variable was not present in the best-performing model. Present-correct and absent-correct indicate the number of colony survivals and extinctions correctly predicted by the model, respectively. False negative indicates the number of colonies predicted to go extinct that actually survived. False positive indicates the number of colonies predicted to survive that actually went extinct.

	Best five persistence models 2005-2006				
Variable	1	2	3	4	5
Colony area	1.050***	1.051***	1.037***	1.049***	1.047***
Latitude	-0.270***	-0.272***	-0.286***	-0.267***	-0.260***
Longitude	0.127	0.106		0.126	0.156*
Neighbor distance	-0.114			-0.114	-0.122
Surrounding cultivated crops	0.142*	0.127	0.111	0.146	0.145*
Surrounding pasture/hay	-0.207**	-0.200**	-0.222***	-0.206**	-0.206***
Surrounding developed-low intensity					-0.155***
Barren land				0.010	
ΔAIC	0	0.5	0.8	1.6	1.9
Present correct	1251	1254	1251	1252	1251
False negative	32	39	32	31	32
Absent correct	19	19	22	19	19
False positive	259	259	256	259	259

*p<0.05 **p<0.01 ***p<0.001

Table 5. The best five models predicting black-tailed prairie dog (*Cynomys ludovicianus*) colony persistence from 2006-2010. A blank cell indicates the predictor variable was not present in the best-performing model. Present-correct and absent-correct indicate the number of colony survivals and extinctions correctly predicted by the model, respectively. False negative indicates the number of colonies predicted to go extinct that actually survived. False positive indicates the number of colonies predicted to survive that actually went extinct.

	Best five persistence models 2006-2010				
Variables	1	2	3	4	5
Log(Colony area)	0.856***	0.858***	0.856***	0.860***	0.859***
Latitude	-0.443***	-0.416***	-0.445***	-0.418***	-0.417***
Longitude	-0.373***	-0.356***	-0.377***	-0.360***	-0.357***
Nearest neighbor distance			0.019	0.016	
Surrounding cultivated crops	-0.157**	-0.149**	-0.159**	-0.151**	-0.149**
Surrounding pasture/hay		0.076		0.076	0.076
Surrounding developed-low intensity					0.011
Surrounding barren land	0.125*	0.128*	0.126*	0.128*	0.128*
ΔAIC	0	0.1	1.9	2	2
Present-correct	711	713	711	713	712
False-negative	271	269	271	269	270
Absent-correct	602	610	604	609	612
False-positive	309	301	307	302	299

*p<0.05 **p<0.01 ***p<0.001

Table 6. The best five models predicting black-tailed prairie dog (*Cynomys ludovicianus*) colony persistence from 2010-2012. A blank cell indicates the predictor variable was not present in the best-performing model. Present-correct and absent-correct indicate the number of colony survivals and extinctions correctly predicted by the model, respectively. False negative indicates the number of colonies predicted to go extinct that actually survived. False positive indicates the number of colonies predicted to survive that actually went extinct.

	Best five persistence models 2010-2012				
Variables	1	2	3	4	5
Log(Colony area)	1.018***	1.013***	1.021***	1.017***	1.018***
Latitude				0.024	
Longitude	0.200**	0.178*	0.207**	0.205**	0.183*
Nearest neighbor distance	0.148	0.164*	0.152	0.141	0.170*
Surrounding cultivated crops					
Surrounding pasture/hay			0.061		0.061
Surrounding developed-low intensity	-0.178*	-0.171*	0.176*	0.180*	0.174*
Surrounding barren land	-0.077		-0.078	-0.075	
ΔAIC	0	1.4	2.1	2.6	2.7
Present-correct	1077	1078	1078	1080	1076
False-negative	45	44	44	42	46
Absent-correct	57	55	56	57	55
False-positive	275	277	276	275	277

*p<0.05 **p<0.01 ***p<0.001

Table 7. The best five models predicting black-tailed prairie dog (*Cynomys ludovicianus*) colony persistence from 2012-2014. A blank cell indicates the predictor variable was not present in the best-performing model. Present-correct and absent-correct indicate the number of colony survivals and extinctions correctly predicted by the model, respectively. False negative indicates the number of colonies predicted to go extinct that actually survived. False positive indicates the number of colonies predicted to survive that actually went extinct.

	Best five persistence models 2012-2014				
Variables	1	2	3	4	5
Log(Colony area)	1.154***	1.152***	1.155***	1.145***	1.144***
Latitude	0.102	0.102	0.097		
Longitude	0.141**	0.122	0.125	0.137*	0.133*
Nearest neighbor distance					
Surrounding cultivated crops	-0.111		-0.110	-0.115	
Surrounding pasture/hay					
Surrounding developed-low intensity		0.088	0.088		
Surrounding barren land	0.189**	0.243**	0.192*	0.167	0.218*
ΔAIC	0	0.4	0.7	1.0	1.2
Present-correct	1080	1080	1081	1078	1076
False-negative	59	59	58	61	63
Absent-correct	79	83	79	80	82
False-positive	277	273	277	276	274

*p<0.05 **p<0.01 ***p<0.001

Table 8. The best five models predicting black-tailed prairie dog (*Cynomys ludovicianus*) colony persistence from 2014-2015. A blank cell indicates the predictor variable was not present in the best-performing model. Present-correct and absent-correct indicate the number of colony survivals and extinctions correctly predicted by the model, respectively. False negative indicates the number of colonies predicted to go extinct that actually survived. False positive indicates the number of colonies predicted to survive that actually went extinct.

	Best five persistence models 2014-2015				
Variables	1	2	3	4	5
Log(Colony area)	1.011***	1.020***	1.011***	1.010***	1.012***
Latitude					0.017
Longitude	0.326***	0.305***	0.325***	0.324***	0.331***
Nearest neighbor distance	-0.094		-0.095	-0.096	-0.096
Surrounding cultivated crops	0.131*	0.119*	0.127*	0.132*	0.134*
Surrounding pasture/hay			-0.038		
Surrounding developed-low intensity				0.023	
Surrounding barren land	0.160	0.170	0.160	0.161	0.163
ΔAIC	0	0.5	1.5	1.8	1.9
Present-correct	834	838	833	832	836
False-negative	218	214	219	220	216
Absent-correct	410	419	410	411	409
False-positive	350	341	350	349	351

*p<0.05 **p<0.01 ***p<0.001

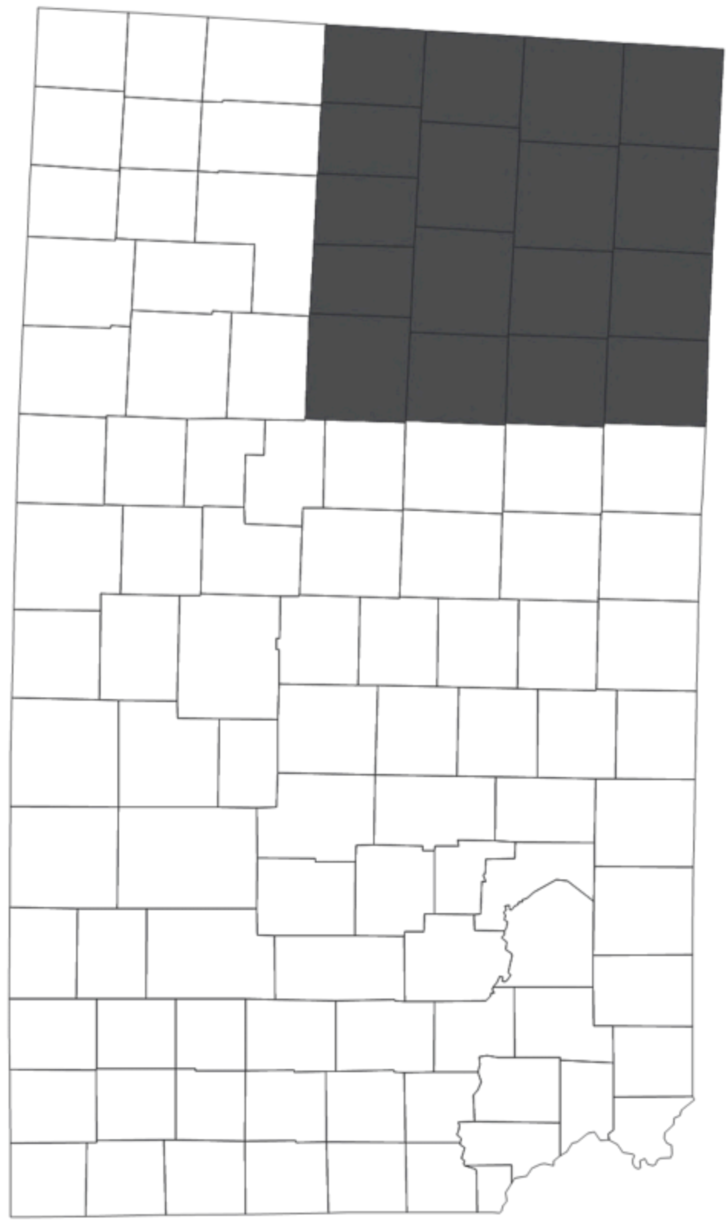

Figure 1. Map of the state of Kansas. The 17 counties comprising the northwest corner of the state that were surveyed for this study are seen in dark grey.

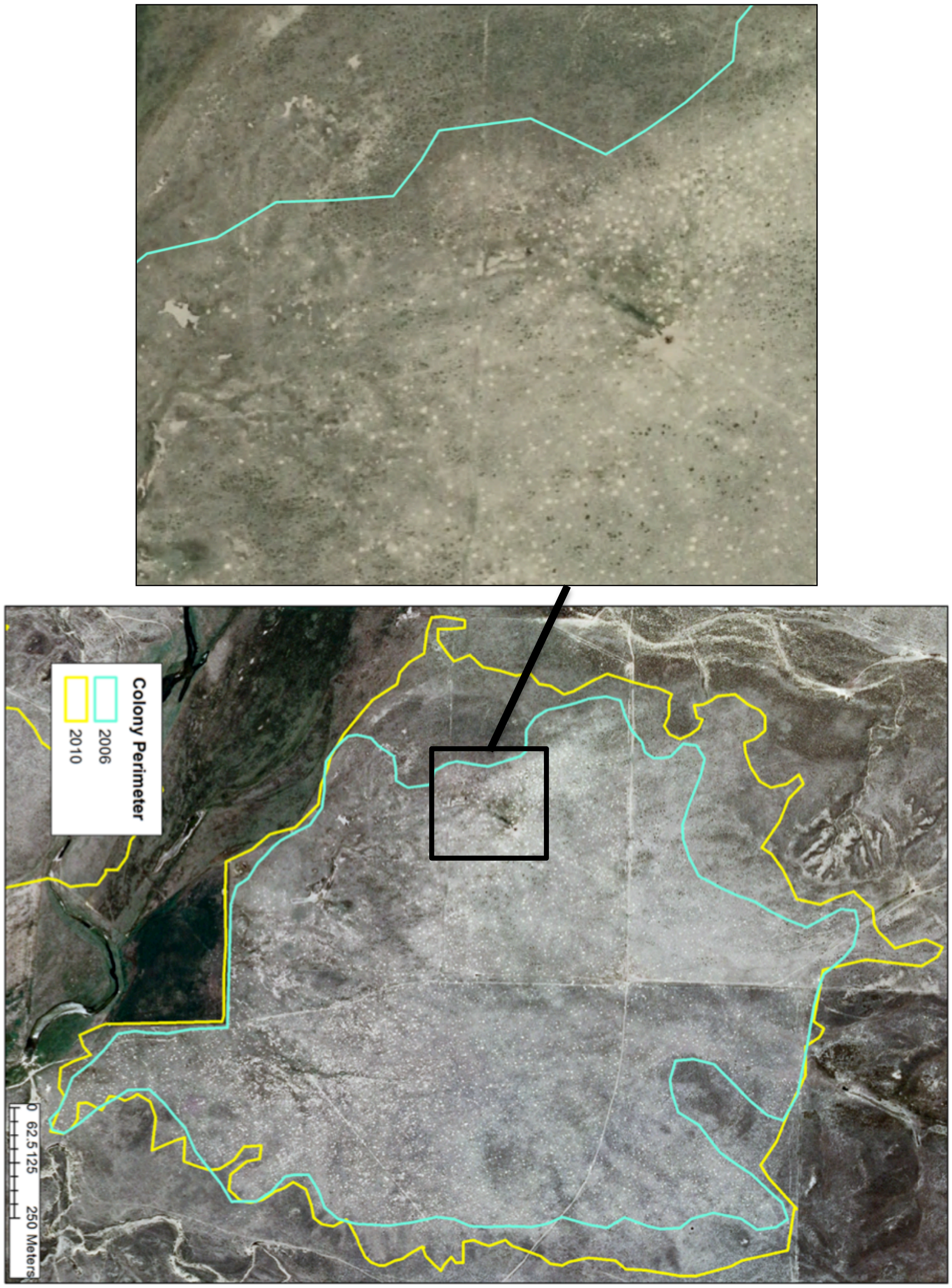

Figure 2. An example of a delineated black-tailed prairie dog colony located on NAIP imagery in Logan county Kansas in 2006, with the 2010 colony perimeter overlain. Note in the image on the left the milky-hued clip lines and small white burrow mounds that are used to distinguish this as an active black-tailed prairie dog colony

APPENDIX A

Descriptions of the 15 land cover classes present in northwest Kansas in the 2006 and 2011 National Land Cover Database (NLCD) rasters (USGS 2011).

Land cover class	Definition
Open water	All areas of open water, generally with less than 25% cover or vegetation or soil
Developed – open space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed – low intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
Developed – medium intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
Developed – high intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.
Barren land	Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
Shrub/scrub	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Grassland/herbaceous	Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Pasture/hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
Cultivated crops	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
Woody wetlands	Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

APPENDIX B

The best five models per year predicting black-tailed prairie dog colony persistence from 2005-2015. Plus (+) sign indicates variable was present in the model.

Time Period	Model	Variables
2005-2006	1	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Pasture/hay
	2	Log (Colony area) + Latitude + Longitude + Cultivated crops + Pasture/hay
	3	Log (Colony area) + Latitude + Cultivated crops + Pasture/hay
	4	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Pasture/hay + Barren land
	5	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Pasture/hay + Developed-low
2006-2010	1	Log (Colony area) + Latitude + Longitude + Cultivated crops + Barren land
	2	Log (Colony area) + Latitude + Longitude + Cultivated crops + Pasture/hay + Barren land
	3	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Barren land
	4	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Pasture/hay + Barren land
	5	Log (Colony area) + Latitude + Longitude + Cultivated crops + Pasture/hay + Developed-low + Barren land
2010-2012	1	Log (Colony area) + Longitude + Nearest neighbor + Developed-low + Barren land
	2	Log (Colony area) + Longitude + Nearest neighbor + Barren land
	3	Log (Colony area) + Longitude + Nearest neighbor + Pasture/hay + Developed-low + Barren land
	4	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Developed-low + Barren land
	5	Log (Colony area) + Longitude + Nearest neighbor + Pasture/hay + Developed-low
2012-2014	1	Log (Colony area) + Latitude + Longitude + Cultivated crops + Barren land
	2	Log (Colony area) + Latitude + Longitude + Developed-low + Barren land
	3	Log (Colony area) + Latitude + Longitude + Cultivated crops + Developed-low + Barren land
	4	Log (Colony area) + Longitude + Cultivated crops + Barren land
	5	Log (Colony area) + Longitude + Barren land
2014-2015	1	Log (Colony area) + Longitude + Nearest neighbor + Cultivated crops + Barren land
	2	Log (Colony area) + Longitude + Cultivated crops + Barren land
	3	Log (Colony area) + Longitude + Nearest neighbor + Cultivated crops + Pasture/hay + Barren land
	4	Log (Colony area) + Longitude + Nearest neighbor + Cultivated crops + Developed-low + Barren land
	5	Log (Colony area) + Latitude + Longitude + Nearest neighbor + Cultivated crops + Barren land

APPENDIX C

Institutional Animal Use and Care Committee Form D – Research and Scholarly Activities: Exempt Protocol Form

Revised 12/15/16

FORT HAYS STATE UNIVERSITY
Forward thinking. World ready.

Institutional Animal Use and Care Committee

For Office Use Only:
Protocol #
Date Received:
PI Name:
Study Title:

FORM D
Research and Scholarly Activities
Exempt Protocol Application Form

This form is to be completed by Principal Investigators, graduate students, curators or Museum Directors.
When the form is complete, email the form to IACUC@fhsu.edu. Appropriate and current licensing/collection permits must be on file in the Office of Scholarship and Sponsored Programs, 306D Picken Hall or attached to the email. **EFFECTIVE APRIL 1, 2015**: Completion of the appropriate CITI training is required prior to submission of Form D by faculty. Graduate students and staff at Sternberg Museum, the Wetlands Center and Farm Supervisors that are involved in the use and care of animals are also required to complete the appropriate CITI training prior to submission of protocols for IACUC review.

Exemption Request

Some activities involving animals may be exempt. SEE BELOW FOR CRITERIA. IF YOU BELIEVE THE PROPOSED ACTIVITY IS EXEMPT, PLEASE INDICATE THE TYPE OF ACTIVITY:

☑ Field Studies: Research and/or teaching field studies are exempted from filing an animal care and use protocol and obtaining IACUC approval provided that the field studies are only observational in nature and do not involve capturing/trapping, physical/chemical restraint, and/or invasive procedures.

☐ Studies That Do Not Use Live Animals: Research, teaching, or testing protocols that do not involve the care or use of live animals *(i.e.,* only involves the use of animal cadavers, body parts, organs, tissues, blood, *etc.)* are categorically exempt from having to file an animal care and use protocol and obtain IACUC approval provided that the animal cadavers, body parts, organs, tissues, blood, *etc.* are obtained from an IACUC approved source and are disposed of in accordance with state law and FHSU policy for disposal of hazardous/infectious/pathologic waste. IACUC approved sources for animal cadavers, body parts, organs, tissues, blood, *etc.* are listed below:

- USDA inspected slaughterhouses
- Kansas State Veterinary Diagnostic Laboratory (KSVDL) *(i.e.,* derived from animals presented for euthanasia and/or necropsy that would otherwise be disposed of as pathological waste.)
- Kansas State Veterinary Health Center (KSVHC) *(i.e.,* derived from veterinary hospital patients that die or are euthanized that would otherwise be disposed of as pathological waste with the consent of the client/owner.)
- A FHSU IACUC approved animal use protocol *(i.e.,* derived from dead animals that would otherwise be disposed of as pathological waste.) *(Note: An IACUC approved A* animal care and use protocol *is required if additional/special ante-mortem procedures are required in order to harvest/utilize the cadaver, body parts, organs, tissues, blood, etc.)*
- Commercial grocery store and/or meat market *(i.e.,* fresh/frozen beef, pork, poultry, fish, *etc.)*

☐ Studies That Use Intact Animal Cadavers from Extramural Sources: All research, teaching, or testing protocols that involve the use of intact animal cadavers *(i.e.,* whole dead body of a warm blooded animal) from an extramural source *(i.e.,* non-FHSU) must be covered by an IACUC approved animal care and use protocol. The use of cold-blooded vertebrate cadavers obtained from extramural sources is categorically exempt and does not require IACUC review or approval.

☐ Studies That Use Fertilized Shell Eggs or Embryos: All research, teaching, or testing that uses fertilized shell eggs (e.g., chicken eggs) or embryos of fertilized shell eggs is categorically an "exempt activity" provided that:

- the fertilized eggs/embryos are destroyed and not allowed to hatch; **and**
- the activity does not involve the care or use of the adult female which laid or was the source of the eggs/embryos.

☐ Other Exempt Animal Use Activities: Principal investigators/instructors (PI's) wishing to conduct research, teaching, or testing that involves the use of animal cadavers, body parts, organs, tissues, blood, *etc.* that may qualify as an "exempt activity" and is not otherwise addressed/covered above shall complete the information below and submit it to the OSSP for a determination on whether or not their proposed "animal use" is an "exempt activity" or requires IACUC approval. Please provide the following information:

- A brief description of what the animal cadavers, body parts, organs, tissues, *etc.* will be used for;
- The source(s) of animal cadavers, body parts, organs, tissues, blood, *etc.;*
- Where the animal cadavers, body parts, organs, tissues, *etc.* will be stored and/or used; and
- How the animal cadavers, body parts, tissues, blood, *etc.* will be disposed of.

Section 1: General Information

Principal Investigator Name (Last, First, MI): Channell, Robert, B

Degree: PhD Title: Professor of Biological Sciences

Department, including building and room # Biological Sciences; Alber

E-mail: rbchannell@fhsu.edu On-Campus telephone: 785-628-5 Fax: 785-628-4

Emergency Contact (Home, mobile): 785-650-407C

Date CITI training Completed:____________________

Please list all principal investigators (Co-PIs) such as faculty members from this and other institutions, federal and state agency personnel, and research group leader(s) from company(s) involved in the project.

Jamie A Oriez	Biological Sciences	Fort Hays State U
Co-PI	Department	Institution

Date CITI training Completed: 3/23/2017

Co-PI	Department	Institution

Date CITI training Completed: ______________________________

Co-PI	Department	Institution

Date CITI training Completed: ______________________________

Proposed title of the project: An Examination of the Factors Affecting the Persistence of Pı

Proposed project start date: 05/01/2017 Proposed project termination date: 05/01/2018

*Upon approval, the protocol is in effect for 3 (three) years, starting at the proposed start date, regardless of the termination date. The PI must submit a request form for extension PRIOR to the expiration date. Otherwise, a new protocol application must be submitted.

Type of protocol (Check one)

(●) New ( ) Continuation/Renewal ( ) Resubmission

Type of project (Check one)

(●) Research ( ) Museum collection ( ) Exhibition

Funding Source

Extramural (list the name of funding agency, title of grant, and business office account number):

____

Intramural (Check one):

Academic Department (specify) Biological Sci Graduate School (●) URE ( ) K-INBRE ( ) Other ( )

Section 2. Investigator Assurance

I, Rob Channell ____________________________ agree to abide by the USDA Animal Welfare Regulations (CFR 1985). I also have reviewed and agree to abide by all institutional policies governing the use of vertebrate animals for research, testing, teaching, or demonstration purposes at FHSU. I assure that the proposed studies are not unnecessary duplication of experiments conducted previously. I also assure that animals used in the study will receive humane care throughout the duration of the study and that, in the event that animals in this study experience pain or distress which cannot be adequately relieved, animals will be euthanized humanely and immediately based on recommendations of the veterinarian or IACUC.

The PI's name should be typed or signed below.

Rob Channell	7 April 2017
Principal Investigator	Date

The approval period is for three years from the date this protocol is approved. The Principal Investigator is responsible for submitting the appropriate forms to modify the approved activities or for a renewal prior to the expiration date. Otherwise, a new protocol application must be submitted.

For Office Use Only

Exempt? ◯ Not Exempt? ◯ Modifications Required? ◯

Date Approved:

Annual Review Received Dates:

Expiration Date:

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Thesis: The Influence of Landscape Factors on Black-Tailed Prairie Dog (Cynomys ludovicianus) Colony Persistence in Northwest Kansas

Author: Jamie Oriez

Signature: Jamie Oriez

Date: November 17 2020