Factors Limiting the Expansion of Black-tailed Prairie Dog Colonies at Their Northern Extent

by

Tehlu Singh

M.Sc. Wildlife Science, University of Kota (India), 2017

B.Tech, Punjabi University Patiala (India), 2015

Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

In the
Ecological Restoration Program
Faculty of Environment (SFU)
and
School of Construction & Environment (BCIT)

SIMON FRASER UNIVERSITY
British Columbia Institute of Technology
2018 - 2020

Approval

Name:	**Tehlu Singh**
Degree:	**Master of Ecological Restoration**
Title:	**Factors Limiting the Expansion of Black-tailed Prairie Dog Colonies at Their Northern Extent**
Examining Committee:	**Chair: Doug Ransome** Supervisor, BCIT
	Anayansi Cohen-Fernandez Examiner Co-Supervisor, BCIT
	Kim Ives Examiner Faculty, BCIT
Date Defended/Approved:	17 April 2020

Abstract

Prairie dogs (*Cynomys ludovicianus*) are considered a keystone species due to their ecological role in maintaining the prairies. In Canada, they are federally listed as a threatened species. This study was conducted to identify the limiting factors to the expansion of prairie dog colonies in Grasslands National Park, Saskatchewan. I tested different hypotheses to compare landforms, vegetation, and soil characteristics in three treatments: consistently occupied (*Consistent*), inconsistently occupied (*Inconsistent*), and never occupied (*Buffer*) by prairie dogs. I sampled four prairie dog colonies (*blocks*) from 17 July 2019 to 28 August 2019 using a randomized complete block design. I used ANOVA to test variables for significant differences among treatments. My results showed that hills, water channel, shrublands, grass cover, shrub cover and vegetation height classes (>30 cm) were significantly higher ($p < 0.05$) in Buffer compared to Consistent and Inconsistent. Shrubs and tall vegetation should be mowed down to enhance the expansion of prairie dog colonies for restoring their population.

Keywords: prairie dogs; *Cynomys ludovicianus*; colony expansion; barriers; habitat use; restoration

Acknowledgments

I would like to acknowledge Calgary Zoo Centre for Conservation Research for giving me this wonderful opportunity to study Black-tailed prairie dogs for my master's research. I am heartily thankful to my project partners Dr. Axel Moehrenschlager, Tara Stephens, and Sian Wilson, for believing in me to provide me with funding and guidance throughout my research. I am grateful to Tara and Sian for their immense support since the beginning of this project to its end.

I would like to thank my supervisor Douglas Ransome for sharing his valuable time and knowledge to design and implement this project. His feedbacks helped me to advance my writing, technical and critical thinking skill. He will always be a big inspiration in my wildlife career. I feel lucky to be his student - thank you, Doug. I would also like to thank my co-supervisor, Anayansi Cohen Fernandez, for helping in designing my study and setting up a soil lab to run my analysis. I am thankful to my School of Construction and Environment at BCIT for covering my travel expenses and providing me facilities to work on my soil analysis.

My research would not have been completed so effectively without support from my department faculty and staff members at BCIT and SFU. I would like to thank Dr. Ken Ashley, Dr. Ruth Joy, Dr. Susan, Dr. Gwilym for training me in ecological restoration. I am especially thankful to Giti Abouhamzeh, Dave Harper, Millie Kuyer, Julia, and Jeff Becker for helping me with logistics. I would like to thank Renata Wood from Civil engineering department for providing me equipment for soil analysis.

Not the less, I am thankful to all my housemates in Val Marie field house, Stefano and Maggi from Grasslands National Park and the local community of Val Marie for providing me such a memorable experience in the remote village of Canada. I am especially thankful to Amber for helping me collecting my vegetation data and Mandeep for volunteering in my project.

I am particularly grateful to my family, friends, and mentors who supported me throughout my master`s program. I am thankful to ‘Waheguru’ for providing me this excellent learning opportunity and building confidence to pursue my dreams in wildlife restoration. In the end, I am thankful to mother nature for my first experience of exploring and enjoying the wilderness in Canada.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Prairie dog biology and their decline

Prairie dogs (*Cynomus* spp.) are social, burrowing animals forming an integral part of the North American prairie grasslands (Hoogland, 2006). Prairie dogs maintain species diversity, ecosystem function and habitat heterogeneity with their feeding and burrowing behavior (Miller et al., 2007; Davidson et al., 2012), and so are regarded as a keystone species (Kotliar et al., 2006) and habitat engineer (Jones et al., 1994).

There are five sub-species of prairie dogs in two subgroups (black-tailed and white-tailed) within the genus *Cynomys* (Hoogland, 2006). The black-tailed subgroup (subgenus *Cynomys*) contains black-tailed prairie dog (*C. ludovicianus*) and mexican prairie dog (*C. mexicanus*). The white-tailed subgroup (subgenus *Leucocrossuromys*) contains gunnison prairie dog (*C. gunnisoni*), utah prairie dog (*C. parvidens*), and white-tailed prairie dog (*C. leucurus*). Among these, black-tailed prairie dog ('prairie dogs' from here) is the most widely distributed, ranging from southern Canada to northern Mexico (Knowles et al., 2002).

In the last 20th century, black-tailed prairie dog populations suffered drastic decline across their entire range (Proctor et al., 2006) due to multiple factors such as habitat loss and fragmentation from native prairies conversion into agriculture and urban lands (Hoogland, 2006), prairie dog poisoning programs (Delting, 2006), and sylvatic plague outbreak (Cully et al., 2010). At present, prairie dogs are distributed within 2% of their historical range (Knowles et al., 2002; Proctor et al., 2006; Miller et al., 2007).

The decline in prairie dog populations negatively impacted the native prairies as the result of loss of ecological service provided by prairie dogs to habitat (Ceballos et al., 2010; Lourdes et al., 2013) and to associated wildlife species such as burrowing owls (*Athene cunicularia*), mountain plover (*Charadrius montanus*) and black-footed ferrets (*Mustela nigripes*) (Miller et al., 2007; Davidson et al., 2012). Burrowing owls and mountain plovers rely on prairie dog colonies for their nesting habitat (Kotliar et al., 1999), and black-footed ferrets prey on prairie dogs (Kotliar et al., 2006; Miller et al., 2007). The decline in the prairie dog populations enhanced shrub encroachment (Van

Auken, 2000), which reduced forage quality and quantity for plains bison (*Bison bison*) (Fahnestock & Delting, 2002).

1.2. Background and Rationale

In Canada, a small population of prairie dogs is confined within and around the west block of Grasslands National Park (GNP) in southern Saskatchewan. It is geographically isolated from all other populations found in the US (COSEWIC, 2011). Federally, it is listed as 'threatened' (SARA, 2020) and provincially ranked as S2 (Imperiled/very rare) (Saskatchewan Conservation Data Centre, 2019). The primary drivers of historical declines and current fluctuation in abundance of this population are poorly understood, but most likely, climate plays an important role (Stephens et al., 2018). Also, the spatial analysis of prairie dog colonies from year 2000 to 2017 (GIS data for prairie dog colonies was shared by GNP) showed that colonies didn't expand beyond their maximum perimeter observed in 2009.

Severe winters, short growing seasons, and an expected increase in drought periods can potentially limit food availability for prairie dogs in Canada (COSEWIC, 2011; Lloyd et al., 2013). Based on research in the United States, prairie dogs prefer areas with high availability and quality of grass and forb. Their diet contains more than 85% grass and a maximum of 12% forb (Uresk,1984; Clippinger, 1989;). Prairie dogs prefer areas with low shrub density and low vegetation height (optimal <30 cm and maximum ≤60 cm) for predator vigilance (Clippinger, 1989; Hoogland, 2006; Avila-Flores, 2009). They select terrain with slope <10 degrees, with deep (>1 m), well-drained soil suitable for burrow construction (avoiding extreme soil and rocky content) (Reading & Matchett, 1997; Clippinger, 1989; Hoogland, 2006).

Peripheral populations often have less optimal habitat comparing to center of their distribution (Brown, 1984; Caughley et al., 1988). So, animals become more selective to choose habitat patches at periphery of their distribution (Brown, 1984; Proctor, 2006; Avila-Flores, 2009). This selection can decrease the frequency of occurrence and population density at periphery (Brown, 1984; Hampe & Petit, 2005). Selection criteria could be different at the regional and site-specific scale (Johnson,1980). The relationship between occupancy and habitat attributes could be studied by comparing used and unused sites (Manley, 2002).

Few studies have been done in Canada to understand the mechanism behind fluctuation of prairie dog population and steady maximum colonies extent, using both observational and manipulative experiments. Lloyd (2011) examined if food is a limiting factor for growth of prairie dog population and expansion of prairie dog colonies in GNP using a control. She did not find significant results for food as a limiting factor to prairie dogs. She also stated that predator pressure is not such abundant to decline the prairie dog populations. Lloyd suggested that prairie dog colonies are surrounded by tall vegetation, a non-preferred food, which might be limiting factor for expansion of prairie dog colonies in GNP, along with a temporal variation in food demands.

Stephens (2012) studied factors associated with the distribution of prairie dogs by comparing abiotic variables (elevation, slope, terrain ruggedness, mean winter solar radiation, surficial geology, and soil texture) in used and unused units on a regional level using remote sensing data. She found that elevation, slope, and terrain ruggedness were significantly lower in used sites. She did not use vegetation (primarily a food requirement) as a predictor variable because the difference in vegetation characteristics is heavily influenced on and off colonies by prairie dogs foraging and clipping behavior (Koford, 1958; Hoogland, 1995). Stephens et al. (2018) studied the potential impact of climate change on prairie dog populations in Canada. Their study suggested that the predicted increase in drought conditions may affect prairie dog populations in the future.

Thorpe and Stephens (2017) developed a habitat suitability model (HSM) as an early initiative to form a conservation strategy for the population of prairie dogs and greater sage grouse (*Centrocercus urophasianus*) at a regional scale. They mapped potential habitat for prairie dogs in the west block of GNP, using coarse remote sensing data on slope, mean winter solar radiation, soil texture, pH, organic carbon, and distance from water. They did not use vegetation data as a result of prairie dogs influence (Thorpe & Stephens, 2017).

1.3. Study Approach

My study goal was to collect ground data on both abiotic and biotic factors to compare between occupied and non-occupied sites, to see if they are limiting the expansion of prairie dog colonies in GNP. I classified my variables into three types: landforms (hills, water channel, shrublands, topology), vegetation (grass cover, forb cover, shrub cover and vegetation height), and soil (soil texture, relative soil moisture , soil pH and nutrients). I selected these variables based on their direct and indirect influence on prairie dogs habitat requirements and preference (Koford,1958; Clippinger, 1989; Hoogland, 1995; Reading & Matchett, 1997; Roe & Roe, 2003; Gummer, 2005; Avila-Flores, 2009; Moebius-Clune et al., 2016). Soil pH and nutrients have a direct influence on vegetation growth and thus could indirectly affect the availability and quality of forage for prairie dogs (Moebius-Clune et al., 2016).

When I compared the boundaries of prairie dog colonies from year 2000 onwards in ArcMap (10.6), it was interesting to see that some habitat was consistently occupied by prairie dogs in every year. In contrast, some patches were inconsistently occupied by prairie dogs. Prairie dogs could have a significant impact on vegetation and soil at occupied (active), abandoned (inactive) sites as a result of their foraging, clipping, and burrowing activities (Osborn and Allain,1949; Koford,1958; Klatt and Hein 1978; Coppock et al.,1983; Barth et al., 2014; Gervin et al., 2019). Considering this, I divided occupied sites into Consistent and Inconsistent treatments. Consistently occupied sites might represent a preferred habitat in comparison to Inconsistently occupied (T. Stephens, personal communication, May 25, 2019).

I tested different hypotheses to see if landforms, vegetation, and soil characteristics were significantly different across occupied (Consistent & Inconsistent) and non-occupied sites (Buffer) of prairie dogs. This study will fulfill the research gap in understanding the critical limiting factors for the expansion of prairie dog colonies in GNP. This information will be further useful to refine the Habitat Assessment Index (HAI) (unpublished, Calgary Zoo) as a decision tool for the restoration and creation of prairie dog colonies in GNP.

Chapter 2. Study Area

2.1. Location

This study was conducted in GNP (49°070N 107°450W), situated in southern Saskatchewan near the United States border (Fink, 2014). GNP was founded in 1981 to protect an area of 905.52 km^2. It is divided into isolated east and west blocks, both having different physical characteristics (He & Guo et al., 2006). The east block contains the badlands of rock creek and wood mountains uplands. The west block is bisected by the Frenchman River valley (Parks Canada Agency, 2016) and subdivided into north and south sections based on grazing regime. The north section is grazed by bison whereas the south section is grazed by cattle. Prairie dogs colonies (n=20) are distributed along the Frenchman river, 18 in West block (ten in North and eight in South) and two colonies lies outside park boundary (Figure 1).

2.2. Climate

The climatic condition of the park is semi-arid, with mean temperature varying between 12°C in January to 18°C in July. The minimum temperature recorded in January was -49°C and the highest was 41°C in July (Fink, 2014). The average annual precipitation is 398 mm and it falls mostly in June and July. Summer drought is quite common and occur frequent; the most recent severe drought occurred in 2017 (T. Stephens, personal communication, May 20, 2020).

2.3. Flora and fauna

GNP is classified as a mixed-grass prairie. It is a transitional zone between tallgrass prairie and short grass prairie (Bragg, 1995). Uplands, valleys, and badlands characterize the vegetation. Uplands are dominated by spear grass (*Heteropogon contortus*), needle and thread grass (*Hesperostipa comate*), and blue grama (*Bouteloua gracilis*) grass and western wheatgrass (*Pascopyrum*). Valley vegetation communities mainly consist of western and northern wheatgrass (*Agropyron cristatum*) and sagebrush (*Artemisia tridentate*) with shrubs and occasional trees along the Frenchmen River (Zhaoqin & Xulin, 2012). Sloped communities have mixed upland and valley vegetation species. Crested wheatgrass (*A. cristatum*) and smooth bromegrass (*Bromus inermis*) are two predominant invasive species in GNP(Li, 2017).

GNP contains about 300 wildlife species including many endangered and threatened species such as burrowing owl, greater sage grouse, greater short-horned lizard (*Phrynosoma hernandesi*), little brown myotis (*Myotis lucifugus*), mountain plover, sprague pipit (*Anthus spragueii*) and prairie rattlesnake (*Crotalus viridis*) (COSEWIC, 2011). The Extirpated species, such as swift fox (*Vulpes velox*), plains bison, and black-footed ferret were reintroduced in GNP in 1983, 2006 and 2009 respectively (Parks Canada Agency, 2016). At present, there is no recent sighting of reintroduced black-footed ferret (T. Stephens, personal communication, June 5, 2020), but swift fox and plains bison got down listed to threatened species (SARA, 2019).

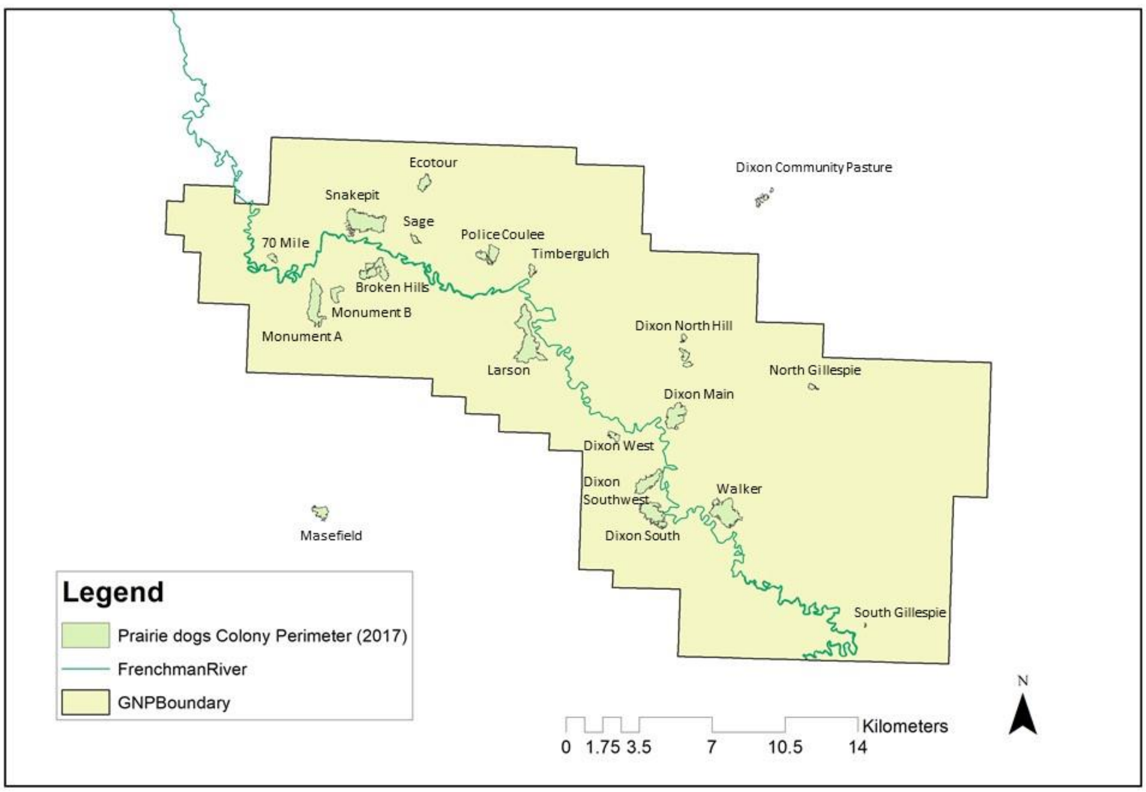

Figure 1: Map of west block of Grasslands National park, Saskatchewan showing the location of prairie dog colonies in 2017. Colonies were distributed along the Frenchman River, 18 colonies lying within west block and two colonies are present outside the park boundary.

Chapter 3. Goals and Objectives

3.1. Goal: To identify factors limiting the expansion of prairie dog colonies in GNP.

3.1.1. Objective: To evaluate if landforms are limiting the expansion of prairie dog colonies in GNP.

a. **Hypothesis:** Presence of hills are limiting the expansion of prairie dog colonies.

Prediction: Hills are present higher in Buffer comparing to Inconsistent and Consistent.

b. **Hypothesis:** Presence of shrublands are limiting the expansion of prairie dog colonies.

Prediction: Shrublands are present higher in Buffer comparing to Inconsistent and Consistent.

c. **Hypothesis:** Presence of water channel is limiting the expansion of prairie dog colonies.

Prediction: Water channels are present higher in Buffer comparing to Inconsistent and Consistent.

d. **Hypothesis:** Topology limits the expansion of prairie dog colonies.

Prediction: Buffer has steeper, highly undulating terrain in comparison to Inconsistent and Consistent.

3.1.2. Objective: To evaluate if vegetation composition and structure is limiting the expansion of prairie dog colonies.

a. **Hypothesis:** Vegetation composition is limiting the expansion of prairie dog colonies.

Prediction: Buffer has higher shrub cover, low grass, and forb cover in comparison to Inconsistent and Consistent.

b. **Hypothesis:** Vegetation height is limiting the expansion of prairie dog colonies.

Prediction: Buffer has high vegetation height in comparison to Inconsistent and Consistent.

3.1.3. Objective: To evaluate if soil characteristics are limiting the expansion of prairie dog colonies.

a. **Hypothesis**: Soil texture and relative soil moisture is limiting the expansion of prairie dog colonies.

Prediction: Buffer has unsuitable soil texture and low relative soil moisture in comparison to Inconsistent and Consistent.

b. **Hypothesis**: Soil pH and nutrients (organic matter (C), available nitrogen (ammonia (NH_4), nitrate (NO_3)), and phosphorus (P) are limiting the expansion of prairie dog colonies extent:

Prediction: Buffer has either acidic or alkaline soil, lower C, NH_4, $NO_{3,}$ and P in comparison to Inconsistent and Consistent.

Chapter 4. Methods

4.1. Sampling design:

Sampling was conducted in four prairie dog colonies (Sage, Monument, Police, and Larson) in northern section of GNP, from 17 July 2019 to 28 August 2019 (Figure 2). I combined Monument colonies A and B into a single sampling site because of their proximity to each other. Colonies were chosen based on expansion potential as per the HSM developed by Thorpe and Stephens (2017) and Parks Canada priorities for multi-species conservation (L. Stefano, personal communication, June 3, 2019). Following a randomized complete block design (RCBD) (Morrison et al., 2009), I stratified colonies into three treatments: Consistent, Inconsistent, and Buffer (Figure 2). Treatments were classified based on spatial analysis of boundaries of prairie dogs colonies from year 2000 to 2017 in ArcMap (10.6) using the GIS database provided by Parks Canada.

Treatment ‘Consistent’ was mapped as an occupied area by prairie dogs every year since 2000, and ‘Inconsistent’ was mapped as an intermittently occupied area by prairie dogs from 2000 to 2017. The ‘Buffer’ was mapped as an area unoccupied by prairie dogs stretched to 120 m by merging occupied (Consistent & Inconsistent) areas since 2000. Buffer width was selected as double the average size of prairie dog coterie (0.3 ha) given by Hoogland (1995). In each treatment, I laid 25 points systematically (at an equal distance) to sample landform and vegetation variables (Figure 3). For soil sampling, I established six points systematically to collect soil samples (Figure 4). If a sampling point laid on or near the edge of other treatments, I moved the point 20 m inside relative treatment in a random direction to avoid the effect of other treatment.

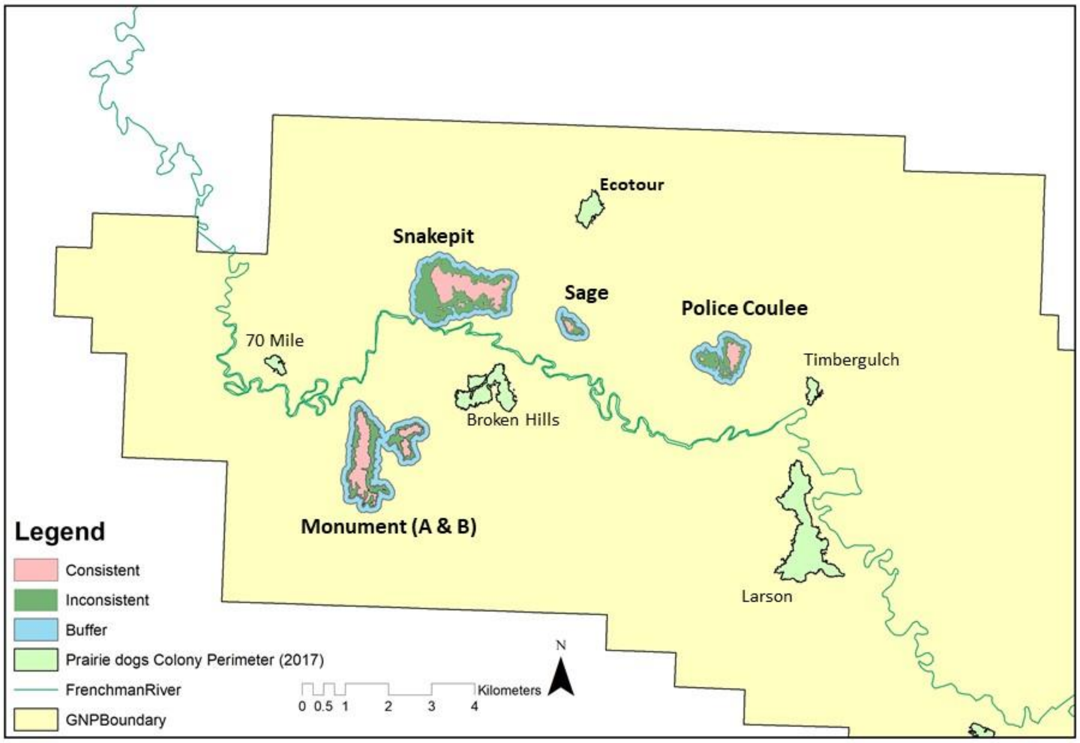

Figure 2: Map of northern section of Grasslands National Park (west block), Saskatchewan, representing nine colonies (merged Monument A & B). Four sampling sites (Sage, Monument, Snakepit, Police (Police Coulee)) were selected for sampling (highlighted in multi-colors) and stratified into three treatments: Consistent (in rose red), Inconsistent (in green), and Buffer (in blue) during 17 July 2019 - 28 August 2019.

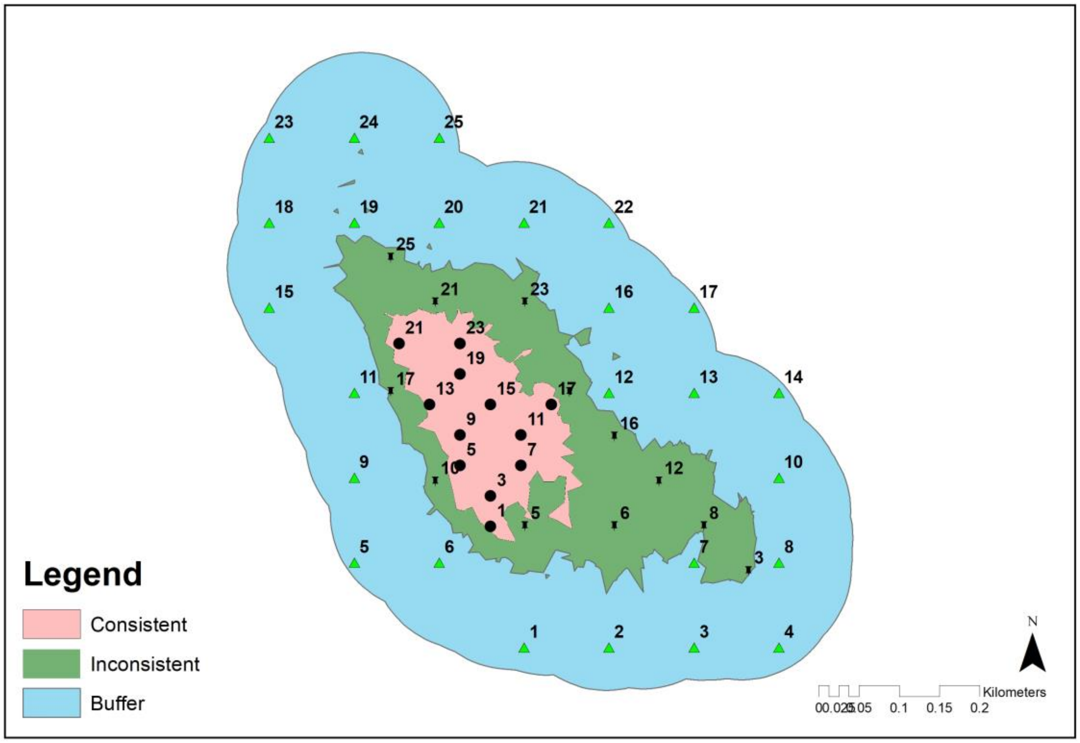

Figure 3: Map showing systematically laid points (n = 25) for sampling landforms and vegetation variables in occupied (Consistent in rose red, Inconsistent in green) and unoccupied (Buffer in blue) treatments on Sage colony of prairie dogs in Grasslands National Park, Saskatchewan during 17 July 2019 - 3 August 2019 using ArcMap (10.6).

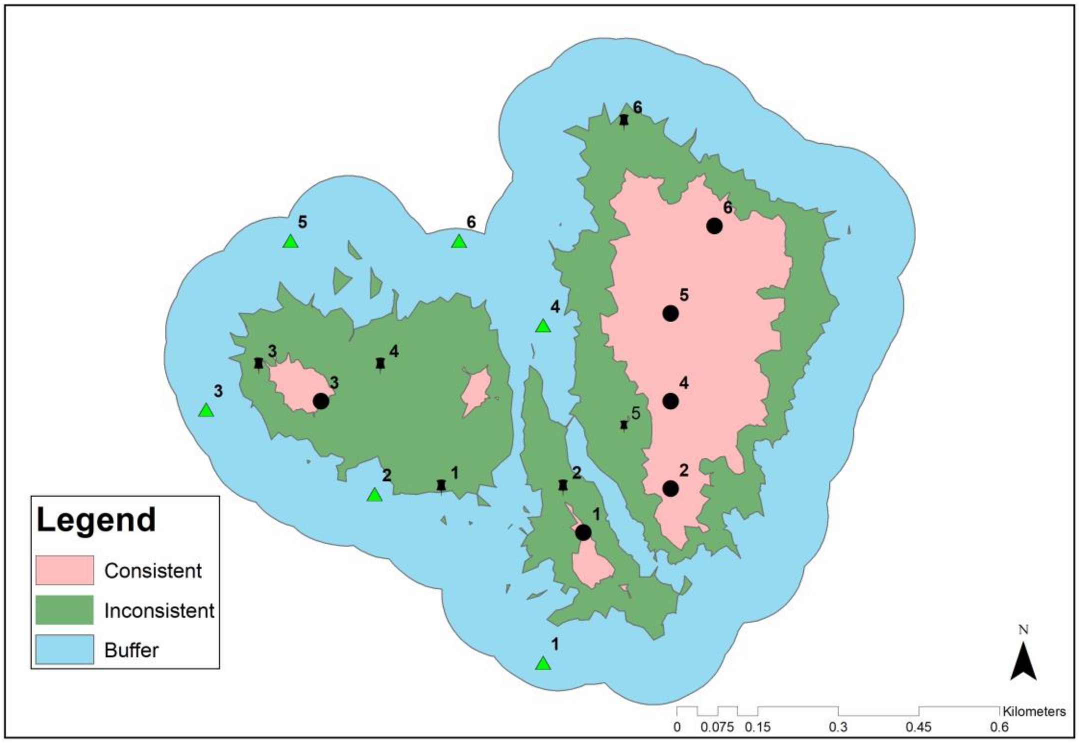

Figure 4: Map showing systematically established points (n=6) for soil sampling in occupied (Consistent in rose red, Inconsistent in green) and unoccupied (Buffer in blue) treatments on Police colony of prairie dogs in Grasslands National Park, Saskatchewan during 17 July 2019 - 3 August 2019 in ArcMap (10.6).

4.2. Data Collection

The landform and vegetation data were collected from 17 July 2019 to 3 August 2019 from all three treatments on all four colonies ('blocks' from now). All three treatments at each block were sampled simultaneously for vegetation to minimize phenological variations (Swacha et al., 2017). Soil samples were collected between 18 August 2019 and 28 August 2019 from all three treatments on all four blocks. Samples were collected on dry days and at least 72 hours after the last rain.

1. Objective: To evaluate if landforms are limiting the expansion of prairie dog colonies in GNP.

To assess if hills, water channels, and shrublands are limiting the expansion of prairie dog colonies, I gathered data visually on presence/absence of hills, water channels (both permanent and ephemeral) within 30 m, and shrublands (>80% shrubcovered) within 100 m of each sampling location. Hills were defined as a naturally elevated area of land above the surrounding terrain.

To assess if topography is limiting the expansion of prairie dog colonies, I collected data (visually) on topographical features at each sampling location. Topography was categorized into three broad types: flat, undulating, and sloped. Undulating was further divided into three sub-types: low, medium, and high. The slope was classified into three categories: less than 10%, 10 to 20%, greater than 20%. The slope was measured by Clinometer. Topography was classified and sub-classified to account for the varying preferences of each category by prairie dogs (Clippinger, 1989; Avila-Flores et al., 2009).

2. Objective: To evaluate if vegetation composition and structure is limiting the expansion of prairie dog colonies in GNP.

To assess if prairie dogs are limited by vegetation composition (grass, forbs, and shrub cover), I used the quadrat method to visually estimate total ground cover (%) at each sampling point (Sutherland, 2006). A quadrat (50 cm x 50 cm) was placed in a random direction at the center of each point. Ground cover was grouped into different categories: grasses (live & dead), forbs (live & dead), shrubs, moss, lichen, litter, and bare ground (Avila-Flores et al., 2009). Shrubs (> 50 cm) were also assessed in a square plot of 25 m^2 around the center of sampling point. Percent cover for each group was estimated using the canopy cover reference sheet (Bonham, 2013).

To assess if prairie dogs are limited by vegetation height (low, medium, and high), I recorded vegetation height at each sampling point using a Robel pole (Robel et al., 1970) and classified into four class: less than 10 cm, 10 cm-30 cm, 30 cm-60 cm, and greater than 60 cm (Clippinger, 1989).

3. Objective: To evaluate if soil characteristics are limiting the expansion of prairie dog colonies in GNP.

A pit was dug to a minimum depth of 30 cm. From one side of the pit, soil samples were collected from two layers: A (0 cm-15 cm) & B (15 cm-30 cm), due to differences in soil characteristics within depth (Barth et al., 2014). From each layer, a 300 g sample was collected in a plastic bag and stored (below 4 °C) until processed.

To assess if soil physical properties are limiting the expansion of prairie dog colonies, all samples were analyzed for texturing using hydrometer (Ashworth et al., 2011), and oven dried for relative soil moisture (Carter et al., 2008) at British Columbia Institute of Technology (BCIT). For chemical analysis, all six samples from each treatment were mixed in equal proportion to make one consolidated sample (150 g) for each layer separately. These samples were analyzed at the "BC Provincial Soil Lab" to estimate pH, C, NH_4, NO_3, and P.

4.3. Statistical analysis:

A univariate statistical analysis was performed in SPSS (IBM SPSS Statistics for Windows, Version 24.0) to examine the magnitude of difference for each variable among Consistent, Inconsistent, and Buffer. Soil data were analyzed separately for layers A and B. Count data was transformed using square root transformation, and Continuous data was transformed using Arcsine transformation (Zar, 2010). One-way analysis of variance (ANOVA) was used to compare the presence of landforms (hills, water channel, and shrubland, terrain classes), vegetation height, and soil texture classes among three treatments.

A two-factor ANOVA was used was to compare vegetation (grass cover, forb cover, and shrub cover) and relative soil moisture among three treatments and four blocks (Mcdonald 2014). The Interaction term (between treatment and block) for forb and shrub cover and relative soil moisture was significant (Appendix A), so a one-way ANOVA were performed to test treatments within each block to avoid the effect of site(block) variation. Soil nutrients (NH_4, NO_3, C, P) and pH was also analyzed using one-way ANOVA among three treatments. A tukey test was used for post hoc analysis.

Chapter 5. Results

5.1. To evaluate if landforms are limiting the expansion of prairie dogs colonies in GNP.

5.1.1. Hills:

There was a significant difference in presence of hills ($F_{2,9} = 5.007$, $p = 0.035$) among treatments (Table 1). Hills were present significantly higher in Buffer than Inconsistent (p = 0.031) (Figure 5). The mean proportion of sample plots with hills present in Consistent was much lower in comparison to Buffer (Figure 5), but I failed to detect any significant difference (p = 0.141) (Table 1).

Table 1: Summary of one-factor ANOVA performed to test landforms for significant difference among treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 03 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant. (df = degree of freedom, f = F value, p = probability).

	One factor ANOVA Among treatments			Post hoc (Tukey test) Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
	df	f	p	p	p	p
Hills	2,9	5.007	**0.035**	0.609	0.141	**0.031**
Shrub land	2,9	15.980	**<0.001**	0.276	**<0.001**	**0.010**
Water Channel	2,9	7.340	0.**013**	0.657	**0.031**	**0.051**
Flat terrain	2,9	0.806	0.476	0.954	0.474	0.640
Undulating low	2,9	0.133	0.877	0.868	0.979	0.948
Undulating medium	2,9	1.491	0.276	0.811	0.255	0.548
Undulating high	2,9	1.000	0.405	1.000	0.469	0.469
Slope < 10 %	2,9	0.295	0.751	0.931	0.731	0.914
Slope 10 – 20 %	2,9	1.990	0.192	0.907	0.194	0.346
Slope > 20 %	2,9	2.100	0.178	0.921	0.184	0.315

Figure 5: Mean (± SE) proportion of sample plots with hills present across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. Hills were absent in Inconsistent.

5.1.2. Shrublands

Shrublands were significantly different ($F_{2,9} = 15.980$, $p \leq 0.001$) among treatments (Table 1). Shrublands were significantly higher in Buffer compared to Consistent ($p < 0.001$), and Inconsistent ($p = 0.010$) (Figure 6, Table 1).

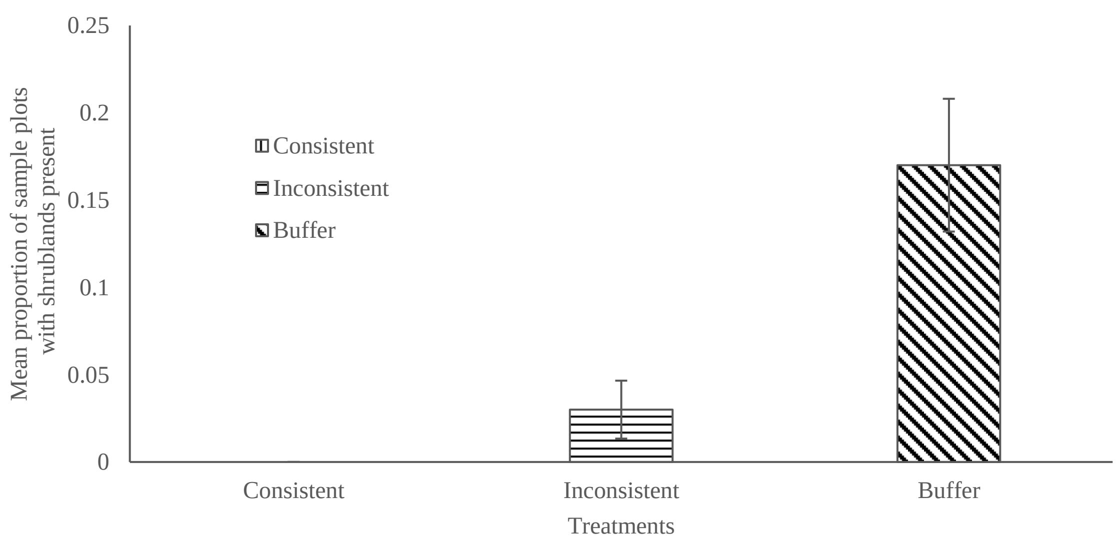

Figure 6: Mean (± SE) proportion of sample plots with shrublands present across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. Shrublands were absent in Consistent.

5.1.3. Water Channel:

Water channels were significantly different ($F_{2,9} = 7.380$, $p = 0.013$) across treatments (Table 1). The mean proportion of sampling plots that had water channels present was significantly higher in Buffer than Consistent ($p = 0.013$) and Inconsistent ($p = 0.05$) treatments (Figure 7, Table 1).

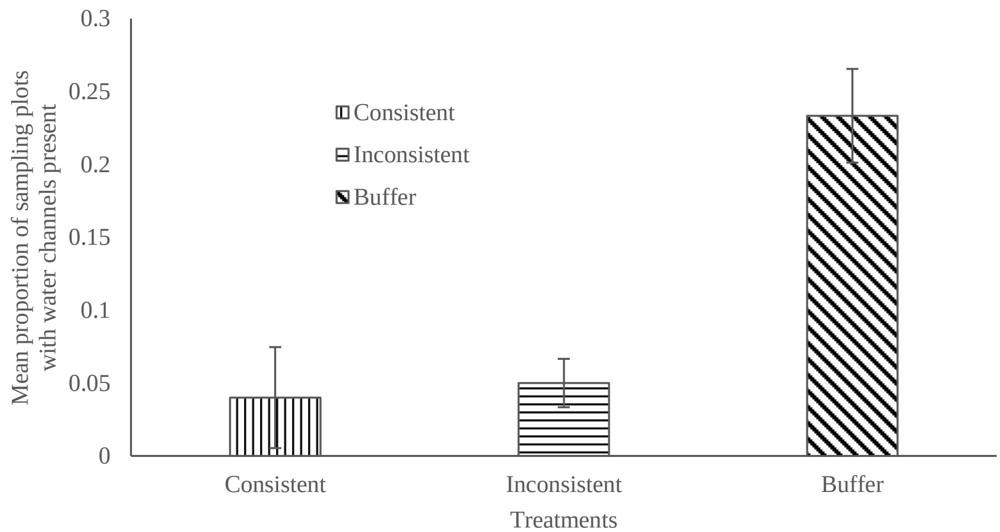

Figure 7: Mean (± SE) proportion of sample plots with water channels present across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019.

5.1.4. Topography

Topography analysis revealed that terrain classes (flat, undulating (low, medium & high) and slope (<10%, 10-20%, >20%)) were not significantly different among treatments ($p > 0.05$) (Table 1). I failed to detect a significant difference in treatments relative to each other (Table 1). Mostly treatments fall under flat category for all three treatments (Figure 8).

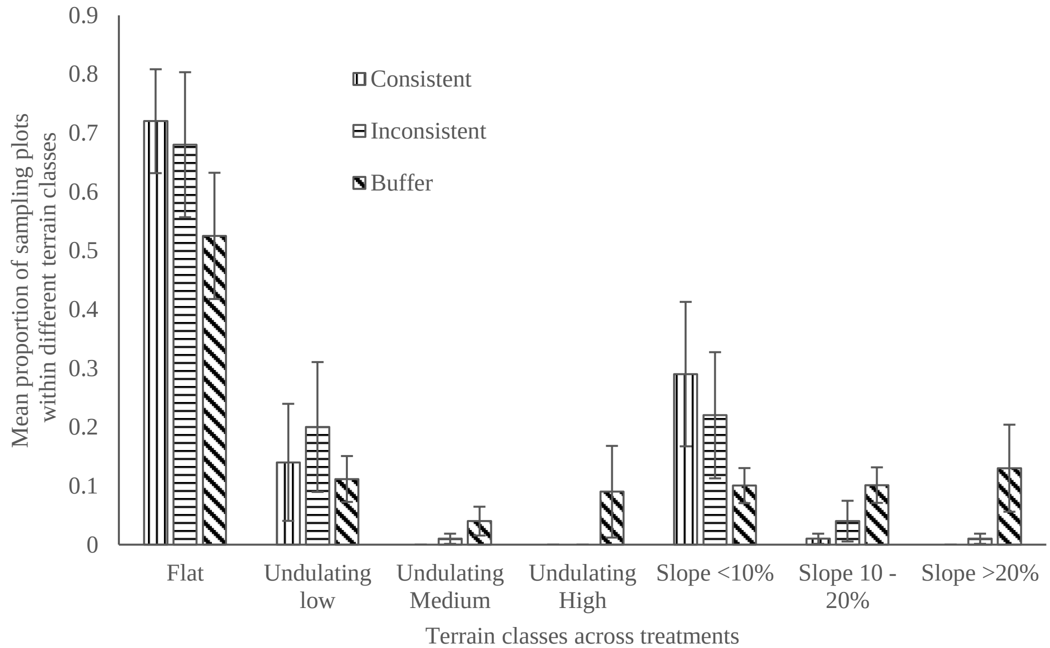

Figure 8: Mean (± SE) proportion of sample plots within each of terrain class across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. Undulating medium, high and slope >20% was absent in Consistent. Undulating high was absent in Inconsistent.

5.2. To evaluate if vegetation composition and structure is limiting the expansion of prairie dog colonies in GNP.

5.2.1. Grass cover:

Grass cover was significantly different among all three treatment ($F_{2,6}$ = 14.560, p = 0.005) and relative to each other ($F_{2,6}$ = 14.560, p < 0.05) (Table 2). Percent of grass cover was observed to be highest in Buffer, followed by Inconsistent and Consistent (Figure 9).

Table 2: Summary of two-factor (treatments & blocks) ANOVA performed to test grass cover for significance difference among treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant (df = degree of freedom, f = F value, p = probability).

	Treatments			Blocks			Interaction (treatment * block)			Post hoc analysis		
	df	f	p	df	f	p	df	f	p	Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
Grass	2, 6.180	14.560	**0.005**	3, 6.396	23.561	**<0.001**	6, 257	.908	.489	**0.007**	**0.000**	**.044**

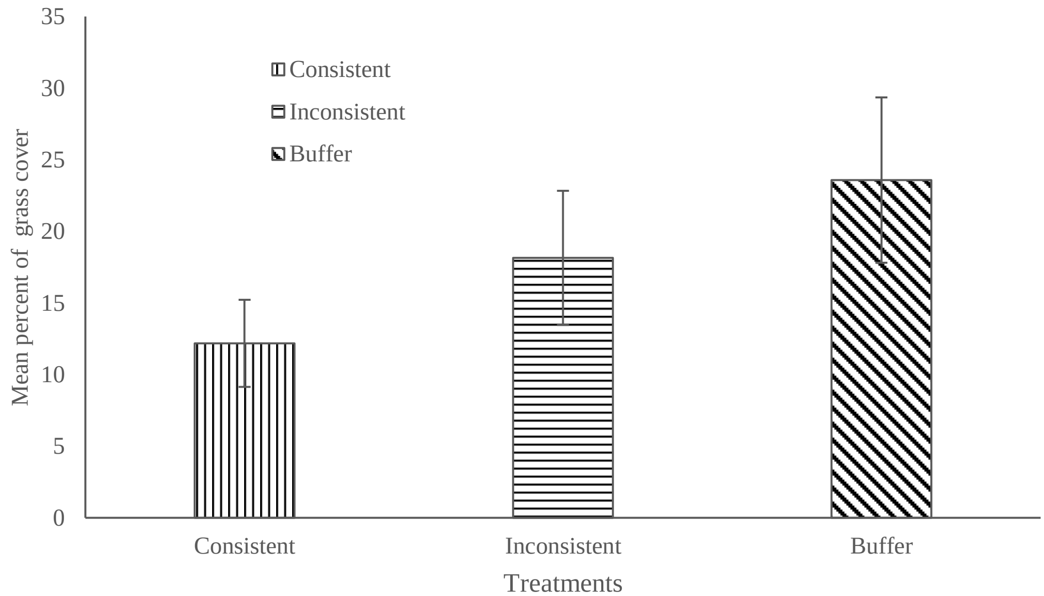

Figure 9: Mean (± SE) percent cover of grass across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019.

5.2.2. Forb cover:

Forb cover was significantly different among treatments at the Snakepit and Police Colonies. At Snakepit, forb cover was significantly higher in Consistent than Inconsistent ($F_{2,63}$ = 5.427, p = 0.006) (Table 3). At Police Colony, forb cover was significant lower in Buffer as compared to Consistent ($F_{2,64}$ = 11.420, p < 0.001) and inconsistent ($F_{2,64}$ = 11.420, p = 0.003) (Figure 10).

Table 3: Summary of one-factor ANOVA performed to test vegetation (forb and shrub) cover and height for significant difference among treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant. (df = degree of freedom, f = F value, p = probability).

	One – factor ANOVA			Post hoc (Tukey test)		
	Among treatments			Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
	df	f	p	p	p	p
Forb (Monument)	2, 58	0.483	0.620	0.636	1.000	0.767
Forb (Police)	2, 64	11.420	**<0.001**	0.373	**<0.001**	**0.003**
Forb (Sage)	2, 72	1.837	0.167	0.626	0.141	0.585
Forb (Snake Pit)	2, 63	5.427	**0.007**	**0.006**	0.101	0.734
Shrub (Monument)	2, 61	13.742	**<0.001**	0.565	**<0.001**	**<0.001**
Shrub (Police)	2, 63	78.171	**<0.001**	0.276	**<0.001**	**<0.001**
Shrub (Sage)	2, 72	76.341	**<0.001**	0.826	**<0.001**	**<0.001**
Shrub (Snake Pit)	2, 64	16.060	**<0.001**	0.062	**<0.001**	**0.002**
Vegetation height (0 cm – 10 cm)	2, 9	2.610	0.128	0.876	0.129	0.263
Vegetation height (10 cm – 30 cm)	2,9	1.029	0.396	0.723	0.797	0.366
Vegetation height (30 cm – 60 cm)	2,9	37.453	**<0.001**	**0.030**	**<0.001**	**<0.001**
Vegetation height (> 60 cm)	2,9	9.852	**0.005**	0.463	**0.005**	**0.032**

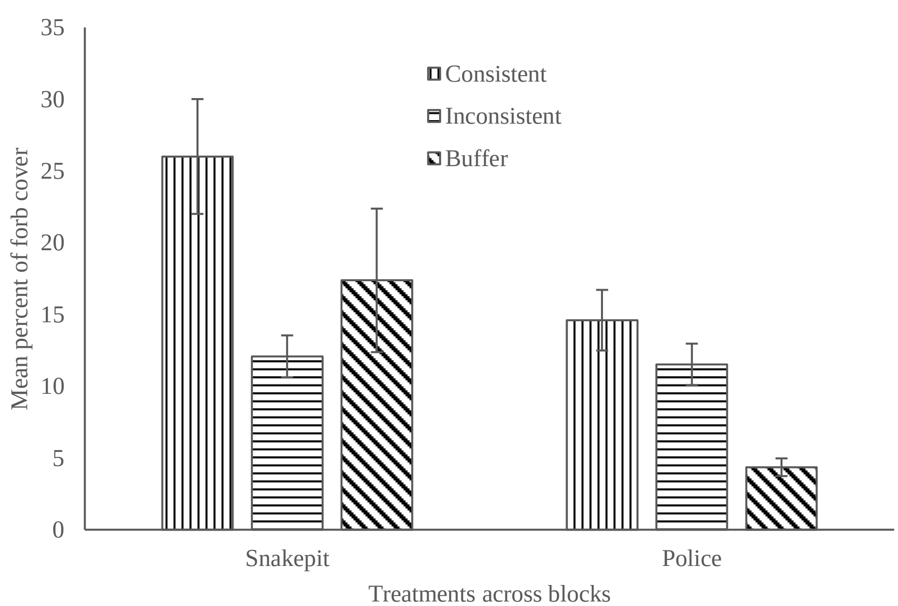

Figure 10: Mean (± SE) percent cover of forb across three treatments at Snakepit and Police in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019.

5.2.3. Shrub cover:

Results showed a significant difference ($p < 0.05$) among treatments within each block (Table 3). Shrubs were significant higher in Buffer compared to Inconsistent ($p < 0.05$) and was absent in Consistent ($p < 0.05$) in each block (Figure 11).

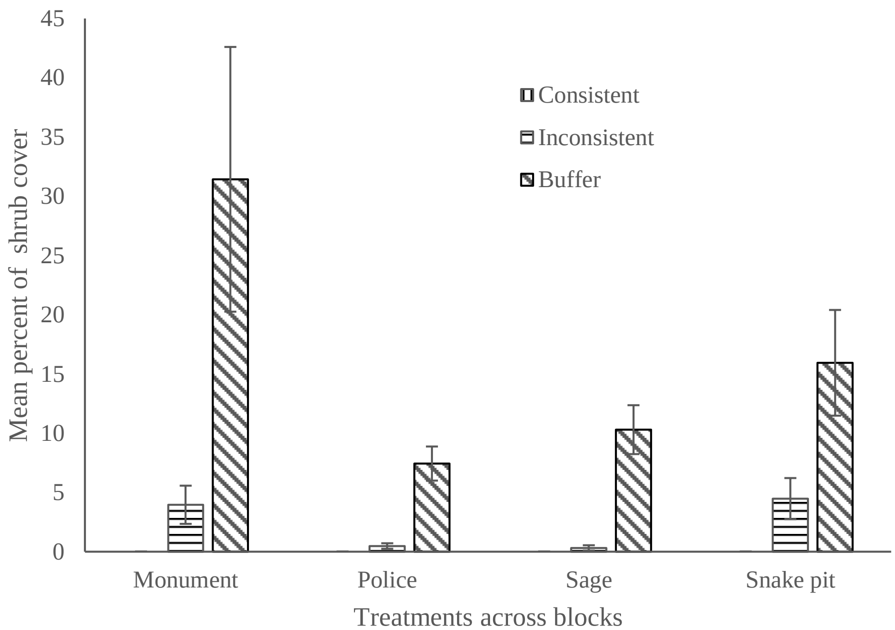

Figure 11: Mean (± SE) percent cover of shrub across three treatments at each block in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. Shrubs were absent in Consistent.

5.2.4. Vegetation height

Vegetation height class (30 cm-60 cm) and (>60 cm) was significantly different among treatments (Table 3). Both were absent in Consistent (Figure 12). Vegetation height class (30 cm-60 cm) was significantly higher ($F_{2,9} = 37.453$, $p < 0.05$) in Buffer and Inconsistent relative to Consistent and between each other (Table 3). Vegetation height class (>60 cm) was significantly higher in Buffer comparing to Inconsistent ($F_{2,9} = 9.852$, $p = 0.032$) and Consistent ($F_{2,9} = 9.852$, $p = 0.05$) (Figure 12).

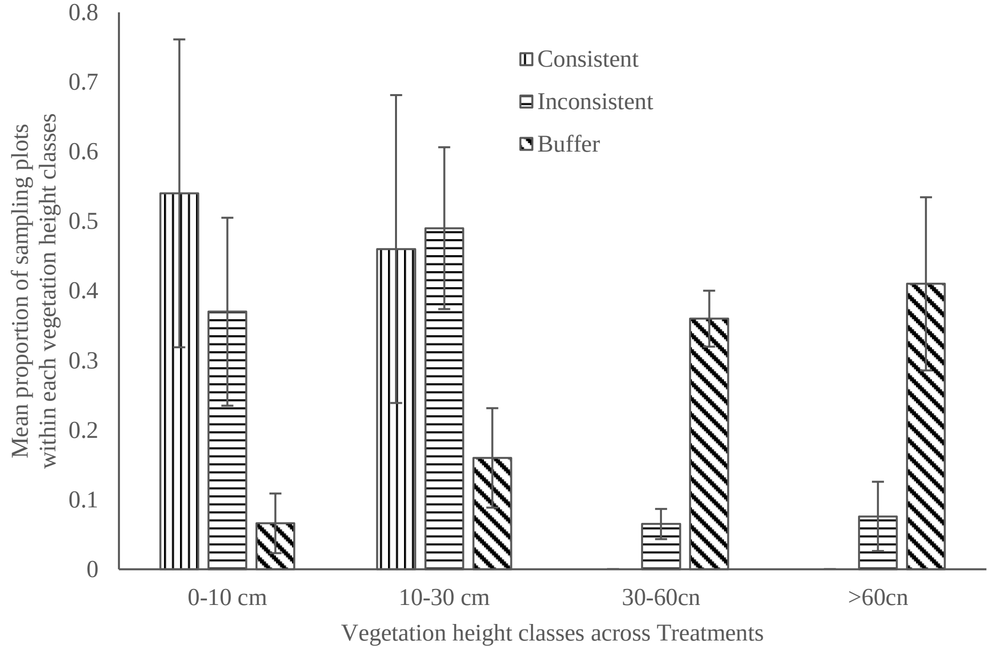

Figure 12: Mean (± SE) proportion of sampling plots within each vegetation height classes across three treatments in Grasslands National Park, Saskatchewan, from 17 July 2019 to 3 August 2019. Vegetation height class 30 cm-60 cm and >60 cm was absent in Consistent.

5.3. To evaluate if soil characteristics are limiting the expansion of prairie dog colonies in GNP.

5.3.1. Soil Texture:

a. Layer A (0 cm-15 cm):

Soil layer 'A' had seven types of soil texture: Clay, Clay Loam, Loam, Sandy Clay Loam, Silt Loam, Silty Clay, and Silty Clay Loam (Figure 13). All were non-significantly different among treatments ($p > 0.05$) and relative to each treatment ($p > 0.05$) (Table 4).

Table 4: Summary of one factor ANOVA was performed to test Soil Texture (Layer A and B) for significant difference among treatments in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant. (df = degree of freedom, f = F value, p = probability).

	One – factor ANOVA			Post hoc (Tukey test)		
	Among treatments			Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
	df	f	p	p	p	p
Soil texture, Layer A (Clay)	2, 9	0.422	0.668	0.978	0.784	0.667
Soil texture, Layer A (Clay Loam)	2, 9	0.018	0.983	0.986	0.986	1.000
Soil texture, Layer A (Loam)	2, 9	0.175	0.842	0.968	0.830	0.937
Soil texture, Layer A (Sandy Clay Loam)	2, 9	1.444	0.286	0.769	0.260	0.601
Soil texture, Layer A (Silt Loam)	2, 9	0.529	0.607	0.954	0.595	0.765
Soil texture, Layer A (Silty Clay)	2, 9	1.118	0.368	0.812	0.341	0.673
Soil texture, Layer A (Silt Clay Loam)	2, 9	0.000	1.000	1.000	1.000	1.000
Soil texture, Layer B (Clay)	2, 9	0.085	0.919	0.932	1.000	0.932
Soil texture, Layer B (Clay Loam)	2, 9	5.917	**0.023**	0.403	**0.019**	0.153
Soil texture, Layer B (Loam)	2, 9	1.000	0.405	0.469	0.469	1.000
Soil texture, Layer B (Sand Clay Loam)	2, 9	0.503	0.621	0.850	0.594	0.894
Soil texture, Layer B (Sandy Loam)	2, 9	1.000	0.405	0.469	1.000	0.469
Soil texture, Layer B (Silt Loam)	2, 9	1.000	0.405	1.000	0.469	0.469
Soil texture, Layer B (Silty Clay)	2, 9	2.653	0.124	0.420	0.108	0.610
Soil texture, Layer B (Silty Clay Loam)	2, 9	0.980	0.412	0.835	0.384	0.703

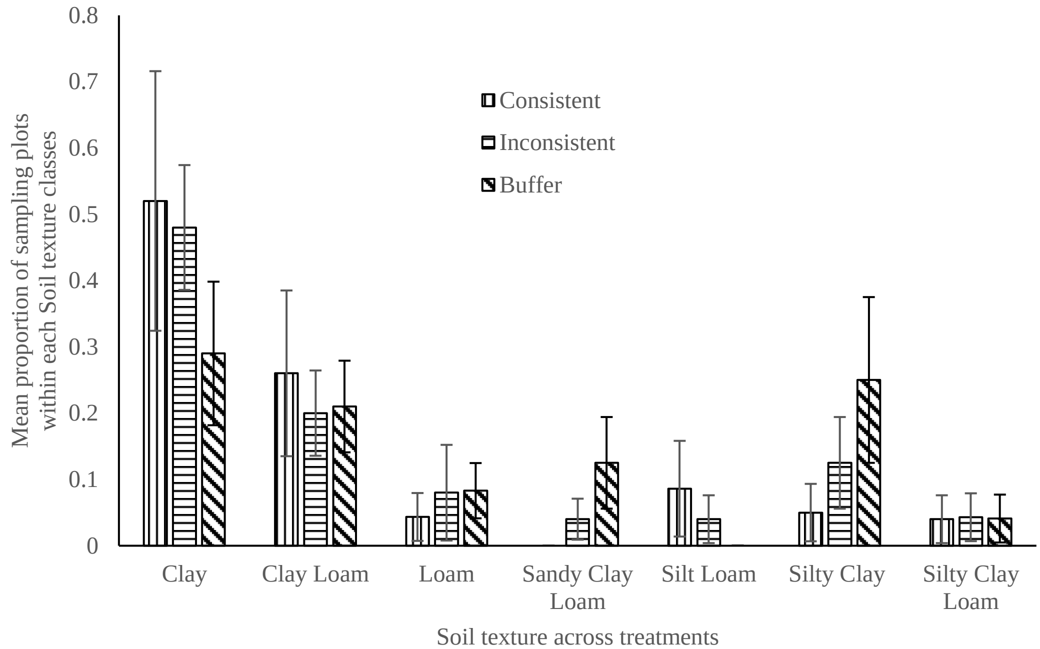

Figure 13: Mean (± SE) proportion of sampling plot within each soil texture classes across three treatments from layer A (0 cm-15 cm) in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019. Sandy Clay Loam was absent in Consistent. Silt Loam was absent in Buffer.

b. Layer B (15 cm-30 cm):

Soil samples from layer 'B' had eight types of soil texture: Clay, Clay Loam, Loam, Sandy Clay Loam, Sandy Loam, Silt Loam, Silty Clay, Silty Clay Loam (Figure 14). Clay Loam ($F_{2,9}$ = 5.917, p = 0.023) was only significantly different among treatments. It was significantly higher in Consistent compared to Buffer ($F_{2,9}$ = 5.917, p = 0.019) (Table 4).

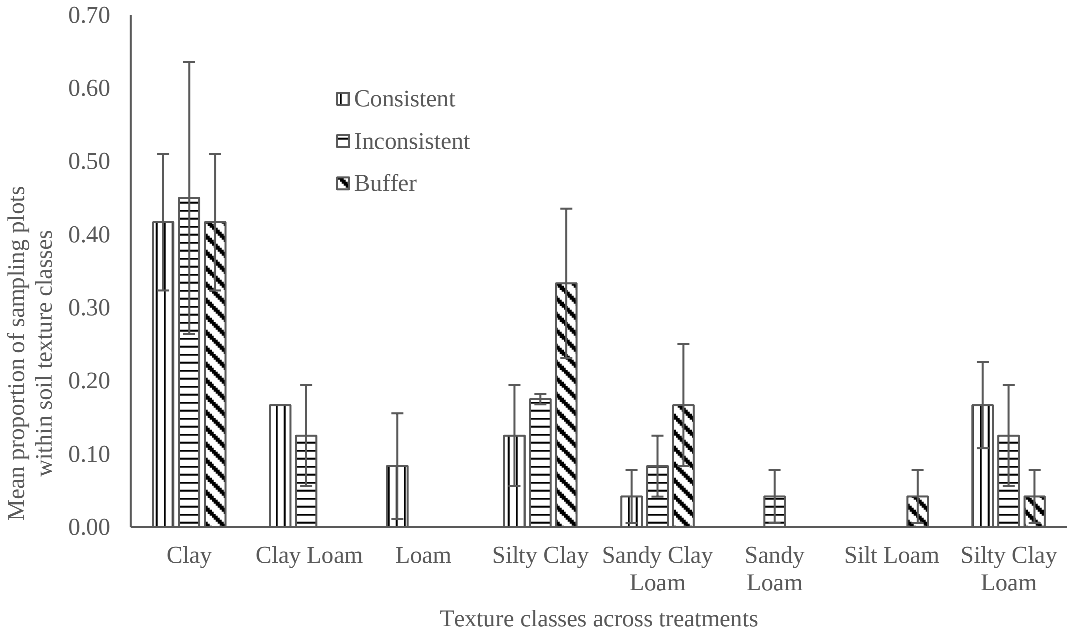

Figure 14: Mean (± SE) proportion of sampling plots within each soil texture classes across three treatments from layer B (0 cm-15 cm) in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019. Sandy Loam and Silt Loam was absent in Consistent. Loam and Silt Loam was absent in Inconsistent. Loam and Sandy Loam was absent in Buffer.

5.3.2. Relative Soil Moisture:

a. Layer A (0 cm-15 cm):

Relative soil moisture was non-significant within each block in layer 'A', except at Monument (Table 5). It was significant higher in Buffer comparing to Consistent ($F_{2,14}$ = 10.746, p = 0.004) and Inconsistent ($F_{2,14}$ = 10.746, p = 0.003) (Figure 15).

Table 5: Summary of one-factor ANOVA was performed to test Relative soil moisture (Layer A and B) for significant difference among treatments in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant. (df = degree of freedom, f = F value, p = probability).

	One – factor ANOVA			Post hoc (Tukey test)		
	Among treatments			Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
	df	f	p	p	p	p
Relative Soil Moisture - Monument (Layer A)	2,14	10.746	**<0.001**	0.993	**0.004**	**0.003**
Relative Soil Moisture - Police (Layer A)	2, 15	0.864	0.442	0.447	0.993	0.542
Relative Soil Moisture - Sage (Layer A)	2, 16	2.168	0.147	0.496	0.126	0.519
Relative Soil Moisture – Snake Pit (Layer A)	2, 15	0.765	0.483	0.458	0.730	0.890
Relative Soil Moisture - Monument (Layer B)	2, 15	3.456	**0.058**	0.842	**0.059**	0.161
Relative Soil Moisture - Police (Layer B)	2, 15	1.247	0.315	0.377	1.000	0.387
Relative Soil Moisture - Sage (Layer B)	2, 14	4.359	**0.034**	0.825	**0.039**	0.096
Relative Soil Moisture – Snake Pit (Layer B)	2, 15	.765	0.483	0.458	0.730	0.890

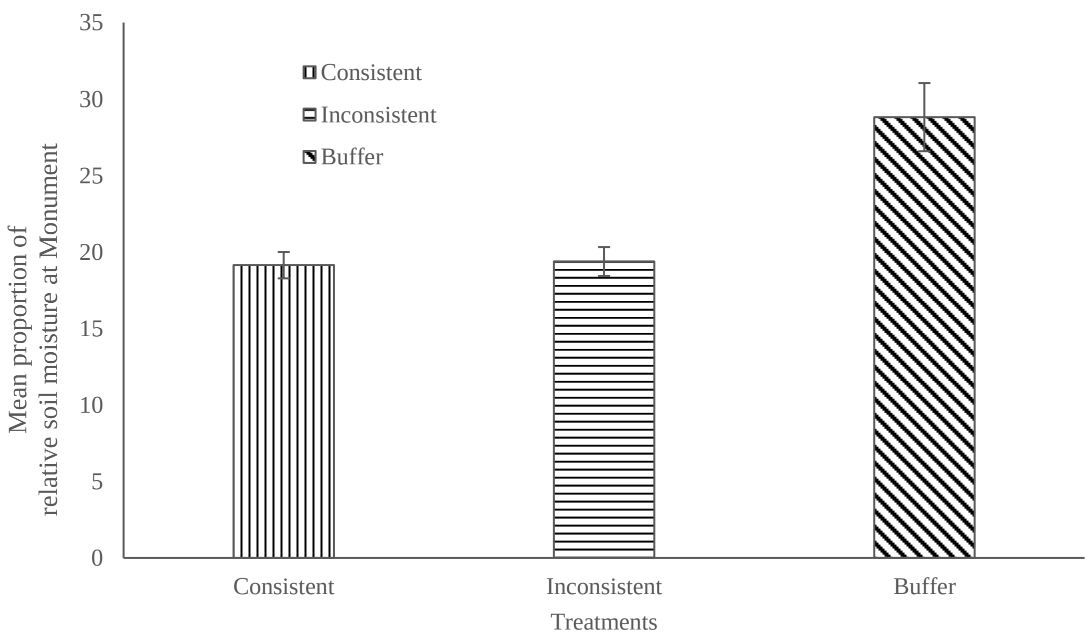

Figure 15:Mean (± SE) proportion of relative soil moisture across three treatments from layer A (0 cm-15 cm) at Monument in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019.

b. Layer B (15 cm-30 cm):

I failed to detect a significant difference for relative soil moisture in Layer 'B' within each block except at Sage (Table 5). Relative soil moisture was significantly higher in Consistent compared to Buffer at Sage ($F_{2,15} = 4.359$, $P = 0.039$) (Figure 16).

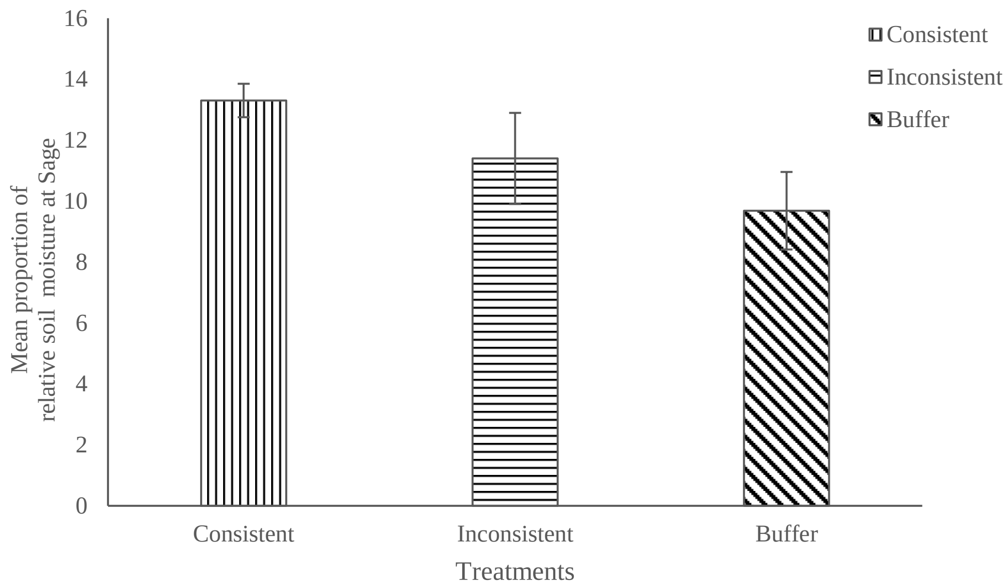

Figure 16: Mean (± SE) proportion of relative soil moisture across three treatments from layer B (15 cm-30 cm) at Sage in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019.

5.3.3. Soil pH and nutrients:

a. Layer A (0 cm-15 cm):

Soil pH and all soil nutrients have non-significant difference among treatments ($p > 0.05$) and relative to each other ($p > 0.005$) in top layer (Table 6, Figure 17).

Table 6: Summary of one-factor ANOVA was performed to test soil nutrients (Layer A and B) for the significant difference among treatments in Grasslands National Park, Saskatchewan, from 18 August 2019 to 4 August 2019. The level of significance was < 0.05. Values in bold were significant or close to significant. (df = degree of freedom, f = F value, p = probability).

	One – factor ANOVA			Post hoc (Tukey test)		
	Among treatments			Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
	df	f	p	p	p	p
NH_4 (Layer A)	2, 9	.173	0.844	0.849	0.894	0.995
NO_3 (Layer A)	2, 9	.426	0.665	0.703	0.722	0.999
C (Layer A)	2, 9	1.726	0.232	0.956	0.360	0.246
pH (Layer A)	2, 9	1.587	0.257	0.437	0.253	0.906
P (Layer A)	2, 9	2.049	0.185	0.167	0.452	0.744
NH_4 (Layer B)	2, 9	1.983	0.193	0.491	0.715	0.173
NO_3 (Layer B)	2, 9	.084	0.921	0.981	0.973	0.913
C (Layer B)	2, 9	2.204	0.166	0.676	0.147	0.468
pH (Layer B)	2, 9	.637	0.551	0.679	0.558	0.977
P (Layer B)	2, 9	.554	0.593	0.723	0.595	0.974

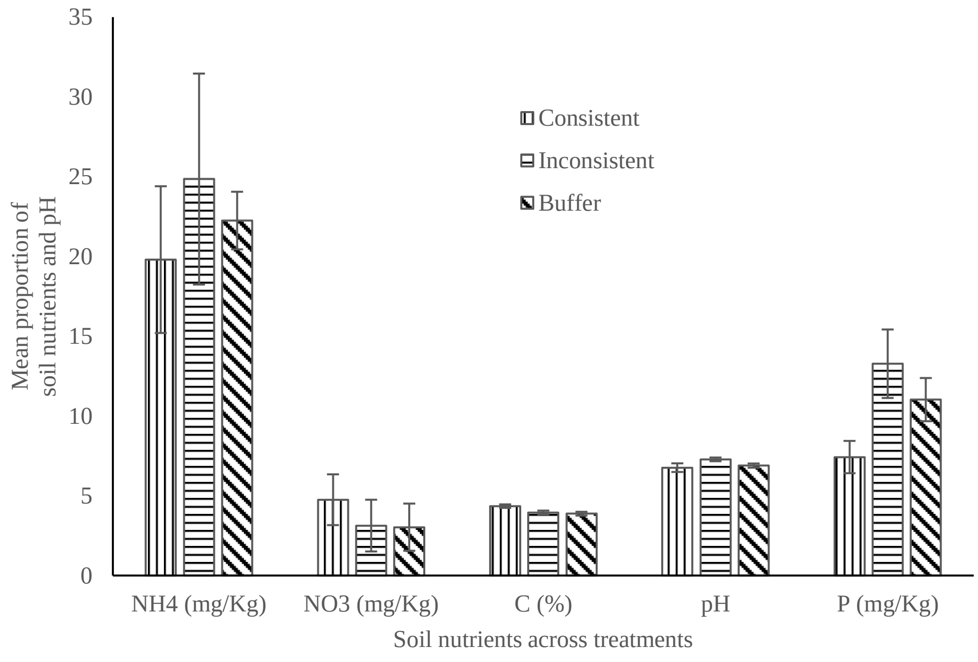

Figure 17: Mean (± SE) of soil pH and nutrients in layer A (0 cm - 15 cm) across three treatments in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019.

b. Layer B (15 cm-30 cm)

Soil pH and all soil nutrients have a non-significant difference among treatments ($p > 0.05$) and relative to each other ($p > 0.005$) in bottom layer (Table 6, Figure 18).

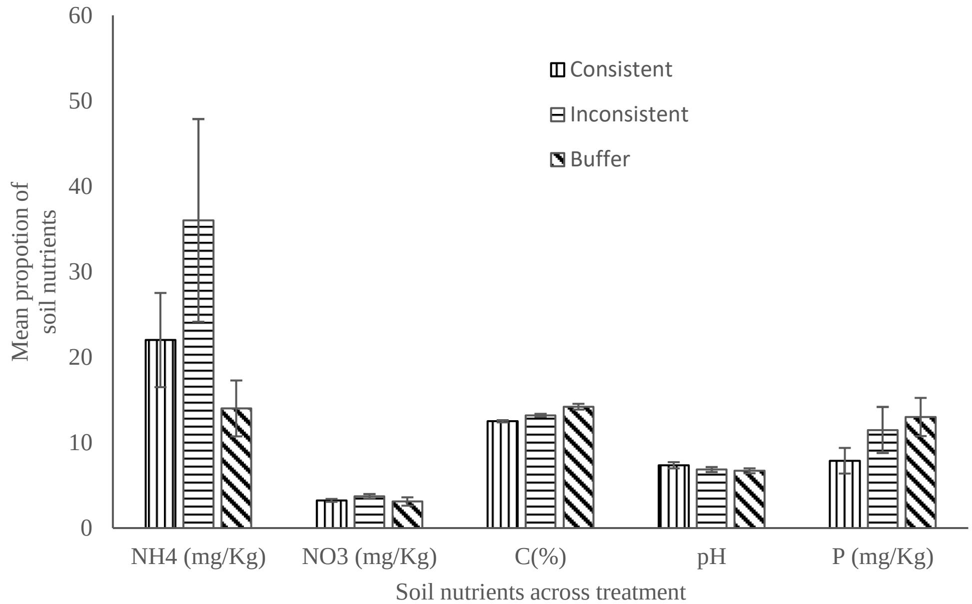

Figure 18: Mean (± SE) of soil pH and nutrients in layer B (15 cm-30 cm) across three treatments in Grasslands National Park, Saskatchewan, from 18 August 2019 to 28 August 2019.

Chapter 6. Discussion

Spatial analysis of prairie dog colonies in Grasslands National Park (from year 2000 to 2017) showed that prairie dog colonies did not expand beyond their maximum extent recorded in 2009. It was crucial to examine what is restricting prairie dog colonies from expanding to foster the long-term goal of prairie dogs and their habitat conservation in Canada. This was study conducted to determine if habitat attributes (abiotic and biotic) are limiting the expansion of prairie dog colonies. It was the first observational research done at Colony scale to compare physical and biological variables among consistently occupied (Consistent), inconsistently occupied (Inconsistent), and never occupied (Buffer) areas in GNP at the northern edge of prairie dogs distribution.

6.1. Landforms

Landforms might be limiting the prairie dog colonies expansion. My results showed a significant difference in the presence of shrublands and water channels among all three treatments. Shrublands were present significantly higher in Buffer compared to Inconsistent and was absent in Consistent. It shows that the prairie dog avoids occupying areas dominated by shrubs. Similar results were found by (Koford 1958; Clippinger, 1989; Hoogland, 1995; Avila-Flores, 2009). This trend could be explained by the fact that shrublands act as a visual barrier, whereas the prairie dog prefers low visual obstruction to keep predator vigilance (Archer et al., 1987; Roe & Roe, 2003; Ponce-Guevara et al., 2016). Another reason for avoiding shrubland could be limited food availability in these areas as the prairie dog diet constitutes mostly grasses (>85%) (Clippinger, 1989; Hoogland,1995) and shrubs are seen suppressing grass growth when present in abundance (Kochy & Wilson, 2000; Alvarez et al., 2011). Prairie dogs are seen decreasing shrubs by foraging on seedlings and clipping them (Weltzin et al., 1997; Ceballos et al., 2010; Ponce-Guevara et al., 2016).

Water channels were present significantly higher in Buffer comparing to Consistent and Inconsistent. Prairie dogs probably avoid occupying areas in or close to the waterways banks due to flood risk. They meet with their daily water needs from grasses and forb (May, 2003), so they do not require a direct water source (Clippinger, 1989). Relocated Utah prairie dogs were seen avoiding constructing new burrows in drainage (Curtis &

Frey, 2013). Roy and Roy (2003) recommended enough soil (2.4 m, Boulder county staff, 2000) must be available over water table for prairie dog to establish new burrows. Prairie dog builds conical mound around their burrows to avoid water flow in their burrows (Koford, 1958).

Presence of hills might not be a limiting factor for prairie dog colonies expansion provided gentle slope. Hills were present significantly higher in Buffer compared to Inconsistent. On the contrary, presence of hills did not vary significantly between Consistent and Buffer. My field observation that was prairie dogs had constructed burrows on hills (at Monument & Snake Pit) only when the slope was gentle. (Koford, 1958; Dalsted et al., 1981; Clippinger,1989; Hoogland,1995; Avila-Flores, 2009; Reading & Matchett, 1997; Proctor, 1998; Wagner & Drickamer, 2004).

The topography is probably not limiting colonies to expand prairie dogs. My analysis showed a non-significant difference for the three subtypes (flat, undulating, and sloped terrain) among all three treatments. Mostly sampling points fall under flat terrain even in Buffer (Avilla-Flores, 2009). Prairie dog prefers to occupy flat, gentle and moderate slope areas (Clippinger, 1989;Reading & Matchett, 1997; Proctor,1998; Magle & crooks 2007; Stephens, 2012;).Wagner and Drickamer (2004) and Hoogland (1995) suggested that prairie dogs occupy sites with less varying slopes to detect predator and surge alarm calls.

Reading and Matchett (1997) found that flat or moderate slopes might also be less prone to erosion, and thus enhance the structural stability of burrows. Prairie dogs prefer slope less than < 20% for building burrows (Dalsted et al., 1981; Clippinger,1989; Roe & Roe, 2003). At my site, terrain with a slope greater than 20% was observed in Inconsistent, which could be due to the use of less optimal habitat on higher slope sometimes as colonies expand (Koford,1958). The undulating terrain classes showed a similar trend as slope among treatments; Stephens (2012) also found a correlation between slope and terrain ruggedness in GNP. Canadian prairie dog colonies mostly occur along bottoms and lower slopes of the Frenchman River valley and its tributaries (Stephens, 2012)

6.2. Vegetation

Vegetation attributes might be contributing to limit prairie dog colonies expansion. Grass and shrub cover were found significantly different among the three treatments. Grass cover was lowest in Consistent, intermediate in Inconsistent, and highest in Buffer. Most likely, it is an artifact of difference in intensity of habitat use by prairie dogs (Gervin et al., 2019, Klatt & Hein, 1978). As mentioned above, prairie dog mostly feeds on grasses so continuous presence of prairie dog in Consistent lowered the grass cover comparative to others (Bonham & Lerwick, 1976; Coppock et al., 1983; Clippinger, 1989; Winter et al., 2002; Magle & crooks 2007; Avilla-Flores, 2009). Mean grass cover found in Consistent was around minimum forage cover (15%) required for continuous habitation of prairie dog as given by Clippinger (1989). Different authors explained this decline in the United States and Mexico as well (Bonham & Lerwick,1976; Archer et al., 1987; Coppock et al., 1983b; Daniel & Robert, 2001;Connel et al., 2019). Grazing preference by other large grazing animals such as bison and cattle on prairie dog sites due to enhance food quality at prairie dog colonies could also contribute to this decline (Coppock et al., 1983b).

Bonham and Lerwick (1976) found that prairie dogs increases plants species diversity, and perennial grasses but reduce annual grasses. Daniel and Robert (2001) explained that this change could be due to climatic conditions, and it is observed differently on landscape and site scale. Archer et al.(1987) also found an increase in species diversity. Connel et al. (2018) said on prairie dog sites, multiple mechanisms such as rainfall, species composition, growth, and soil influence forage quality and quantity across years. He found non-significant difference for above ground herbaceous biomass on and off prairie dog colonies on a landscape scale, but a significant difference was found between colonies. It is worth mentioning here prairie dogs maintain short grass communities rather than removing vegetation; if this were the case, they would not have flourished in prairies from the centauries (Koford 1958; Clippiner, 1989).

Grass cover in Inconsistent was found in between Consistent and Buffer, possibly because of intermittent use of habitat by prairie dog in this treatment and it gives a lag for grass to regrow when prairie dogs are not using the area when shrubs are not outcompeted yet (Cid et al., 1991; Gervin et al., 2019). As expected, Buffer had the highest grass cover because of the absence of a prairie dog (Koford, 1958; Bonham &

Lerwick,1976). In comparison, Gervin found significantly higher grass cover in inactive comparing to active and control. It could be because he used Control as non-occupied habitat, which was identified as suitable based on low cover grasslands and lower slope. Still mean grass cover at my site in Inconsistent and Buffer was less than 25% minimum reported by Fagerstone et al. (1997). It could be possible that forage is limited for prairie dog, which could be contributing to temporal fluctuation in the prairie dog population (Stephens, 2012) and thus limiting the expansion of prairie dog colonies. Lloyd (2011) found that prairie dogs are not limited by food in GNP, at least during her study time frame (2008-2009). She suggested it could be a different trend yearly. If food is not limiting prairie dog colonies expansion, the other possible factors could be high vegetation density, and tall height as prairie dog avoids occupying areas which have lower predator detection (Koford, 1958; Clippinger, 1989; Hoogland, 1995; Roe & Roe, 2003; Lloyd, 2011).

Results for shrub cover were comparable to other research on shrub cover patterns on sites with and without prairie dogs across United States and Mexico (Weltzin et al.m 1997; Nistler et al., 2004; Avila-Flores, 2009; Gervin et al., 2019; Connell et al., 2018). Shrubs were absent in Consistent and significantly lower in Inconsistent compared to Buffer. As mentioned above, prairie dog avoids inhibiting areas occupied with shrubs due to reduction in predator detection (Clippinger,1989; Hoogland, 1985; Milne-Laux et al., 2006; Avila-Flores, 2009;) or due to shrubs impact on grass growth (Koford, 1958; Alvarez et al., 2011; Kochy & Wilson, 2000). Prairie dogs also clip shrubs to facilitate detection (Bonham & Lerwick, 1976; Guevara et al., 2016; Koford, 1958; Archer et al., 1987; Roe & Roe 2003) so higher shrub cover recorded in Buffer could be restricting the expansion of prairie dog colonies (Hoogland,1995; Knowles et al., 2002; Milne-Laux et al., 2006).

Prairie dog prefers small vegetation height (<30 cm) to keep high visibility (>30%) for predator detection and often find clipping vegetation to maintain high visibility (Koford,1958; Clippinger, 1989; Bonham & Lerwick, 1976; Hoogland,1995; Winter et al., 2002; Roe & Roe 2003; Avila-Flores, 2009; Connell et al., 2018). Similar results were found in my study. Vegetation height classes 30 cm to 60 and >60 cm was significantly different among three treatments. Both classes were absent in Consistent and significantly higher in Buffer comparing to Inconsistent. Thus, vegetation height could be a factor restricting the expansion of prairie dog colonies in GNP (Cincotta et al. 1987, Milne-Laux et al. 2006).

My results for forb cover showed a varied trend in colonies. It was non-significant at Monument and Sage (Avilla-Flores, 2009) but significantly differed at Snakepit and Police (Gervin et al., 2019). At Snakepit, it was higher in Consistent compared to Inconsistent but did not differ with Buffer. At Police, it was similar on Consistent and Inconsistent but significantly lower at Buffer (Gervin et al.,2019). Forb cover in Consistent could be higher because of prairie dog activities (Koford,1958; Bonham & Lerwick, 1976; Dalsted et al., 1981; Coppock et al., 1983; Archer et al., 1987; Beals et al., 2014) or due to grazing by Bison (Coppock et al., 1983, Desmond, 2004, Ceballos et al., 2005, Siera-Corona et al., 2015). Area colonized by Prairie dog changes from grass-dominated to forb dominated (Dalsted et al., 1981; Coppock et al., 1983; Daniel & Robert, 2001; Magle and crook, 2008). Coppock et al. (1983) stated that forbs are disturbance tolerated (annual forbs) (Braidek et al., 1984). Inconsistent could have lower forb cover because of the intermittent absence of prairie dogs (Cid et al., 1991).

Prairie dogs require at least 5% forbs in their diet for nutritional purposes (Clippinger, 1989). They prefer grass over forbs (Hansen and Gold, 1977; Hoodland, 1995; Clippinger, 1989;Uresk, 1984; Fagerstone et al., 1981). Fagerstone et al. (1977) observed that prairie dogs switch diet between forbs and grass depending on availability (Koford, 1958; Clippinger, 1989;). Authors saw a shift from 73% forb & 5% grass to 9% forb & 82% grass when forbs were reduced in abundance, and prairie dogs did not show any prevalent effect on the weight, health, or activities. Thus, it seems like prairie dogs are probably not limited by food in GNP. Relative Soil moisture and nutrients were non–significant at Snakepit and Police (refer soil results), so probably these variations in forb cover influenced by prairie dog grazing or in the combination of other grazing animals (Coppock et al., 1983).

6.3. Soil

Soil texture was non-significantly different among three treatments in both layers excepting Clay Loam soil in layer B (15 cm-30 cm), which was significantly differed between Consistent and Buffer ($\mu = 0$). In contrast, Stephens (2012) found clay loam significantly higher in non-occupied sites. This difference might be because Stephens

(2012) used broad soil texture classifications on the regional scale, whereas I used original texture classes, and data were analyzed on a colony scale. I found layer A (0 cm-15 cm) has Clay, Clay Loam, Silty Clay, and Silty Clay Loam soil present across all three treatments. In comparison, layer B also has Clay, Silty Clay, and Sandy Clay Loam soil common across three treatments, but Clay loam soil was absent in Buffer as described earlier.

These textures classes are suitable for prairie dog occupancy as supported by other studies (Koford, 1958; Clippinger,1989; Proctor,1998; Roe & Roe, 2003; Stephens, 2012; Avilla-Flores, 2010). In general, prairie dogs can habitat all types of soil until suitable for burrows and well-drained, without excessive sand and rock content (Koford,1958; Dalsted et al., 1981; Clippinger,1989; Reading & Matchett,1997; Roe & Roe, 2003; Wagner & Drickamer 2004; Stephens, 2012;). Apps et al. (2002) suggested that soil with high clay and silt content could collapse easily.

Moisture was suggested important attribute for habitat selection (; Koford, 1958; Avilla-Flores 2009). At my site, relative soil moisture was found non-significantly different at colonies in both layers except at Monument in Layer A and Sage in Layer B. Avilla-Flores (2009) also found a moisture regime non-significant differences among used and non-used habitat units. At Monument, relative soil moisture was significantly higher in Buffer comparing to Consistent and Inconsistent. Whereas at Sage, it was significantly higher in Consistent compared to Buffer. These exceptions could be explained as a result of colonies variation. Overall it reflects that relative Soil moisture might not be limiting the expansion of prairie dog colonies in GNP.

Soil nutrients were non-significantly different in both layers. It reveals that soil is probably not limiting prairie dog colonies expansion in Buffer. In contrast, Broth et al. (2014) and Carlson & White (1987) found soil nutrients significantly higher at the site occupied by prairie dogs in comparison to the non-occupied site.

6.4. Restoration Recommendation

Prairie dog populations are observed fluctuating in GNP without any significant expansion of prairie dog colonies (Lloyd, 2011; Stephens, 2012). My study findings state that expansion is restricted probably because of tall vegetation, and shrub presence along the boundaries of prairie dog colonies. As its consequence, these limitation on expansion probably driving the fluctuation in prairie dog population (Lloyd,2011). These prairie dog colonies are relatively old (>15 years), and possibly they have reached their carrying capacity due to food limitation (Garett et al., 1982). The foremost step for restoring prairie dog populations should be to assist prairie dogs in expanding their colonies.

Habitat is found suitable for wildlife species to survive and reproduce if it could provide food, shelter, and predator cover (Halls & Morrison, 1977; Morrison et al., 2009). Grass cover is significantly higher in Buffer, but as we have seen, prairie dogs avoid occupying areas dominated by shrubs and tall vegetation (Clippinger, 1989; Roe & Roe, 2003). It is highly recommended to reduce shrub cover and vegetation height in Buffer to assist prairie dogs in expanding their colonies. Vegetation (>30 cm) must be mowed down using machinery or fire as a grassland management tool (Milne–Laux & Sweitzer, 2006; Northcott et al., 2008; Augustine et al.,2007). Studies have illustrated that expansion of prairie dogs colonies is possible with habitat manipulation (Koford,1958; Franklin & Garrett,1989; Milne-Laux & Sweitzer 2006). While implementing measures for prairie dogs, care should to avoid any negative impact on other species as every species have individual habitat requirements (Morrison et al. 2009).

The habitat patches were also seen predominated by invasive grass species, which could lower forage quality for grazing animals (Ditomaso et al., 2000; Henderson & Naeth, 2005;). It is recommended to restore those patches to foster native species diversity and biomass using grassland restoration techniques (Bailey et al., 2010). Species should be selected those are preferred by prairie dogs and other grazers. Soil properties and topography were found similar between occupied and non-occupied sites to construct their burrows for shelter and predator cover, so restoration measures should be taken to make forage accessible to prairie dogs to enhance their population.

Populations must be well connected to enhance genetic diversity (Magle et al., 2010; Palmer et al., 2016). Although the linear distance between colonies is within the range (≤10 km) of prairie dog dispersal distance (Stephens, 2012), Prairie dog has seen using the meandering route for dispersal with corridor characteristic by lower vegetation height (Garrett & Franklin,1988; Knowles, 1982). So, it is recommended to regulate vegetation height to ensure proper corridors within prairie dog colonies (Cincotta et al., 1987).

Vegetation height or mechanical structure could also be used as a visual barrier to avoid prairie dog following a false trap to less optimum habitat or private land (Franklin & Garrett,1989; Merriman et al., 2004; Morrison et al., 2009). Visual barriers should be selected based on individual site assessment and other species requirements.

Adaptive management must be followed to measure the success of restoration actions (Palmer et al., 2016). Monitoring must be setup following BACI (Before-after-control-impact) experiment design to test our restoration approaches (Green,1979). If there seems any requirement to augment populations of prairie dogs in GNP; this could be done through the captive breeding program (Morrison et al., 2009) or by translocating population from other metapopulation but make sure that populations are genetically same (Truett & Savage, 1988; Truett et al. 2001; Roe & Roe 2004; Dullum et al., 2005; Morrison et al., 2009).

6.5. Conclusions

This study showed that expansion of prairie dog colonies might be limited because of different physical, and vegetation factors. The presence of shrublands and water channels in Buffer could be restricting the expansion of prairie dog colonies. In contrast, topography and hill presence did not show a comparable difference between occupied (Consistent/Inconsistent) and non-occupied (Buffer) sites. Vegetation analysis showed that shrub cover and vegetation height might be a limiting factor for expansion of prairie dog colonies in Buffer. Whereas the soil was found similar to occupied sites with few exceptions. Clay Loam soil was absent in Buffer at layer B, and relative soil moisture was higher in Buffer (in Layer A) and in Consistent (in Layer B) at Monument and Sage, respectively.

My soil results could be an artifact of fewer sample size and consolidation of soil samples for chemical analysis due to limited resources. Thus, probably average value lowered the variation among treatments. In my methods, I explained choosing a transitional period for vegetation assessment to minimize phenological difference. For future research, it is suggested to collect vegetation data separately for different seasons. Also, I did not separate invasive species, so it will be worth analyzing vegetation separately for native and invasive species in further research. I did a qualitative assessment of hills; results could be enhanced by taking quantifying measures for slope and elevation.

This study was focused only in the north section of GNP, which is grazed by bison. As we have seen colony variation for vegetation and soil is prevalent, it will be worth conducting similar studies in the south section as well, which is grazed by cattle. It will give us better insight if grazers have a diverse impact on prairie dog colonies. This year GNP had good rainfall, it would be interesting to collect data over multiple years to see the trend in vegetation cover between occupied and non–occupied sites over a gradient of precipitation. There could be other factors such as population demography and predation pressure; those might have a significant impact on prairie dogs colonies expansion. It is suggested to contrast habitat attributes with them to understand complex prairie dog ecosystem.

These studies filled a research gap by creating baseline information to compare habitat attributes spatially at Colony scale. My Result showed that habitat could be suitable for prairie dog expansion if we get to manage shrublands, shrub cover, and vegetation height around colonies. Management should prioritize prairie dogs sites for conservation & restoration based on local site history, features, connectivity, gene pool, and multiple species conservation plans. I saw signs of colonies expansion at Sage. Looking at fluctuation in prairie dog populations and expected increase in drought, it is a vital time to take management initiative to restore prairie dog populations in GNP before they get extinct at their northern edge of distribution.

Literature cited

Alvarez, L., Epstein, H., Li, J., & Okin, G. (2011). Spatial patterns of grasses and shrubs in an arid grassland environment. Ecosphere, 2(9), 1-30.

Apps, C., Newhouse, N., & Kinley, T. (2002). Habitat associations of American badgers in southeastern British Columbia. Canadian Journal of Zoology, 80(7), 1228-1239.

Archer, S., Garrett, M., & Detling, G. (1987). Rates of vegetation change associated with prairie dog (Cynomys ludovicianus) grazing in North American mixed-grass prairie. Vegetatio, 72(3), 159-166.

Ashworth, J., Keyes, D., Kirk, R., & Lessard, R. (2001). Standard Procedure in the Hydrometer for Particle Size Analysis. Communications in Soil Science and Plant Analysis, 32(5-6), 633-642.

Augustine, D., & Cully, J. (2007). Influence of Fire on Black-Tailed Prairie Dog Colony Expansion in Shortgrass Steppe. Rangeland Ecology & Management, 60(5), 538-542.

Avila-Flores, R. (2009). Black-tailed prairie dog declines in northwestern Mexico: species-habitat relationships in a changing landscape. (Ph.D. thesis). University of Alberta, Edmonton.

Bailey, A., Mccartney, D., & Schellenberg, M. (2012). Management of Canadian Prairie Rangeland. Agriculture and Agri-Food Canada, n.d,Saskatchewan, Canada.

Barth, C., Liebig, M., Hendrickson, J., Sedivec, K., & Halvorson, G. (2014). Soil change induced by prairie dogs across three ecological sites. Soil Science Society of America Journal, 78(6), 2054-2060.

Beals, S., Hartley, L., Prevéy, J., & Seastedt, T. (2014). The effects of black-tailed prairie dogs on plant communities within a complex urban landscape: An ecological surprise? Ecology, 95(5), 1349-1359.

Bonham, C. (2013). Measurements for terrestrial vegetation / Charles D. Bonham, (Second ed.) Wiley-Blackwell, Colorado State University, Fort Collins, Colorado,USA.

Bonham, C., Lerwick, A. (1976). Vegetation Changes Induced by Prairie Dogs on Shortgrass Range. Journal of Range Management, 29(3), 221-225.

Boulder County Staff. (2002). Boulder County Grassland Management Plan, Prairie Dog Habitat Element. Boulder County Parks and Open Space Department, Boulder, Colorado, USA.

Bragg, T.B. (1995). The Physical Environment of Great Plains Grasslands. Pages. 49-81 In A Joern and K. H. Keeler. Eds. The Changing Prairie: North American Grasslands, Oxford University Press, New York, USA.

Braidek, J., Fedec, P., & Jones, D. (1984). Field survey of halophytic plants of disturbed sites on the Canadian Prairies. Canadian Journal of Plant Science, 64(3), 745-751.

Brown, J. (1984). On the Relationship between Abundance and Distribution of Species. The American Naturalist, 124(2), 255-279.

Carlson, D., & White, E. (1987). Effects of Prairie Dogs on Mound Soils1. Soil Science Society of America Journal, 51(2), 389-393.

Carter, Gregorich, & Carter, Martin R. (2008). Soil sampling and methods of analysis / edited by M.R. Carter, E.G. Gregorich. (2nd ed.). Canadian Society of Soil Science ; CRC Press.

Caughley, G., Grice, D., Barker, R., & Brown, B. (1988). The Edge of the Range. Journal of Animal Ecology, 57(3), 771-785.

Ceballos, G., Davidson, A., List, R., Pacheco, J., Manzano-Fischer, P., Santos-Barrera, G., . . . Hansen, D. (2010). Rapid Decline of a Grassland System and Its Ecological and Conservation Implications (Rapid Decline of Grassland). PLoS ONE, 5(1), E8562.

Cid, M., Detling, J., Whicker, A., & Brizuela, M. (1991). Vegetational Responses of a Mixed-Grass Prairie Site following Exclusion of Prairie Dogs and Bison. Journal of Range Management, 44(2), 100-105.

Cincotta, R. P., D. W. Uresk, & R. M. Hansen. (1987). A statistical model of expansion in a colony of black-tailed prairie dogs. Eight Great Plains Wildlife Damage Control Workshop, Rapid City, SD, USA.

Clippinger, N., & U.S. Fish Wildlife. (1989). Habitat suitability index models: Black-tailed prairie dog. U.S. Dept. of the Interior, Fish and Wildlife Service, Research and Development.

Connell, L., Scasta, J., & Porensky, L. (2018). Prairie dogs and wildfires shape vegetation structure in a sagebrush grassland more than does rest from ungulate grazing. Ecosphere, 9(8), Ecosphere, 2018 Aug, Vol.9(8).

Coppock, D., Detling, L., Ellis, J., & Dyer, K. (1983). Plant-herbivore interactions in a North American mixed-grass prairie. Oecologia, 56(1), 1-9.

Coppock, D., Ellis, J., Detling, J., & Dyer, M. (1983b). Plant-herbivore interactions in a North American mixed-grass prairie : II. Responses of bison to modification of vegetation by prairie dogs. Oecologia, 56(1), 10-15.

COSEWIC (2011) Assessment and Status Report Black-tailed Prairie Dog Cynomys ludovicianus in Canada. In Committee on the Status of Endangered Wildlife in Canada. Retrieved from www.sararegistry.gc.ca/status/status_e.cfm, 22 February 2020.

Cully, J., Johnson, T., Collinge, S., & Ray, C. (2010). Disease limits populations: Plague and black-tailed prairie dogs. Vector Borne and Zoonotic Diseases (Larchmont, N.Y.), 10(1), 7-15.

Curtis. R., Frey. N.S.(2013).Effects of vegetation differences in relocated Utah prairie dog release sites, Natural Science, Vol.5, No.5A, 44-49 (2013) DOI:10.4236/ns.2013.55A006.

Dalsted, J.K.,Sathier-Blair, S., Worcester. B.K., Klukas. R (1981)Application of Remote Sensing to Prairie Dog Management. Journal of Range Management, 34(3), 218-223.

Davidson, A., Detling, J., & Brown, J. (2012). Ecological roles and conservation challenges of social, burrowing, herbivorous mammals in the world's grasslands. Frontiers In Ecology And The Environment, 10(9), 477-486.

Delting, J. K. (2006). Do prairie dogs compete with livestock? Pages 65-88 in Hoogland JL, ed. Conservation of the black-tailed prairie dog: saving North America's western Grasslands. Island Press, Washington, DC, USA.

Desmond, M. (2004). Effects of grazing practices and fossorial rodents on a winter avian community in Chihuahua, Mexico. Biological Conservation, 116(2), 235-242.

Ditomaso, J. (2000). Invasive weeds in rangelands: Species, impacts, and management. Weed Science, 48(2), 255-265.

Dullum, J. A. L., Foresman, K., & Matchett, M. R. (2005). Evaluating effective group release size, population growth, and survival rate of translocated black-tailed prairie dogs on the Charles M. Russell National Wildlife Refuge, Montana. Wildlife Society Bulletin 33:842–850.

Fagerstone, K., & Tietjen, H. (1977). Effects of Range Treatment with 2,4-D on Prairie Dog Diet. Journal of Range Management, 30(1), 57-60.

Fagerstone, K.A. (1979). Food habits of the black-tailed prairie dog. (M.S. Thesis). University of Colorado, Boulder, Colorado, USA.

Fahnestock, J., & Detling, T. (2002). Bison-prairie dog-plant interactions in a North American mixed-grass prairie. Oecologia, 132(1), 86-95.

Fink, K.A. (2014). Landscape- and micro-scale habitat selection by Greater Short-horned Lizards, (M.Sc. thesis), University of Alberta, Edmonton, Alberta, Canada.

Franklin, W., & Garrett, M. (1989). Nonlethal Control of Prairie Dog Colony Expansion with Visual Barriers. Wildlife Society Bulletin (1973-2006), 17(4), 426-430.

Garrett, M., Hoogland, J., & Franklin, W. (1982). Demographic Differences Between an Old and a New Colony of Black-tailed Prairie Dogs (Cynomys ludovicianus). The American Midland Naturalist, 108(1), 51-59.

Gervin, C., Bruun, H., Seipel, T., & Burgess, N. (2019). Presence of Both Active and Inactive Colonies of Prairie Dogs Contributes to Higher Vegetation Heterogeneity at the Landscape Scale. American Midland Naturalist, 181(1), 104.

Green, R. (1979). Sampling design and statistical methods for environmental biologists / Roger H. Green. Wiley.

Grzegorz Swacha, Zoltán Botta-Dukát, Zygmunt Kącki, Daniel Pruchniewicz, & Ludwik Żołnierz. (2017). A performance comparison of sampling methods in the assessment of species composition patterns and environment–vegetation relationships in species-rich grasslands. Acta Societatis Botanicorum Poloniae, 86(4), Acta Societatis Botanicorum Poloniae, 01 December 2017, Vol.86(4).

Gummer, D.L. (2005). Geographic variation in torpor patterns: the northernmost prairie dogs and kangaroo rats. (Ph.D. Thesis). University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Hall, L., Krausman, P., & Morrison, M. (1997). The Habitat Concept and a Plea for Standard Terminology. Wildlife Society Bulletin (1973-2006), 25(1), 173-182.

Hampe, A., & Petit, R. (2005). Conserving biodiversity under climate change: The rear edge matters. Ecology Letters, 8(5), 461-467.

Hansen, R., Gold, I.K. (1977). Blacktail Prairie Dogs, Desert Cottontails and Cattle Trophic Relations on Shortgrass Range. Journal of Range Management, 30(3), 210-214.

He, Y., & Guo.X., (2006). Leaf Area Index Estimation Using Remotely Sensed Data in a Mixed Grassland Ecosystem. Prairie Perspectives,9(1),105-117.

Henderson, D., & Naeth, C. (2005). Multi-scale impacts of crested wheatgrass invasion in mixed-grass prairie. Biological Invasions, 7(4), 639-650.

Hoogland, J. (1995). The black-tailed prairie dog : Social life of a burrowing mammal / John L. Hoogland. (Wildlife behavior and ecology). University of Chicago Press. Chicago, Illinois, USA.

Hoogland, J. (2006). Conservation of the black-tailed prairie dog : Saving North America's western grasslands / edited by John L. Hoogland. (1st ed.). Island Press. Washington, DC, USA.

Johnson, D. (1980). The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology, 61(1), 65-71.

Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as Ecosystem Engineers. Oikos, 69(3), 373-386.

Klatt, L., & Hein, D. (1978). Vegetative Differences among Active and Abandoned Towns of Black-Tailed Prairie Dogs (Cynomys ludovicianus). Journal of Range Management, 31(4), 315-317.

Knowles, C. J. 1982. Habitat affinity, populations and control of black-tailed prairie dogs on the Charles M. Russell National Wildlife Refuge (Montana). Thesis. University of Montana, Missoula, Montana, USA.

Knowles, C., Proctor, J., & Forrest, S. (2002). Black-tailed prairie dog abundance and distribution in the great plains based on historic and contemporary information. Great Plains Research, 12(2), 219-254.

Kochy, M., & Wilson, S. (2000). Competitive Effects of Shrubs and Grasses in Prairie. Oikos, 91(2), 385-395.

Koford, C. (1958). Prairie Dogs, Whitefaces, and Blue Grama. Wildlife Monographs, (3), 3-78.

Kotliar, N. B., B. J. Miller, R. P. Reading, & T. W. Clark. (2006). The prairie dog as a keystone species. Pages 53-64 in J. L. Hoogland, editor. Conservation of the black-tailed prairie dog. Island Press, Washington, DC, USA.

Kotliar, N., Baker, B., Whicker, A., & Plumb, G. (1999). A Critical Review of Assumptions About the Prairie Dog as a Keystone Species. Environmental Management, 24(2), 177-192.

Lloyd, A.N. (2011). Effects of food supplementation on black-tailed prairie dogs (Cynomys ludovicianus) at their northern extent. (M.Sc. thesis). University of Calgary, Calgary, Alberta, Canada.

Lloyd, N., Moehrenschlager, A., Smith, D., & Bender, D. (2013). Food limitation at species range limits: Impacts of food availability on the density and colony expansion of prairie dog populations at their northern periphery. Biological Conservation, 161(C), 110-117.

Lourdes Martínez-Estévez, Patricia Balvanera, Jesús Pacheco, & Gerardo Ceballos. (2013). Prairie dog decline reduces the supply of ecosystem services and leads to desertification of semiarid grasslands. PLoS ONE, 8(10), E75229.

Magle, S., & Crooks, K. (2008). Interactions between black-tailed prairie dogs (Cynomys ludovicianus) and vegetation in habitat fragmented by urbanization. Journal Of Arid Environments, 72(3), 238-246.

Magle, S., Ruell, E., Antolin, M., & Crooks, K. (2010). Population genetic structure of black-tailed prairie dogs, a highly interactive species, in fragmented urban habitat. Journal of Mammalogy, 91(2), 326-335.

Manly, B. (2002). Resource selection by animals : Statistical design and analysis for field studies / Bryan F.J. Manly [and others]. (2nd ed.). Kluwer Academic.

May, L.H.(2003) Black-tailed Prairie Dog. Fish and Wildlife Habitat Management Leaflet. (Number 23). Wildlife Habitat Management Institute. Washington, DC, USA.

McDonald, J.H. (2014). Handbook of Biological Statistics (3rd ed.). Sparky House Publishing, Baltimore, Maryland, USA.

Merriman, J., Zwank, P., Boal, C., & Bashore, T. (2004). From the Field: Efficacy of visual barriers in reducing black-tailed prairie dog colony expansion. Wildlife Society Bulletin, 32(4), 1316-1320.

Miller, Brian J., Reading, Richard P., Biggins, Dean E., Detling, James K., Forrest, Steve C., Hoogland, John L., Uresk, Daniel W. (2007). Prairie Dogs: An Ecological Review and Current Biopolitics. Journal of Wildlife Management, 71(8), 2801-2810.

Miller, Reading, Hoogland, Clark, Ceballos, List, . . . Uresk. (2000). The Role of Prairie Dogs as a Keystone Species: Response to Stapp. Conservation Biology, 14(1), 318-321.

Milne-Laux, S., & Sweitzer, R. (2006). Experimentally induced colony expansion by Black-tailed prairie dogs (Cynomys ludovicianus) and implications for Conservation. Journal of Mammalogy, 87(2), 296-303.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, K.S.M Kurtz, D.W. Wolfe, and G.S. Abawi.(2016). Comprehensive Assessment of Soil Health – The Cornell Framework, Edition 3.2, Cornell University, Geneva, New York, USA.

Morrison, M., & Society for Ecological Restoration International. (2009). Restoring wildlife : Ecological concepts and practical applications / Michael L. Morrison. (Science and practice of ecological restoration). Island Press. Washington, DC, USA.

Morrison, M., Block, W., Strickland, M., Collier, B., Peterson, M., Anderson, B., . . . Walker, L. (2008). Wildlife Study Design (Springer Series on Environmental Management). Springer, New York, USA.

Nistler, J.C.M, Sowell, B., & Wambolt, C. (2004). Black-Tailed Prairie Dog Effects on Montana's Mixed-Grass Prairie. Journal of Range Management, 57(6), 641-648.

Northcott, J., Andersen, M., Roemer, G., Fredrickson, E., DeMers, M., Truett, J., & Ford, P. (2008). Spatial Analysis of Effects of Mowing and Burning on Colony Expansion in Reintroduced Black-Tailed Prairie Dog (Cynomys ludovicianus). Restoration Ecology, 16(3), 495-502.

Osborn, B., & Allan, P. (1949). Vegetation of an Abandoned Prairie-Dog Town in Tall Grass Prairie. Ecology, 30(3), 322-332.

Palmer, M., Zedler, J., & Falk, D. (2016). Foundations of Restoration Ecology edited by Margaret A. Palmer, Joy B. Zedler, Donald A. Falk. (Second ed., Science and practice of ecological restoration). Island Press/Center for Resource Economics : Imprint: Island Press, Washington, DC, USA.

Parks Canada Agency. (2016). Multi-species Action Plan for Grasslands National Park of Canada [Proposed]. Species at Risk Act Action Plan Series. Parks Canada Agency, Ottawa. iv + 57 pp.

Ponce-Guevara, E., Davidson, A., Sierra-Corona, R., & Ceballos, G. (2016). Interactive Effects of Black-Tailed Prairie Dogs and Cattle on Shrub Encroachment in a Desert Grassland Ecosystem. PloS One, 11(5), E0154748.

Proctor, J. (1998). A GIS model for identifying potential black-tailed prairie dog habitat in the northern Great Plains shortgrass prairie. Thesis. University of Montana, Missoula, Montana, USA.

Proctor, J., B. Haskins, & S. C. Forrest. (2006). Focal areas for conservation of prairie dogs and the grassland ecosystem. Pages 232—247 in J. L. Hoogland, editor. Conservation of the black-tailed prairie dog. Island Press, Washington, DC, USA.

Reading, R., & Matchett, R. (1997). Attributes of Black-Tailed Prairie Dog Colonies in Northcentral Montana. The Journal of Wildlife Management, 61(3), 664-673.

Robel, R., Dayton, A., & Hulbert, L. (1970). Relationships between Visual Obstruction Measurements and Weight of Grassland Vegetation. Journal of Range Management, 23(4), 295-297.

Roe, Ka, & Roe, CM. (2004). A relocation technique for black-tailed prairie dogs. Western North American Naturalist, 64(4), 445-453.

Roe, Kelly A., & Roe, Christopher M. (2003). Habitat Selection Guidelines for Black-Tailed Prairie Dog Relocations. Wildlife Society Bulletin (1973-2006), 31(4), 1246-1253.

Ryerson, D., & Parmenter, R. (2001). Vegetation Change Following Removal of Keystone Herbivores from Desert Grasslands in New Mexico. Journal of Vegetation Science, 12(2), 167-180.

Saskatchewan Conservation Data Centre. (2019). Saskatchewan Vertebrate Tracked Taxa List. Regina, Saskatchewan. Retrieved from www.biodiversity.sk.ca/SppList.htm. 22 February 2020.

Sierra–Corona, R., Davidson, A., Fredrickson, E., Luna-Soria, H., Suzan-Azpiri, H., Ponce-Guevara, Machado, R. (2015). Black-Tailed Prairie Dogs, Cattle, and the Conservation of North America’s Arid Grasslands. PLoS ONE, 10(3), E0118602.

Species at Risk Act (2019) Black tailed prairie dog, Retrieved from https://species-registry.canada.ca/index-en.html#/species/151-454. 22 February 2020.

Stephens, T. (2012). Habitat and population analysis of black-tailed prairie dogs (Cynomys ludovicianus)(M.Sc. thesis). University of Calgary, Calgary, Alberta, Canada.

Stephens, T., Wilson, S., Cassidy, F., Bender, D., Gummer, D., Smith, D., . . . Moehrenschlager, A. (2018). Climate change impacts on the conservation outlook of populations on the poleward periphery of species ranges: A case study of Canadian black-tailed prairie dogs (Cynomys ludovicianus). Global Change Biology, 24(2), 836-847.

Sutherland, & Sutherland, William J. (2006). Ecological census techniques : A handbook / edited by William J. Sutherland. (2nd ed.). Cambridge University Press, New York, USA.

Thorpe, J., Stephens, T.(2017). Development of Habitat Mapping and Decision Support Tool for Greater Sage-grouse and Black-tailed Prairie Dog. (13826).

Truett, J. C., and T. Savage. (1998). Reintroducing prairie dogs into desert grasslands. Restoration and Management Notes ,16,189–195.

Truett, J. C., J. A. Dullum, M. R. Matchett, E. Owens, and D. Seery. (2001). Translocating prairie dogs: a review. Wildlife Society Bulletin 29:863–872.

Uresk, D. (1984). Black-Tailed Prairie Dog Food Habits and Forage Relationships in Western South Dakota. Journal of Range Management, 37(4), 325-329.

Van Auken, O. (2000). Shrub Invasions of North American Semiarid Grasslands. Annual Review of Ecology and Systematics, 31, 197-215.

Wagner, D., & Drickamer, L. (2004). Abiotic Habitat Correlates of Gunnison's Prairie Dog in Arizona. The Journal of Wildlife Management, 68(1), 188-197.

Weltzin, J., Archer, S., & Heitschmidt, R. (1997). Small-mammal regulation of vegetation structure in a temperate Savanna. Ecology, 78(3), 751-763.

Winter, S., Cully, J., & Pontius, J. (2002). Vegetation of Prairie Dog Colonies and Non-Colonized Shortgrass Prairie. Journal of Range Management, 55(5), 502-508.

Zar, J. (2010). Biostatistical analysis / Jerrold H. Zar. (5th ed.). Pearson, Northern Illinois University, Dekalb, Illinois, USA.

Zhaoqin Li, & Xulin Guo. (2012). Detecting Climate Effects on Vegetation in Northern Mixed Prairie Using NOAA AVHRR 1-km Time-Series NDVI Data. Remote Sensing, 4(1), 120-134.

Zhaoqin, Li. (2017). Quantifying grassland non-photosynthetic vegetation biomass using remote sensing data (M.Sc. thesis), University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Appendix A. Two factor ANOVA table (When Interaction term was significant)

Table A1. Summary of (treatments & blocks) ANOVA performed to test vegetation variables for significance difference among treatments in Grasslands National Park, Saskatchewan from 17 July 2019 to 3 August 2019. The level of significance was < 0.05. Value equal or near to significance are bold. (df = degree of freedom, f = F value, p = probability).

	Treatments			Blocks			Interaction (treatment * block)			Post hoc analysis		
	df	f	p	df	f	p	df	f	p	Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
Forb	2, 6	3.276	.108	3, 6	8.570	**.013**	6, 257	2.603	**.018**	**.002**	**.000**	.450
Shrub	2, 6	30.690	**.001**	3, 6	1.933	.224	6, 260	2.545	**.021**	.043	**.000**	**.000**

Table A2. Summary of two - factor ANOVA (treatments & blocks) performed to test relative soil moisture (Layer A and B) for significance difference among treatments Grasslands National Park, Saskatchewan from 18 August 2019 to 28 August 2019. The level of significance was < 0.05. Value equal or near to significance are bold. (df = degree of freedom, f = F value, p = probability).

	Treatments			Blocks			Interaction (treatment * block)			Post hoc analysis		
	df	f	p	df	f	p	df	f	p	Consistent vs. Inconsistent	Consistent vs. Buffer	Inconsistent vs. Buffer
Layer A, Relative Soil Moisture	2, 6.009	.428	.670	3, 6.011	17.296	**.002**	6, 60	4.529	**.001**	.698	**.050**	.229
Layer B, Relative Soil Moisture	2, 6.006	.236	.796	3, 6.005	7.087	**.021**	6, 58	3.717	**.003**	.509	.573	.995

Appendix B. Photos of prairie dogs and their habitat

Figure B1. View of prairie dog colony matrixed in hetrogeneous landscape.

Figure B2. Photo representings hills sourrounded prairie dog colonies.

Figure B3. View of tall vegetation and shrubs sorrounding a prairie dog colony.

Figure B4. Photo representing a prairie dog active burrow.

Figure B5. Photo representing mounds built by prairie dogs at their burrows.

Figure B6. Photo showing dense, tall vegetation and shrubs in Buffer.

Figure B7. Photo representing a site unused by prairie dogs.

Figure B8. Frenchman river passing along the prairie dog colony.