Cattle-Use Distribution in Pastures with Black-tailed Prairie Dog *(Cynomys ludovicianus)* Colonies in Southeastern Colorado

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Abstract

This study investigated cattle *(Bos taurus)* use of black-tailed prairie dog (*Cynomys ludovicianus*) towns in two pastures in southeastern Colorado by measuring fecal pat density distribution in pastures on prairie dog towns, off prairie dog towns, and near water sources, during the summer of 2000. I analyzed the data using an ANOVA procedure that accounts for spatial autocorrelation in the data. Analysis indicated no significant difference ($P > .05$) between cattle use of prairie dog towns and use of random sites off towns. The mean densities of fecal pats on towns were 16.13 fecal pats/0.01 ha and 15.59 fecal pats/0.01 ha for pastures 1 and 2 respectively, and the mean densities off towns at random sites were 15.95 fecal pats/0.01 ha and 14.48 fecal pats/0.01 ha in the two pastures respectively. This research suggests cattle on the shortgrass steppe use prairie dog towns randomly, i.e. neither avoid nor prefer them.

Introduction

Since the introduction of cattle (*Bos taurus*) to the prairies of the Great Plains, prairie dogs have been the subject of heated debate. As the prairies were settled, the prairie dog (*Cynomys ludovicianus*) was viewed as a destructive rangeland pest rather than an interesting curiosity or driver of ecosystem processes. Prairie dog habitat was reduced in size and became more fragmented with settlement, because of growth of dryland agriculture and urbanization. In addition, widespread extermination campaigns were conducted because of both real and imagined competition with livestock for forage resource. These campaigns were so successful that prairie dogs apparently now number only a small fraction of what they did a century ago (Bonham and Lerwick 1976). This drastic reduction has placed the black-tailed prairie dog in the public eye. Federal legislation (the Endangered Species Acts of 1969 and 1973) allowed the United States Fish and Wildlife Service to consider petitions to list the black-tailed prairie dog as

1

a threatened or endangered species. This has resulted in increasing interest in the welfare of the black-tailed prairie dog.

Much research has been done on the apparent competition between livestock and prairie dogs. Early literature on prairie dog-livestock competition was negative toward the prairie dog. Merriam (1901) and Bell (1920) described losses in crops and range forage due to prairie dogs and recommended prairie dog elimination. Recent information suggests that black-tailed prairie dogs compete with cattle for forage, but possibly not enough to warrant control measures (Klatt and Hein 1978) (Collins, Workman and Uresk 1984).

Previous studies (Hansen and Gold 1977) provide evidence that black-tailed prairie dogs are an important part of prairie ecosystems, as they disturb the soil, increase plant diversity, increase animal diversity, and cause a decrease in the primary production of the areas they use. Recently, there has been a debate about whether or not prairie dogs are a keystone species for shrub-steppe landscape systems. In their critical review, Kotlier, et al. (1999), examined the strength of the evidence and magnitude of the prairie dog's effects on ecosystem structure and function. They conclude that although some prairie dog functions may be smaller than previously assumed, they concur that keystone status for prairie dogs is appropriate.

Within a shortgrass ecosystem, prairie dogs may depress the habitat suitability for cattle grazing while enhancing habitat for other animals [e.g., desert cottontails (*Sylvilagus auduboni*), burrowing owls (*Speotyto cunicularia*), rattlesnakes (*Crotalis viridus*)], and some plants. In the shortgrass ecosystem where the prairie dog is a keystone species, cattle grazing does not seem to influence prairie dog numbers but may be affected by the presence of prairie dogs (Hansen and Gold 1977).

The historically assumed interaction between cattle and prairie dogs is negative: i.e. that either the amount of forage is reduced or the actual amount of grazing (carrying capacity) is reduced. Cattle have spatial memory and can remember quantity and quality of forage patches as well as their location (Bailey *et al.* 1989, Rittenhouse 1991). Cattle will remember a low quality patch and will avoid it for up to 21 days (Bailey 1995). Therefore, movements of cattle are not independent from day to day, and if vegetation on prairie dog towns is remembered as low quality, cattle may not return to the prairie dog town until their memory decays or there are changes in the vegetation. Despite the variability in individual towns. . . cattle did not have a strong preference for prairie dog towns as bison do on the mixed-grass prairie (Kruger 1986).

This study investigated the use of prairie dog towns by cattle on the shortgrass steppe in southeastern Colorado. The objective of this study was to determine pasture use by cattle in response to prairie dog colonies and distribution of foci (e.g, water sources) in southeastern Colorado. This was accomplished by: (a) measuring cattle fecal pat densities on and off prairie dog towns; (b) mapping these densities; and (c) comparing the expected mean densities to determine if there was a significant difference of cattle use on and off the prairie dog towns. My null hypothesis was that cattle pasture utilization is not significantly different on or off prairie dog towns.

Study Area

The study was conducted at the Flying Diamond Ranch, located in Crowley County of southeastern Colorado (Map 1), near the town of Ordway, approximately 90 km south of Limon (Map 2). The dominant plant species of this region are blue grama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), alkali sacaton (*Sporabilus aeriodes*), and prickly pear cactus

3

(*Opuntia polyacantha*). Annual precipitation is approximately 318mm/yr. Most soils are well-drained loams or sandy loams (Heil). The topography consists of large flat expanses with a few rolling hills. The elevation ranges from 1325m to 1510m.

Map 1: Colorado Counties
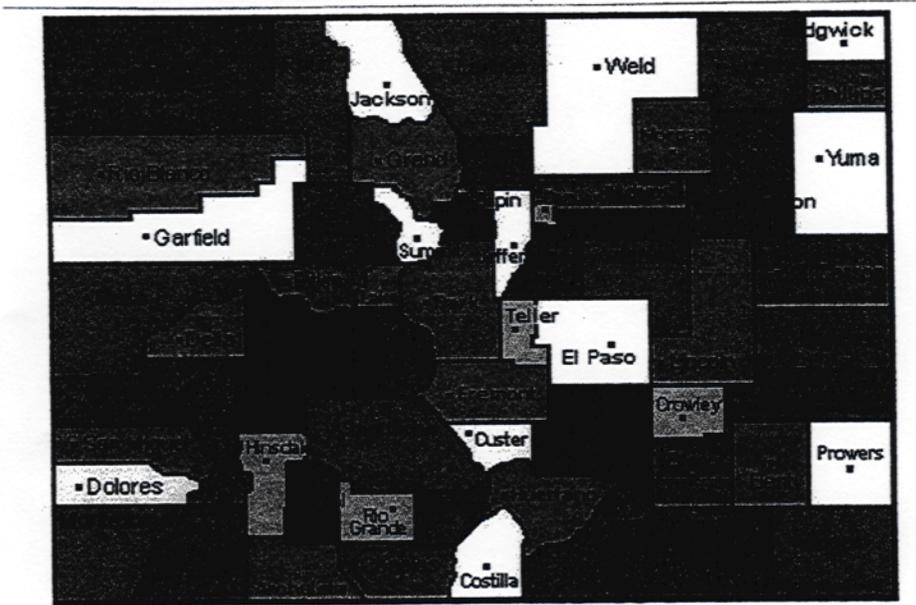
Map 2: Flying Diamond Ranch Location
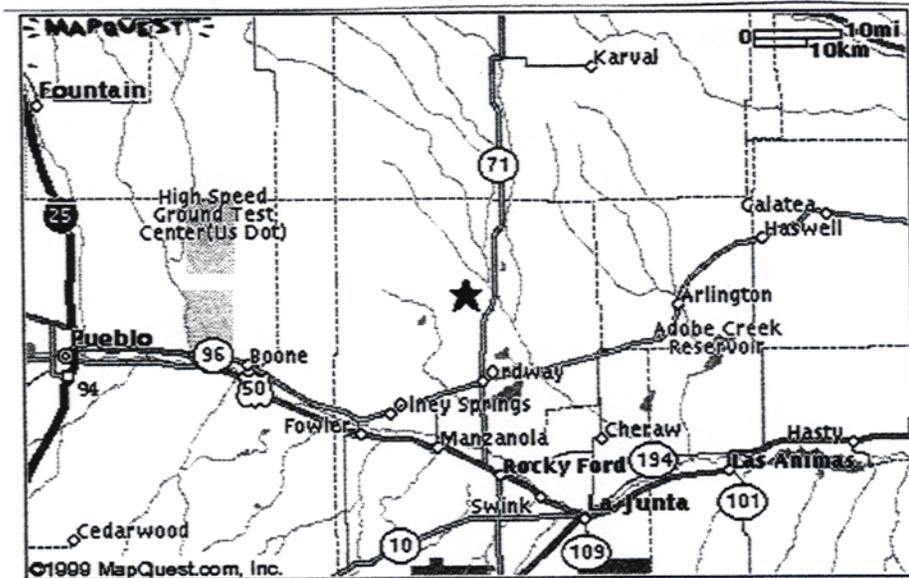
The Flying Diamond Ranch is a working cattle ranch that breeds Texas Longhorn and Black Angus cattle for beef production. Pasture sizes range from 600 to 2000 ha. The black-tailed prairie dog towns in southern Crowley County range in size from 1 to 200 ha and occupies less than 1% and up to 15% of the pastures.

We chose two different study areas. The first study area (Map 3) was a pasture that included two water tanks (north pasture or pasture 1), and the second (Map 4) was a pasture that did not include any permanent water source (south pasture or pasture 2). In that pasture, cattle were removed from the pasture when watered.
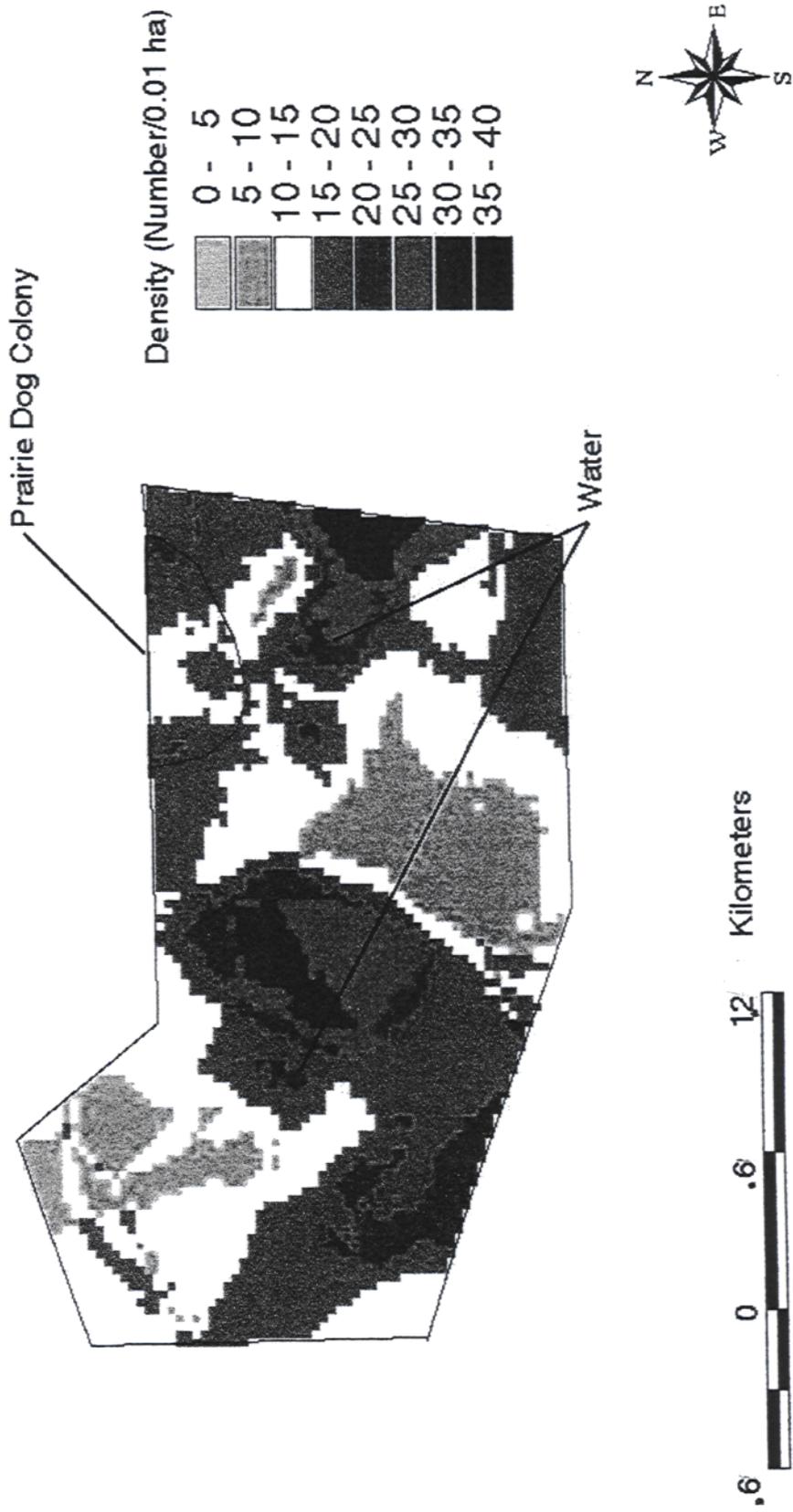
North Pasture

The first study area was the north pasture. The north pasture is 2000 ha in area, with two water sources. Cattle are stocked at a 'heavy' stocking rate. The prairie dog town is located along the northern edge of the pasture and is approximately 35 ha in area.

South Pasture

The second study area was the south pasture. The south pasture was 600 ha in area, with no permanent water source. A dry streambed bisects the pasture, with rainfall sufficient to fill it up only a couple times a year, if at all (Glen Lewis, pers. comm.). Cattle are removed to an adjacent pasture for watering. This pasture is stocked at a 'heavy' rate. The prairie dog town in this pasture is located in the southwestern corner and is approximately 40 ha in area.

Map3: Flying Diamond North Pasture

Prairie Dog Colony

Water

Density (Number/0.01 ha)

0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40

N E S W

.6   0   .6   12   Kilometers

Map 4:

Flying Diamond South Pasture

Water
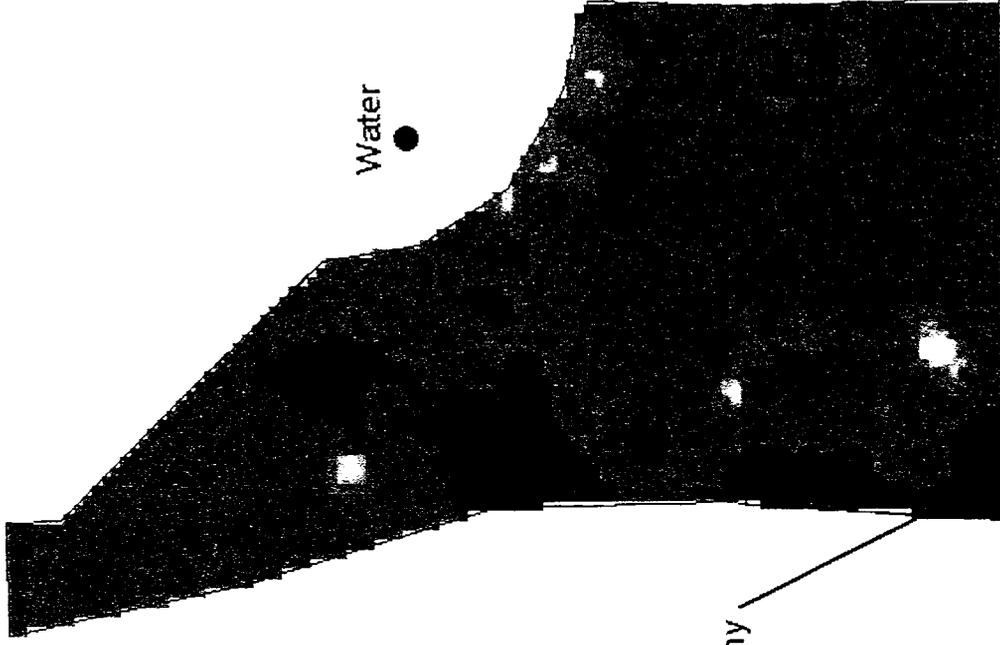
Prairie Dog Colony

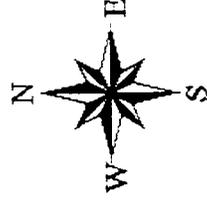Density (Number / 0.01 ha)
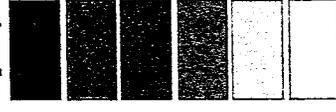
- 4 - 10
- 10 - 16
- 16 - 22
- 22 - 29
- 29 - 35
- 35 - 40

N
W E
S

0.5   0   0.5   1 Kilometers

Methods

This study used a methodology of measuring fecal pat density. Cattle use of the prairie dog towns and surrounding areas was determined by measuring fecal pat densities. Research indicates that fecal pat densities are indicative of the amount of time cattle spend in an area (Senft 1980, Milchunas *et al.* 1989). I measured and mapped cattle fecal pat densities (number/0.01 ha) using 0.01 ha quadrats. Quadrats were located using a Garmin GPS 38. I chose a completely random design with three treatments and two replications. Treatments included: (1) on prairie dog colony, (2) near water source, and (3) off prairie dog colony at randomly chosen points. The sampling design was based in radial transects. Six radial transects were separated by approximately 60° angles. The initial transect was chosen at random from 0° to 60°. Transects 2-6 were then spaced at 60° intervals. Transects were 500m. in length. Five quadrats were located on each radial transect and one quadrat at the center for a total of 31 quadrats at each treatment/replication location (Figure 1).

All replications were chosen at random when possible. (Water treatments were fixed features and therefore could not be chosen randomly.) A rough grid of each pasture was made and replication locations were chosen based on random numbers assigned to each grid point/interaction using a random number table.
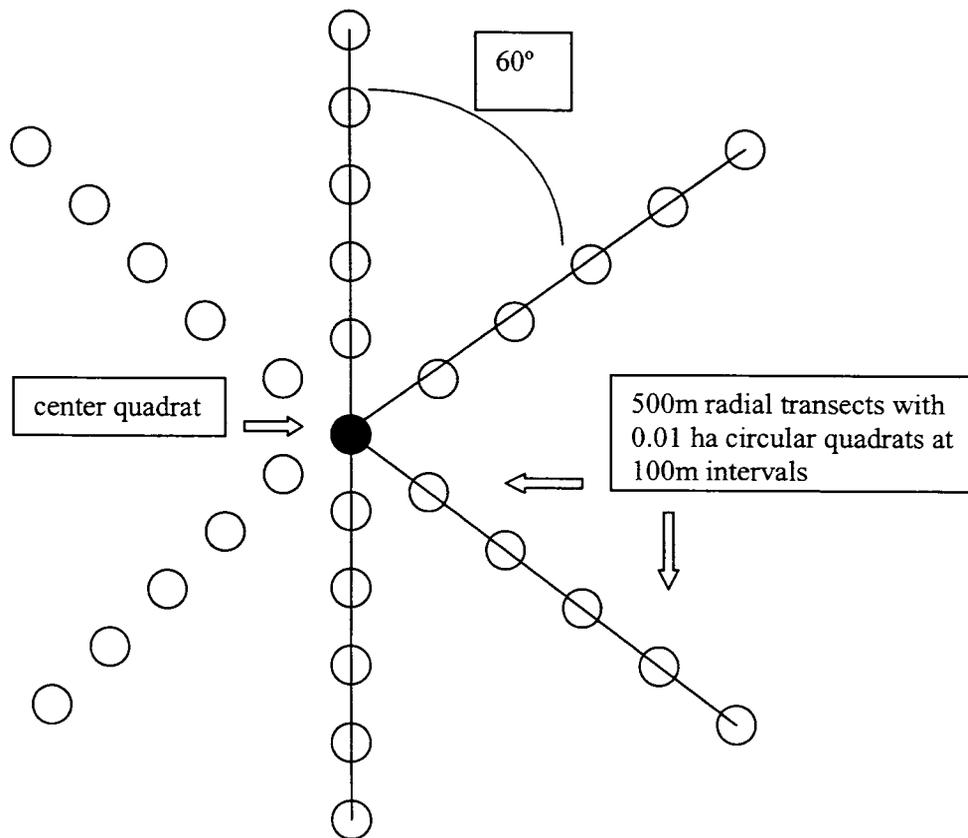
Figure 1: Sampling Design. The design consists of 31 circular quadrats (0.01ha each) in a 'snowflake' pattern. The location for the center quadrat was determined by using a rough grid of the pasture and a random number table. The direction of the first spoke (from true north) was also determined with a random number table (#'s 0-59). The remaining five spokes were approximately 60° apart. Each spoke was 500m in length and had five quadrats at 100m intervals.

Analysis of Variance

A three-factor analysis of variance model was used to test a null hypothesis of no significant differences in fecal pat densities near sources of water, on prairie dog colonies and the randomly located sites (control). Using the notation of a three-factor analysis of variance, let Y_{ijkm} represent the mth observation (m = 1, . . ., n) on the ith treatment (i = 1, . . ., a), the jth spoke

(j = 1, . . ., b), and the kth distance along a given spoke (k = 1, . . ., c). The total number of

observation is equal to n_T = abcn. The functional form the analysis of variance model is given by

$$Y_{ijkm} = \mu_{..} + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + \varepsilon_{ijkm}$$ [1]

where μ is a constant, α_i is the effect of the ith treatment, β_j is the effect of the jth spoke, γ_k is the

effect of the kth distance subject to the restriction Σαi = 0, Σβj = 0, and Σγk =0, $(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$,

$(\beta\gamma)_{jk}$ are interaction terms, and ε_{ijkm} are independent $N(0,\sigma^2)$ random errors. No interactions

were assumed to exist between treatments, spokes and distances along the spokes.

I tested the equality of fecal pat densities across sites with a restatement of the analysis of

variance model (Eq. 1) in the form of a regression model. The final model is given by

$$
\begin{aligned}
Y_{ijkm} = \mu_{..} &+ \alpha_1 X_{ijkm1} + \alpha_2 X_{ijkm2} + \beta_1 X_{ijkm3} + \beta_2 X_{ijkm4} + \beta_3 X_{ijkm5} + \beta_4 X_{ijkm6} + \beta_5 X_{ijkm7} + \gamma_1 X_{ijkm8} \\
&+ \gamma_2 X_{ijkm9} + \gamma_3 X_{ijkm10} + \gamma_4 X_{ijkm11} + (\alpha\beta)_{11} X_{ijkm1} X_{ijkm3} + (\alpha\beta)_{12} X_{ijkm1} X_{ijkm4} \\
&+ (\alpha\beta)_{13} X_{ijkm1} X_{ijkm5} + (\alpha\beta)_{14} X_{ijkm1} X_{ijkm6} + (\alpha\beta)_{15} X_{ijkm1} X_{ijkm7} + (\alpha\beta)_{21} X_{ijkm2} X_{ijkm3} \\
&+ (\alpha\beta)_{22} X_{ijkm2} X_{ijkm4} + (\alpha\beta)_{23} X_{ijkm2} X_{ijkm5} + (\alpha\beta)_{24} X_{ijkm2} X_{ijkm6} + (\alpha\beta)_{25} X_{ijkm2} X_{ijkm7} \\
&+ (\alpha\gamma)_{11} X_{ijkm1} X_{ijkm8} + (\alpha\gamma)_{12} X_{ijkm1} X_{ijkm9} + (\alpha\gamma)_{13} X_{ijkm1} X_{ijkm10} + (\alpha\gamma)_{14} X_{ijkm1} X_{ijkm11} \\
&+ (\alpha\gamma)_{21} X_{ijkm2} X_{ijkm8} + (\alpha\gamma)_{22} X_{ijkm1} X_{ijkm9} + (\alpha\gamma)_{23} X_{ijkm2} X_{ijkm10} + (\alpha\gamma)_{2} X_{ijkm2} X_{ijkm11} \\
&+ (\beta\gamma)_{11} X_{ijkm3} X_{ijkm8} + (\beta\gamma)_{12} X_{ijkm3} X_{ijkm9} + (\beta\gamma)_{13} X_{ijkm3} X_{ijkm10} + (\beta\gamma)_{14} X_{ijkm3} X_{ijkm11} \\
&+ (\beta\gamma)_{21} X_{ijkm4} X_{ijkm8} + (\beta\gamma)_{22} X_{ijkm4} X_{ijkm9} + (\beta\gamma)_{23} X_{ijkm4} X_{ijkm10} + (\beta\gamma)_{24} X_{ijkm4} X_{ijkm11} \\
&+ (\beta\gamma)_{31} X_{ijkm5} X_{ijkm8} + (\beta\gamma)_{32} X_{ijkm5} X_{ijkm9} + (\beta\gamma)_{33} X_{ijkm5} X_{ijkm10} + (\beta\gamma)_{34} X_{ijkm5} X_{ijkm11} \\
&+ (\beta\gamma)_{41} X_{ijkm6} X_{ijkm8} + (\beta\gamma)_{42} X_{ijkm6} X_{ijkm9} + (\beta\gamma)_{43} X_{ijkm6} X_{ijkm10} + (\beta\gamma)_{44} X_{ijkm6} X_{ijkm11} \\
&+ (\beta\gamma)_{51} X_{ijkm7} X_{ijkm8} + (\beta\gamma)_{52} X_{ijkm7} X_{ijkm9} + (\beta\gamma)_{53} X_{ijkm7} X_{ijkm10} + (\beta\gamma)_{54} X_{ijkm7} X_{ijkm11} \\
&+ \varepsilon_{ijkm}
\end{aligned}
$$

[2]

where

$$X_{ijk1} = \begin{cases} 1 \text{ if the observation is from a prairie dog colony} \\ 0 \text{ if the observation is from site with water} \\ -1 \text{ if the observation is a random site} \end{cases}$$

$$X_{ijk2} = \begin{cases} 1 \text{ if the observation is from a site with water} \\ 0 \text{ if the observation is from a prairie dog colony} \\ -1 \text{ if the observation is a random site} \end{cases}$$

$$X_{ijk3} = \begin{cases} 1 \text{ if the observation is from spoke 1 } (0° - 60°) \\ 0 \text{ if the observation is from spokes 2, 3, 4, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk3} = \begin{cases} 1 \text{ if the observation is from spoke 1 } (0° - 60°) \\ 0 \text{ if the observation is from spokes 2, 3, 4, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk4} = \begin{cases} 1 \text{ if the observation is from spoke 2 } (60° - 120°) \\ 0 \text{ if the observation is from spokes 1, 3, 4, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk5} = \begin{cases} 1 \text{ if the observation is from spoke 3 } (120° - 180°) \\ 0 \text{ if the observation is from spokes 1, 2, 4, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk6} = \begin{cases} 1 \text{ if the observation is from spoke 4 } (180° - 240°) \\ 0 \text{ if the observation is from spokes 1, 2, 3, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk7} = \begin{cases} 1 \text{ if the observation is from spoke 5 } (240° - 300°) \\ 0 \text{ if the observation is from spokes 1, 2, 3, or 5} \\ -1 \text{ if the observation is from spoke 6 } (300° - 360°) \end{cases}$$

$$X_{ijk8} = \begin{cases} 1 \text{ if the observation is 0 to 100 m from the center of the spokes} \\ -1 \text{ if the observation is 400 to 500 m from the center of the spoke} \\ 0 \text{ otherwise} \end{cases}$$

$$X_{ijk9} = \begin{cases} 1 \text{ if the observation is 100 to 200 m from the center of the spokes} \\ -1 \text{ if the observation is 400 to 500 m from the center of the spoke} \\ 0 \text{ otherwise} \end{cases}$$

$$X_{ijk10} = \begin{cases} 1 \text{ if the observation is 200 to 300 m from the center of the spokes} \\ -1 \text{ if the observation is 400 to 500 m from the center of the spoke} \\ 0 \text{ otherwise} \end{cases}$$

$$X_{ijkll} = \begin{cases} 1 \text{ if the observation is 300 to 400 m from the center of the spokes} \\ -1 \text{ if the observation is 400 to 500 m from the center of the spoke} \\ 0 \text{ otherwise} \end{cases}$$

In fitting this model it was assumed the residuals were spatially independent, which may not be a valid assumption.

The residuals of the linear model were analyzed for spatial autocorrelation using a Lagrange multiplier and a variation of MORAN's statistic, denoted I_k. This statistic takes into consideration that the residuals are subject to k linear constraints associated with estimating the coefficients of the regression model. A spatial weights matrix (W) was used to calculate the Lagrange multiplier (lm) and I_k. If residuals exhibited a significant spatial autocorrelation, the linear model was refitted using a spatial autoregressive model described below.

The analysis of variance model (Eq. 2) can be expressed in matrix notation as:

$$\underline{Y} = X \underline{b} + \underline{e} \tag{3}$$

where Y is an n_T x 1 column vector of response variables $(Y_{11}, Y_{12}, ..., Y_{nT})'$, b is a 50 x 1 column vector of regression coefficients, X is an n_T x 50 matrix of zeros and ones (both positive and negative) corresponding to the treatments, and $\underline{e}$ is an n_T x 1 column vector of unobserved errors. If the errors are spatially correlated, the relationship between Y and X, is modeled as:

$$\underline{Y} = X \underline{b} + (I - \rho W)^{-1} \underline{e}. \tag{4}$$

where W is an n_T x n_T spatial weights matrix expressing the spatial relationship among the residuals, I is an n_T x n_T identity matrix, and ρ (-1 $\leq \rho \leq$ 1) is a spatial autocorrelation coefficient indicating the level and direction of the error autocorrelation.

The maximum likelihood estimate of the parameter vector, b, is given by:

$$\hat{\beta}_{MLE} = \left(X'(I - \rho W)'(I - \rho W)X\right)^{-1} X'(I - \rho W)'(I - \rho W)\underline{y} \tag{5}$$

with variance

10

$$\sigma_{MLE}^2 = \frac{1}{n}\left(Y - X\,\hat{\beta}_{MLE}\right)'(I - \rho W)'(I - \rho) \tag{6}$$

and covariance

$$Cov(Y) = \sigma_{MLE}^2 (I - \rho\,W)^{-1}\left((I - \rho\,W)'\right)^{-1}. \tag{7}$$

Since ρ varies over the interval of -1 to 1, an iterative procedure that minimized the reduced log

likelihood function was used to estimate ρ:

$$L\left(\rho, \hat{\beta}_{ML}, \hat{\sigma}_{MLE}^2\right) = \frac{-n}{2}\ln(2n) - \frac{n}{2}\ln\left(\hat{\sigma}_{MLE}^2\right) + \sum_{i=1}^{n}\ln(1 - \rho W_i) - \frac{n}{2} \tag{8}$$

If the null hypothesis associated with either the classical or spatial autoregressive analysis

of variance model was rejected, Bonferoni's method of multiple comparisons was used to test for

significant differences between all possible pairs of treatment means.

Kriging density of fecal pats

Ordinary kriging was used to spatially interpolate estimates of the density of fecal pats

throughout the two pastures to 30 m resolution. This was accomplished by first calculating the

sample variogram, which describes the spatial variability in the density of fecal pats at pairs of

points separated by increasingly larger distances. Weighted non-linear least squares was used to

fit various theoretical models (i.e. Gaussian, spherical, exponential, liner) to the sample

variogram data as a function of distance. Akiake's corrected information criteria (AICC) was

used to select a variogram model that best describes the spatial continuity in fecal pat densities.

The variogram model with the smallest AICC was selected as the best fitting model. Using the

fitted variogram model, image maps of the kriging prediction of the density of fecal pats were

developed (Maps 3 and 4).

11

Results and Discussion

Both a classical and spatial ANOVA model were applied to the data. Both pastures exhibited spatial variability through differences in topography, distance from water sources, elevation, and fence lines. These spatial relationships of fecal pat densities became a consideration during analysis, thus I applied both an ANOVA and SANOVA model to the data. Appendix A displays the SANOVA results of both pastures. Appendix B displays the results of the classical ANOVA model for both pastures.

The SANOVA model provided a more precise estimate of the influences of the cattle with respect to the presence of prairie dog colonies and watering sites. The mean squared errors for the two ANOVA and SANOVA models were 49.95 vs 34.14 for the north pasture and 54.48 vs 35.56 for the south pasture. Both models indicated a significant difference in fecal pat densities between the random.

Based on these results there is not enough evidence to reject the null hypothesis. I tentatively must conclude that cattle-use distribution in these pastures was random relative to the portion of the pastures occupied by prairie dogs. I based my conclusion on statistical analysis (SANOVA) of fecal pat density distribution in the pastures and selected literature that (1) reported on cattle behavior under similar conditions and (2) discussed known mechanisms that result in large-herbivore grazing patterns.

Average expected fecal pat density was similar (P > .05) on areas occupied by black-tailed prairie dogs compared to randomly selected areas in the pastures (Table 1). This indicates that the cattle-use distribution is random for those two treatments. Within the prairie dog colony and off-town random site treatments, there were no significant differences of fecal pat densities within the different spokes.

12

Table 1

Expected Mean Density by Treatment			
	Treatments	Number of Quadrats	Average Density[1] (fecal pats/0.01 ha)
North Pasture	Prairie Dog Colony	57	16.13a
	Water	62	18.98b
	Random Site (off colony)	60	15.95a
South Pasture	Prairie Dog Colony	57	15.59a
	Water	28	19.07b
	Random Site (off colony)	59	14.48a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

However, both ANOVA and SANOVA models indicated a significant difference ($P > .05$) in the fecal pat densities between the random and prairie dog sites and water (Table 1). Within the water treatment there were some significant directional differences depending on the location of the quadrats. There was a significantly higher fecal pat density in the southeastern spokes ($120°$-$180°$) in both replications (Appendix A). This may be a result of grazing patterns, location of fencelines, or perhaps the highway near both pastures.

Previous studies have been conducted on the shortgrass steppe in northeastern Colorado, near Ft. Collins, on the CPER (Central Plain Experimental Range). These studies primarily utilized driving surveys and direct observations as their methodologies to determine cattle use of prairie dog towns. Another methodology, measuring cattle fecal pat density, has also been used to examine cattle activity on prairie dog towns in northeastern Colorado (Paul Stapp, Mark

Lindquist, unpublished data). Both types of research indicate that cattle on the shortgrass steppe use prairie dog towns randomly (Guenther, M.S. Thesis, 2000).

Some variability in Guenther's (2000) study was found with relation to pasture size, which has been shown to affect cattle grazing behavior (Hart *et al.* 1993). However, this study only examined two pastures, one at 600ha and the other at 2000ha, and did not address the size of pasture in the experimental design as a contributing factor to cattle utilization.

The water treatments were significantly different from both the prairie dog towns and the random sites off towns. This concurs with existing data. Water sources have been shown to be strong predictors of cattle distribution (Senft et al. 1985). On mixed-grass prairie in Montana, cattle were found more frequently on quarter sections with prairie dog colonies than on quarter sections without (Knowles 1986). Guenther (2000) agrees that this might be due to overgrazing areas near water tanks, forming ideal habitat for prairie dogs to establish a town. In locations like these, it isn't clear whether the cattle are using these areas due to the presence of the prairie dog town or the water source.

Most of our understanding of the effects of prairie dogs comes from studies in mixed-grass prairie (Stapp 1998). In these grasslands, cattle grazing intensity regulates the presence or absence of black-tailed prairie dogs (Hansen and Gold 1977). What, then, accounts for the difference of cattle- and bison-use of mixed-grass prairie and the apparent random cattle-use of shortgrass prairie?

Shortgrass steppe is dominated by blue grama and buffalograss and, as a result of a semiarid climate and a long evolutionary history of herbivory, is relatively resistant to grazing (Milchunas *et al.* 1990). Unlike mixed or tall prairie where grazing leads to invasion by forbs and shrubs, in shortgrass steppe plant diversity decreases under moderate to heavy grazing

14

(Milchunas *et al.* 1990). Therefore, plant species composition and morphology may not be very different between prairie dog towns and surrounding uncolonized areas. In agreement with Stapp (1998), the herbivores of shortgrass steppe may then be less sensitive to the effects of grazing by prairie dogs than are consumers in taller grasslands, thus resulting in no significant difference in cattle-use of prairie dog towns and sites off towns.

Acknowledgements

Appendix A – SAVOVAS of Pastures 1 and 2

Three-factor SANOVA of pasture 1 with missing data.

Source	SS	df	MS	F	P-value
Treatment (T)	301.91	2	150.95	4.42	0.014
Spoke (S)	908.35	5	181.67	5.32	0.000
Distance (D)	313.32	4	78.33	2.79	0.063
TS	1217.32	10	121.73	3.56	0.000
TD	570.01	8	71.25	2.09	0.042
SD	1391.35	20	69.57	2.04	0.009
Error	4199.59	123	34.14		

Expected mean density by treatment.

Treatment	Mean[1]
Prairie Dog Colony	16.13 a
Water	18.98 b
Random Site	15.95 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Expected mean density by treatment and direction [1].

	Treatment		
Spoke	Prairie Dog Colony	Water	Random Site
1 (0°-60°)	15.69 a	16.11 b	13.94 a
2 (60°-120°)	15.67 a	22.03 ab	16.01 a
3 (120°-180°)	13.62 a	30.28 a	19.34 a
4 (180°-240°)	16.12 a	18.25 b	17.63 a
5 (240°-300°)	13.56 a	13.87 b	12.46 a
6 (300°-360°)	19.45 a	13.23 b	14.33 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Three-factor SANOVA of pasture 2 with missing data.

Source	SS	df	MS	F	P-value
Treatment (T)	276.77	2	138.38	3.89	0.024
Spoke (S)	505.14	5	101.03	2.84	0.020
Distance (D)	307.89	4	76.97	2.16	0.079
TS	1254.26	10	125.43	3.53	0.001
TD	545.17	8	68.15	1.92	0.066
SD	1491.31	20	74.57	2.10	0.009
Error	3342.39	94	35.56		

Expected mean density by treatment.

Treatment	Mean[1]
Prairie Dog Colony	15.59 b
Water	19.07 a
Random Site	14.48 b

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Expected mean density by treatment and direction [1].

	Treatment		
Spoke	Prairie Dog Colony	Water	Random Site
1 (0°-60°)	18.50 a	20.57 ab	15.08 a
2 (60°-120°)	21.50 a	24.67 ab	12.51 a
3 (120°-180°)	17.32 a	26.80 a	11.89 a
4 (180°-240°)	13.75 a	20.81 ab	14.40 a
5 (240°-300°)	12.24 a	15.60 ab	15.45 a
6 (300°-360°)	12.51 a	10.83 b	19.23 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Appendix B – AVOVAS of Pastures 1 and 2

Three-factor ANOVA of pasture 1 with missing data.

Source	SS	df	MS	F	P-value
Treatment (T)	405.88	2	202.94	4.06	0.020
Spoke (S)	958.65	5	191.73	3.84	0.003
Distance (D)	263.88	4	65.97	1.32	0.266
TS	1493.12	10	149.31	2.99	0.002
TD	370.76	8	46.34	0.93	0.494
SD	873.87	20	43.69	0.87	0.624
Error	6144.143	123	49.95		

Expected mean density by treatment.

Treatment	Mean[1]
Prairie Dog Colony	15.56 a
Water	19.01 b
Random Site	15.91 ab

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Expected mean density by treatment and direction [1].

Spoke	Treatment		
	Prairie Dog Colony	Water	Random Site
1 (0°-60°)	15.75 a	16.20 b	14.30 a
2 (60°-120°)	15.00 a	21.80 ab	16.00 a
3 (120°-180°)	13.30 a	30.50 a	19.50 a
4 (180°-240°)	16.20 a	18.20 b	18.12 a
5 (240°-300°)	14.30 a	14.10 b	13.00 a
6 (300°-360°)	18.89 a	13.50 b	15.00 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Appendix B (cont'd)

Three-factor ANOVA of pasture 2 with missing data.

Source	SS	df	MS	F	P-value
Treatment (T)	382.58	2	191.29	3.51	0.034
Spoke (S)	556.09	5	111.22	2.044	0.080
Distance (D)	242.42	4	60.60	1.11	0.355
TS	1481.92	10	148.19	2.72	0.005
TD	367.43	8	45.93	0.84	0.567
SD	985.13	20	49.25	0.90	0.583
Error	5121.60	94	54.48		

Expected mean density by treatment.

Treatment	Mean[1]
Prairie Dog Colony	16.21 ab
Water	19.54 b
Random Site	14.73 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

Expected mean density by treatment and direction [1].

	Treatment		
Spoke	Prairie Dog Colony	Water	Random Site
1 (0°-60°)	18.49 a	22.40 a	15.08 a
2 (60°-120°)	21.50 a	25.41 a	12.51 a
3 (120°-180°)	17.33 a	21.24 a	11.89 a
4 (180°-240°)	13.75 a	17.66 a	14.40 a
5 (240°-300°)	12.25 a	16.16 a	15.45 a
6 (300°-360°)	12.50 a	16.41 a	19.23 a

[1]Densities with the same letter are not significantly different at the 0.05 level of significance.

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