5-2007

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Finkbeiner Kempema, Silka Lori, "The Influence of Grazing Systems on Grassland Bird Density, Productivity, and Species Richness on Private Rangeland in the Nebraska Sandhills" (2007). *Dissertations & Theses in Natural Resources*. 204.
https://digitalcommons.unl.edu/natresdiss/204

THE INFLUENCE OF GRAZING SYSTEMS ON GRASSLAND BIRD DENSITY, PRODUCTIVITY, AND SPECIES RICHNESS ON PRIVATE RANGELAND IN THE NEBRASKA SANDHILLS

by

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A THESIS

Presented to the Faculty of
The Graduate College at the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professor Larkin A. Powell

Lincoln, Nebraska

May 2007

THE INFLUENCE OF GRAZING SYSTEMS ON GRASSLAND BIRD DENSITY, PRODUCTIVITY, AND SPECIES RICHNESS ON PRIVATE RANGELAND IN THE NEBRASKA SANDHILLS

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University of Nebraska, 2007

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During 2002-2004, we examined how three grazing system treatments (long, medium, and short duration grazing) used on private rangelands in the Nebraska Sandhills influenced grassland structure and the avian community. Structural heterogeneity increased with increasing grazing duration two spatial scales. Year showed a consistent effect on bunchgrass, lying litter, and bare soil cover and litter depth. Bird species richness was highest on long duration systems which also were the most structurally heterogeneous. Estimation of densities for fourteen species of grassland birds illustrated that avian responses to grazing system are inconsistent among species. However, short duration grazing systems had the highest densities of the most species. Medium duration systems supported the lowest densities of a nest parasite, the brown-headed cowbird. Daily nest survival was not affected by grazing system. Effects of climate as measured by weekly Palmer Drought Severity Indices values explained the most variation in daily nest survival rates. Additional models with strong support included those including stocking density and brown-headed cowbird parasitism. Climate in the region may have as much an influence on the grassland bird community as does grazing system. Therefore, management should consist of a variety of grazing

systems across the landscape with localized management for select grassland species. Additional research should address the influence and relationship between stocking density and parasitism rates on grassland bird daily nest survival rates in grasslands managed by grazing systems.

ACKNOWLEDGEMENTS

This thesis is a culmination of many experiences and personal influences, beginning with my upbringing as a child on a multi-generational family farm. This, more than anything else, has influenced my direction and interest in the natural resources by allowing me to experience, first hand, the connection between humans and the environment. My mother and father have influenced and directed me in many ways, some of which they probably are not aware of, but it is for their everlasting support and belief in me that I am forever grateful and indebted.

My educational path up to this point has been sprinkled with teachers that have inspired. My high school science teacher, Mike Barondeau fostered my interest in research which at the time I simply viewed as participating in the high school science fair. My interest in birds took flight under the instruction of Dr. Les Flake. Your passion was contagious. Dr. Larkin Powell illustrated to me that the ability to teach is one of the most powerful skills a natural resource professional can possess.

My husband, Brent, who was there from the literal start of this graduate journey, has been my most patient and strongest supporter. Thank you for being you. Also, I'd like to recognize the "wildlifers" that I've met, worked, and played with throughout the years in Brookings, Sioux Falls, Upham, Americus, Lincoln, Sumner, Soda Springs, Jamestown, Wall, etc. I believe that those individuals, with whom I had the chance to truly interact with, for however long or short a time, have helped to shape me as a person and as a professional. A little bit of each of you is with me every day.

Most importantly, I'd like to extend my respect and gratitude to the ranchers of the Sandhills whose observations and inquiry initiated this project, helped me further my

education, and furthered our understanding of Nebraska Sandhills avifauna. Thank you for your time, your insights, and the opportunity to work on your land and most of all maintaining your way of life. The Nebraska Sandhills is truly a special place.
Drs. Walter Schacht and Erin Blankenship have been ideal graduate committee members. My interaction with this committee has illustrated to me the benefits of interdisciplinary research. You both are wonderful role models.

This research and my degree could not have been completed without the dutiful assistance of Kenney Elder, Kent Fricke, Josh Jordening, Angie (Noe) Reade, Amanda Richardson, and Kody Unstad along with the financial support of the Nebraska Sandhills Task Force, Nebraska Game and Parks Commission, Sustainable Agriculture Research Education, and the University of Nebraska. Thank you.

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CHAPTER 1. THE INFLUENCE OF GRAZING SYSTEMS ON GRASSLAND BIRD HABITAT STRUCTURE AND HETEROGENEITY ON PRIVATE RANGELAND IN THE NEBRASKA SANDHILLS.[1]

Abstract: We investigated the impacts of grazing systems on grassland vegetation structure as a measure of grassland bird habitat on private rangelands in the Nebraska Sandhills from 2002 to 2004. We had four replications of three grazing system treatments (long, medium, and short duration grazing). Vegetative composition was estimated to the nearest five percent units using a 20 x 50 cm Daubenmire frame. Plant height and density was measured to the nearest quarter decimeter using a Robel pole (VOR). Structural heterogeneity was measured at large- and small-spatial scales using methods modified from Wiens (1974). We conducted our sampling in June (early) and August (late). Effect of system, year, and their interaction were tested using ANOVA. We constructed *a priori* models sets to explain variation in vegetation structure measurements and selected among models within a set using Akaike's Information Criteria (AIC). Seventy-four percent of our study pastures were sands ecological site; the pastures were rated, on average, as high-good condition. There was more variation within grazing system stocking rate than among systems. In 2003 and 2004, cover composition was predominately bunchgrass (14.2%) and rhizomatous grass (9.9%), bare soil (45.5%) and lying litter cover (44.1%). Litter depth (0.28 cm) and VOR (0.40 dm) was minimal. Long duration systems were the most heterogeneous at both spatial scales. Heterogeneity at both spatial scales during both sampling periods was affected by grazing system ($P \leq 0.002$). Year influenced the cover of bunchgrass, bare soil, and lying litter

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[1] Kempema, Powell, Schacht, and Blankenship. To be submitted to Rangeland Ecology and Management.

and litter depth during both sampling periods ($P < 0.05$). Ecological site and year explained variation in many of the vegetation variables analyzed. Creating structural heterogeneity at multiple spatial scales using a variety of grazing systems combined with moderate stocking rates may be an effective method to ecologically and economically managing for sustainable rangeland and grassland wildlife populations.

INTRODUCTION

Nebraska's primary economic activity is agriculture. According to the Nebraska Agricultural Statistics Service (USDA 2002), Nebraska was ranked third in the nation in cattle inventory and value of cattle sold. The primary land type in the Nebraska Sandhills, since the introduction of cattle in the mid to late 1800's, is grazing land (80%; Miller 1998). Unstable sandy soils have made cultivation unsuitable for many areas in the region. In the early 1940's, Cherry County contained some of the best rangeland in the United States (Tolestead 1942). Sustainable range management practices have continued to afford the Nebraska Sandhills a reputation as one of the world's best managed tracts of rangeland (Bose 1977, Stubbendieck 1998). Producers in the area often employ rotational grazing systems to improve range utilization and condition, while promoting forage and animal production to optimize economic gain (Clark and Coady 1993, Martin 1978).

Approximately 97% of the state is in private ownership (Henebry et al. 2005). Ninety-three percent of the state's total land area is used by farms and ranches; half of this area is found in the Nebraska Sandhills (Nebraska Department of Agriculture 2006). Much of the nation's wildlife habitat is found on private lands (Heard et al. 2000). The Nebraska Sandhills is a mosaic of wetlands and mixed grass prairie uplands. Privately owned Nebraska Sandhills rangeland provides grassland and wetland habitats for a variety of wildlife (Stubbendieck 1998) and remains relatively unaltered by agronomic land conversion.

The avifaunal community in the Nebraska Sandhills is a diverse mix of wetland and upland associated species. The region serves as a crossroads supporting a variety of migrating species due to its geographic location within the Great Plains (Labedz 1998). Within the Great Plains and the nation, the Nebraska is one of the last and largest remaining tracts of native prairie. A paucity of information on birds of the region illustrates the need for further describing the region's avifaunal community (Labedz 1998) and understanding its response to grazing practices within the region.

Wildlife require suitable habitat to maintain stable populations, most often provided by vegetation structure (Rottenberry and Wiens 1980). Species differ in their habitat requirements, and in the breadth of their habitat specificity. Studies have shown that grassland birds respond primarily not to variation in plant species composition but to the structure that these plants provide (Cody 1985).

Although studies exist that examine the impact of grazing systems on wildlife, many are conducted at scales smaller than those at which ecological process may operate. Thus, additional information on the landscape-level effects of grazing systems is needed (Vavra 2005). It has been shown that birds respond to habitat differences caused by grazing livestock (Bock and Webb 1984, Knopf 1996). To date, there has only been one study on the effect of grazing systems on grassland bird densities in the Nebraska (Anderson 1990). No studies have been conducted to determine the impacts of grazing systems on grassland bird nest success in the region.

We hypothesized that rotational grazing systems would, through processes similar to historical grazing patterns, provide more suitable vegetation cover for wildlife on Nebraska Sandhills rangeland. Our goal was to examine the influence of common grazing systems in the Nebraska on grassland vegetation structure and composition. Our objectives were to 1) describe grassland bird habitat on our study sites among the grazing systems, 2) determine the effect of the grazing systems on habitat structure and composition, and 3) determine how variation in grazing management influences variation in vegetation structure and composition.

METHODS

Study Area

The Nebraska Sandhills encompasses approximately one-fourth of the state. The 4.8 million ha of grass-stabilized sand dunes and associated valleys compose the largest sand-dune formation of its kind in the Western Hemisphere. Dunes extend up to 125 m high, reach over 30 km, and have maximum slopes of 25%. Elevation and precipitation of the region follow an east to west gradient. Elevation increases from 625 m above sea level in the east to 1,250 m above sea level in the west (Bleed and Flowerday 1998). Regional average annual precipitation decreases from 584 mm in the east to less than 432 mm in the west (Wilhite and Hubbard 1998). Average maximum summer temperatures in July are about 31 °C (Wilhite and Hubbard 1998). January minimum temperatures are about -13 °C. Over 75% of the region's precipitation falls during the growing season months of April through September; half of all precipitation falls during May through July. Valentine, Valentine-Els-Tyron, and Valentine Association-Hilly soil associations characterize the region (Lewis and Kuzila 1998). The poorly developed soils are well-drained, very fine to moderately coarse sands and loamy sands (Steinauer and Rolfsmeier 2003).

Plant communities in the area are comprised of tall, mid-, and short-grasses, grass-like plants, forbs and shrubs. More specifically, the Nebraska Sandhills Prairie (*Andropogon-Calamovilfa*), as described by Kuchler (1964), is dominated by big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman), sand bluestem (*Andropogon gerardii* var. *paucipilus* (Nash) Fern.), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), prairie sandreed (*Calamovilfa longifolia* (Hook)), and needleandthread (*Hesperostipa comata* Trin. *and* Rupr.).

We conducted our study on privately owned rangeland in eastern Cherry and northern Thomas counties of the north central portion of the Nebraska Sandhills region within the state of Nebraska (Appendix I: Figure 1). Participating landowners were selected based upon willingness to cooperate, range management practices, and history. We located pastures on private rangelands throughout the study area (Appendix I: Figure 2). We chose upland sites (no wetlands and very minimal inclusion of subirrigated meadows) in an effort to reduce any bias in landscape position, topography, or soils. We attempted to distribute treatments evenly across the study area.

Sampling Methods

We examined three grazing treatments that encompassed a continuum of grazing durations and intensities, and pasture and herd sizes utilized in the area (Appendix II: Table 1 and 2). These treatments can be best described as variations of continuous, simple rotation (7-9 pastures), and management intensive grazing systems. We refer to these systems as long, medium, and short duration grazing systems, respectively.

In 2002, we examined three replicates each of long, medium, and short duration grazing systems. We added an additional replication per grazing treatment in 2003 and collected data from the twelve study pastures or experimental units in 2003-2004. Average stocking rates were similar among grazing systems; long, medium, and short duration systems had stocking rates of 1.4, 1.3, and 1.4 AUM/ha, respectively (see Appendix II: Tables 1 and 2).

We define a grazing period as an uninterrupted period in which a pasture or paddock was exposed to grazing. Each grazing period occurred within a grazing year and within one of two seasons (dormant or growing season) within the grazing year. We defined the grazing year as 1 October through 30 September of the following calendar year and is comprised of the dormant (1 October - 30 April) and growing (1 May - 30 September) seasons. A pasture is defined as a single, fenced grazing unit in a long duration grazing system or a grazing cell in a medium or short duration grazing system which is composed of multiple paddocks or subdivisions through which cattle are rotated. (Range Term Glossary Committee 1974).

Our basic study design in each pasture consisted of 3,000 m of transects used for vegetation sampling. Transect layout and length was designed to effectively sample the avian community; our vegetation survey was to provide supporting data for the bird study (Chapters 2 and 3, SLFK). We placed a random pair of parallel 1,500-m transects, 250 m apart in each of the long duration pastures (Appendix I: Figure 3a). Initial transect locations were used for the duration of the study. We evenly sub-sampled two paddocks in medium and short duration pastures; we randomly placed two pairs of 750-m transects in each of the two selected paddocks (Figure 3b, c). In 2002, transects were placed 125 m apart. We separated transects by an additional 125 m in 2003 by moving one transect. These new transect locations were used for the remainder of the study. Transect direction and start locations were conditionally random, provided they would fit within paddock borders.

Climate – We gathered precipitation information from weather stations located within and near the cities of Valentine and Mullen, NE to represent the northern and southern reaches of the study area, respectively. Climate data was provided by the High Plains Regional Climate Center (HPRCC) at the University of Nebraska-Lincoln (UNL).

Drought severity information (Palmer Drought Severity Index-PDSI) was gathered from the northern Valentine station and from a station in Purdum, NE to represent the southern study sites. Weekly PDSI data was collected from the 18th through the 35th week (last week in April through August) for each of the three years. Weekly values were obtained from the National Agriculture Decision Support System (https://nadss.unl.edu). Monthly PDSI data was collected for the entire Sandhills region from HPRCC at UNL.

The PDSI is a standardized meteorological drought index calculated using a soil moisture algorithm that takes into account available water holding capacity, precipitation, and temperature to measure the moisture departure from climatological averages. These standardized index values are designed to be comparable across time frames and geographic regions. This is possible by incorporating temporal variations (dry or wet spells) and cumulative effects of past precipitation values so that drought conditions are not indexed to be relieved by short rounds of average or above average precipitation. The PDSI scale runs from approximately +6 to -6; 0.49 to -0.49 is considered near normal; >4.0 is extremely wet, and <-4.0 is extreme drought (Hayes 2005). It is most useful for evaluating impacts related to soil moisture conditions such as the growth and resilience capabilities of grassland vegetation to grazing systems.

Ecological Site and Range Condition - We determined range condition, for the principal ecological site(s) in the sampled area in July 2003. The Sandhills is best characterized by five ecological sites 1) wetland, 2) subirrigated meadow, 3) sandy, 4) sands, and 5) choppy sands sites (Stubbendieck 1998). Range condition classes include excellent, good, fair and poor with subclasses of high, medium, and low in each class. Range condition describes the current state of a unit of range in relation to the potential ecological climax stage for a particular ecological site (Range Term Glossary Committee 1974). Range in excellent condition has at least 75% of projected climax community species composition. Good condition range has at least 50%, fair at least 25%, and poor has less than 25% of the kinds and proportions of climax community plants. Each subclass was assigned a numerical value, ranging from one (low poor) to 12 (high excellent). We assigned each sample point (further description to follow) within a pasture an ecological site description based upon its location; we judged the ecological site for condition. We multiplied the number of points within each ecological site in a pasture times its numerical range condition value; the products were summed and divided by the total number of points within the pasture for the weighted range condition values. The weighted range condition for each pasture or paddock was calculated by

$$\frac{\sum_{i=1}^{12}(n_i \cdot x_i)}{N}$$

where i = 1,...,12 (range condition classes), n = the number of sampling points located within a particular ecological site in a given pasture or paddock, x = the numerical value of the range condition classes (1-12), and N = the total number of points within a pasture or paddock.

Grazing Information – We collected data on grazing dates and duration, estimated pasture or paddock size, herd size, estimated animal weight, animal class, and average calving date from individual ranchers. Stocking rates were calculated as the amount of forage demand per unit area over a unit of time from the data collected from producers. An animal unit (AU) is a measure of the amount of forage consumed daily by a 454 kg animal, generally accepted as 12 kg of air dried forage. Therefore, an animal unit month (AUM) is a measure of a single, 1,000 lb animal's (or its equivalent) forage demand for 30 days, generally accepted as 360 kg (12 kg*30 days). Stocking rate is calculated and defined in this study as AUM per ha (AUM/ha; King and Stine 1998). We recorded the number of pastures in rotation for medium and short duration systems, as well as additional producer comments on range condition and grazing plans. For each pasture, we obtained a history of grazing (timing and system), animal class, and herd size.

We calculated three grazing related parameters, in addition to those described previously, to investigate the impacts of grazing on vegetation structure and composition early in the growing season. *Current growing season grazing* (CGsG) described whether or not (yes or no) a pasture had been grazed before we sampled for vegetation during the early-season vegetation sampling period (mid-June). We defined *previous growing season rest* (PGsR) as a multinomial variable that qualified the amount of rest (measured in days) given a particular pasture or paddock since the last grazing period during the previous year's growing season. We calculated PGsR as the amount of rest between the last grazing period in the previous years growing season and the date of our early-season vegetation sampling. Values for PGsR were: (1) 0-30 days (inadequate rest), (2) 31-60 days (marginal recovery), (3) 61-90 (adequate recovery), and (4) ≥90 days (complete recovery). Last, we defined *current growing season rest* (CGsR) as a similar, but categorical, variable that quantified the amount of rest (days) given a pasture or paddock since the last grazing period in the current year's growing season. We calculated CGsR as the amount of rest between the last grazing period in the current year's growing season and the date of our late-season vegetation measurements.

2002 vegetation – To avoid temporal biases, we arranged our vegetation sampling efforts in blocks, which consisted of one pasture from each grazing system. We measured vegetation structure and composition during three rounds of surveys: 11-19 June, 25 June - 4 July, and 10-18 July. We measured vegetation structure at 30 locations at 100-m intervals along our transects in each pasture. Vegetation samples were taken at a perpendicular distance of 5 m from the transect line. We recorded a visual obstruction reading (VOR) with a Robel pole to quantify horizontal vegetation density (Robel 1970). VOR was recorded to the nearest decimeter.

We estimated percent cover of vegetation into eight cover classes: (1) total vegetation, (2) dead and (3) live vegetation, (4) grass, (5) forb, (6) woody, (7) bare, and (8) litter using a 20x50-m Daubenmire frame (Daubenmire 1959). We considered green vegetation live and brown vegetation dead. We defined litter as vegetation forming a horizontal matte covering the ground, and we included cactus and yucca in the woody vegetation category. We classified percent cover of vegetation as six cover classes: (1) 0-5%, (2) 6-25%, (3) 26-50%, (4) 51-75%, (5) 76-95%, and (6) 96-100%. We allowed for overlapping category coverage; thus, total coverage within the frame could exceed 100%.

We measured litter depth to the nearest centimeter in the center of the Daubenmire frame at each vegetation sampling point. We measured the tallest plant found within the four m distance between the Robel pole and the observer. The tallest plant measurement was recorded during the second and third rounds of vegetation sampling.

2003-2004 vegetation – Following our first field season, we implemented several changes to our vegetation sampling regime, to more effectively sample vegetation structure and composition. We again sampled vegetation twice within each pasture (early-season and late-season) within the growing season; 16-26 June and 29 July-5 August in 2003 and 10-21 June and 28 July-4 August in 2004. At each 100-m interval along the transect, we randomly selected a sampling location within a 15-m radius of the transect point; thus, we sampled 32 locations in each pasture. Each random location served as the center of an equilateral triangle with 3.5-m sides; the three nodes of the triangle served as a sub-sampling points resulting in 96 sub-samples for each pasture (Figure 1).

We again used a 20 x 50-cm Daubenmire frame (Daubenmire 1959) to estimate percent ground cover at each sampling point. But, our cover classes were more specific; they included estimates of bunchgrass, rhizomatous and annual grasses, sedges, forbs, shrubs, cactus, yucca, lying (residual vegetation standing ≤45° to the ground) and standing litter (residual vegetation standing at > 45° to the ground), bare soil, and cattle dung. We recorded all percent cover estimates in more detail—to the nearest 5%, still allowing for total cover classes to exceed 100%. We eventually pooled estimated cover of bunchgrass and rhizomatous grass to create a grass cover category.

We measured vegetation height and density by recording visual obstruction readings (VOR) to the nearest quarter decimeter (Robel et al. 1970); we used the mean of four readings taken at consecutive right-angles to one another to describe the vegetation height and density at each sub-sample point.

We incorporated our VOR means in a modified sampling protocol from Wiens (1974) that allowed us to quantify structural heterogeneity of grassland bird habitat at broad (pasture-level) and fine (patch-level) spatial scales. We refer to these scales as large- and small-scale heterogeneity. Mean small-scale heterogeneity (SSH) for each pasture, *r*, was calculated as:

$$SSH_r = \frac{\left(\sum_{i=1}^{32}\left(Max_{k_i} - Min_{k_i}\right)\right)}{\sum_{i=1}^{32}\bar{x}_{k_i}}$$

where $i = 1, 2, \ldots, 32$ for each sampling unit, $k = 1, 2, 3$ (three sub-samples taken at i), and $\bar{x}_{k_i}$ represents the mean of VOR scores from 3 sub-samples taken at i. We used the coefficient of variation (CV) to represent large-scale heterogeneity (LSH) for each pasture :

$$LSH = \frac{\sigma}{\bar{x}_i} \times 100$$

where $\sigma = SD\left(\bar{x}_{k_i}\right).$

We measured and recorded height of the tallest plant (to the nearest 0.25 dm) located within a 30 cm radius of the sub-sample point, its functional group (grass, forb, shrub, sedge, rush, or yucca), and status (alive or dead). Litter depth was measured to the nearest 0.5 cm within 3 cm of the upper right-hand corner of the Daubenmire frame. We determined origin of plants within the frame and estimated percent cover of native and exotic plants to the nearest 5%. Percent cover values within the frame totaled 100%.

To standardize our vegetation data collection, each year two of the four observers were trained to measure VOR and the remaining two individuals were trained to estimate vegetation composition throughout the field season. To reduce observer bias, we rotated observers for compositional data such that no observer estimated composition on a pasture during both sampling rounds within each year.

Statistical Analysis

Descriptive statistics.—We used least squares means to describe each vegetation variable for each grazing system for 2002 and for 2003-2004. We also calculated the arithmetic mean for each variable as a pooled value across years and systems for 2003-2004 and across systems for 2002. We conducted a preliminary analysis to examine the effects of grazing system and yearly stocking rate on initial range condition. We used 95% confidence intervals about least-squares means of range condition for each system to determine effects of grazing system on range condition. We used a linear model (PROC GLM; SAS Institute 2000) to assess the effect of yearly stocking rate (averaged between 2003 and 2004) on range condition.

Effects of grazing system.—We selected a group of vegetation variables that we felt would be important to grassland bird habitat structure. Compositional variables included: bunchgrass, forb, bare soil, and lying litter cover. Structural variables included: litter depth, VOR, and small- and large-scale heterogeneity of VOR. We used a mixed model analysis of variance (ANOVA; PROC MIXED, SAS Institute 2000) to examine the fixed effects of grazing system and year, as well as the random effect of study pasture, which was nested within system, year and point. We used Kenward-Rodger adjusted degrees of freedom to calculate F-statistics (Littell et al. 2006).

Variation in vegetation structure and composition. - We constructed an *a priori* set of models, related to hypotheses based on our observations or information from prior research, to further explore causes of variation in rangeland vegetation structure. We used two sets of models—one for early-season and one for late-season vegetation data.

We hypothesized that early-season vegetation structure and composition would be affected by variability in range condition, ecological site, grazing early in the growing season, dormant season grazing, and grazing during the previous growing season. Thus, our model set for the early-season vegetation sampling included (1) a weighted range condition (RCND), (2) ecological site (ECO), (3) presence or absence of early current growing season grazing (CGsG), (4) dormant season stocking rate (DsSR), and (5) previous growing season rest (PGsR). We used this model set to explain variation in visual obstruction readings, bunchgrass cover, and LSH—vegetation measurements that seemed especially important to describing grassland habitat quality for wildlife in late spring, prior to much new growth.

Similarly, we hypothesized that late-season vegetation structure and composition could be affected by variability in ecological site, grazing system, drought status, precipitation, range condition, stocking rate during the growing season, and the amount of rest since the last grazing event. Our corresponding model set for the late-season vegetation sampling included (1) ecological site (ECO), (2) grazing system (SYST), (3) weekly PDSI values, (4) cumulative growing season precipitation (PRECIP), (5) weighted range condition (RCND), (6) growing season stocking rate (GsSR), and (7) current growing season rest from grazing (CGsR). We used this model set to explain variation in bunchgrass, forbs, bare soil cover, and lying litter compositional variables, as well as the following structural variables: VOR, and small- and large-scale heterogeneity of VOR.

The estimate of relative expected Kullback-Leibler (K-L) distance, known as Akaike's Information Criterion (AIC) provides us a measure of how suitable a model is given the data and the model set (Burnham and Anderson 2002). The model with the lowest AIC value is the model with the most support within the model set. The AIC values of the remaining models are relative and it is only the distance, as measured by ΔAIC that allows comparison of the competing models, as more than one model can be supported by the data. ΔAIC values estimate the relative expected K-L differences between the process represented by the data (truth or reality) and the set of candidate models created to best approximate this process. The larger the ΔAIC for a given model, the less plausible it is that the fitted model is the best model to represent the biological process the model is attempting to represent. Those models with ΔAIC values ≤ 2 have substantial empirical support. As ΔAIC values increase, the level of empirical support decreases as these models are less suitable as a best approximating model to the K-L best model (Burnham and Anderson 2002).

Akaike weight is the weight of evidence that a model is the K-L best model assuming that one of the R models being evaluated is the K-L best model, given the data. Through the normalization of the relative strength of evidence as calculated by the likelihood of the model given the data, Akaike weights, denoted as w_i, provide the relative likelihood of a model, given the set of R (total # of models) and the data. These weights can be interpreted as percentages within the set evaluated as the weights will sum to 1 (Burnham and Anderson 2002).

RESULTS

Descriptive statistics

Precipitation - In 2002, total annual precipitation was considerably lower than previous short- (2 year) and long-term (30 year) average annual precipitation (Figure 2). The average study area annual precipitation in 2002 (298 mm) was 55% of the long-term average (530 mm). Yearly precipitation totals increased with each consecutive year of study. Average monthly precipitation totals for the study area were lowest during the growing season of 2002 (Figure 3) with the steepest decline from May to June. The following year, precipitation increased considerably over 2002 and was at or above the 30-year average monthly totals in April through June, but dropped sharply in July. The greatest monthly variability was exhibited in 2003. In 2004, average monthly precipitation showed the least temporal variation and appeared most similar to long-term monthly averages during April through August.

In 2002, PDSI values for the Sandhills Climate District (Nebraska Sandhills) indicated a mild drought early in the growing season that continued to increase in severity with the month of July in extreme drought conditions (Figure 4). Early the following year, moderate drought conditions continued and then improved in early summer to mild drought conditions. However, conditions deteriorated towards severe drought as the growing season progressed (Figure 4). Moderate drought conditions were present throughout the 2004 growing season with a sudent and sustained improvement beginning in August (Figure 4).

Ecological Sites and Range Condition - Study pastures were composed primarily of sands (74%; Table 1). Sandy, choppy sands and subirrigated meadow sites also were present (Table 1). Blowouts (barren patches of eroding sand) were a minor component of the sands and choppy sands ecological sites (Table 1). This was apparent among all grazing systems. Composition of grazing systems by ecological site and corresponding range condition may be found in Table 2. Pastures used in our study were in high-good (8.5) range condition. Range condition on long, medium, and short duration systems averaged 8.3 (SE = 0.57), 7.8 (SE = 0.40), and 9.3 (SE = 0.40), respectively (Figure 5). We judged short duration pastures to be in better condition than medium duration pastures (P = 0.033; Fig. 5). On average, long and medium duration systems were in medium-good condition and short duration systems were in high-good condition. Long duration pastures ranged from a high-fair (6) range condition to medium-excellent (11). Medium duration pastures ranged from a high-fair to a low-excellent (10). Short duration pastures were judged to be within the narrowest range of condition from low-good (7) to low-excellent. Average yearly stocking rates did not affect range condition ($\beta = -0.0049$, $P = 0.982$).

Grazing - Long duration grazing systems had an average of 13 years using this grazing system. These systems grazed an average of 158 head of cattle on approximately 574 ha for 78 days during the growing season (Appendix 2: Table 1). Pastures managed using medium duration grazing had an average 16-year history under this system. An average of 196 head of cattle grazed 196 ha during the growing season for 23 days on medium duration systems (Appendix 2: Table 1). Short duration pastures had the longest average grazing system history (19 years).

Growing season short duration systems averaged 626 head of cattle on 82 ha of land for an average of three days (Appendix 2: Table 1). Medium duration systems averaged from 7-9 pastures in a rotation to some unknown number. The unknown range was on a ranch that provided 30-45 days of rest to a pasture. Short duration systems averaged 36 pastures in a rotation.

Long, medium, and short duration grazing systems averaged 1.4, 1.3, and 1.4 AUM/ha, respectively during the growing season (Appendix 2: Table 1). Suggested initial recommended stocking rates in our study area (Nebraska vegetative zone II) for range in <u>100%</u> condition (high-excellent) is 1.73 AUM/ha (King and Stine 1998). Growing season stocking rates did not differ among grazing system treatments (± 1 SD). More variation occurred within grazing systems (Fig. 6 and Appendix 2: Table 1). Short duration systems had the greatest variation ($\bar{x} = 1.42$, SD = 1.27) in growing season stocking rates. This variation was due to higher than average May 2002 stocking rates on one ranch and lower overall stocking rates for short duration grazing systems in 2003.

Growing season stocking rates varied among grazing systems the most during 2002 (range of 1.27 to 2.87 AUM/ha; Figure 6 and Appendix 2: Table 1); shorter duration grazing systems had the highest stocking rates (Figure 6 and Appendix 2: Table 2). Stocking rate differed less among systems in 2003 and 2004 (Figure 6).

We did not collect dormant season grazing information during 2002. Dormant season grazing was absent from long duration systems. Medium duration systems grazed an average of 238 cattle on 206 ha for an average of 44 days during the dormant season. Short duration systems had herds of 518 animals grazing pastures of 87 ha for an average of four days.

Average dormant season stocking rates for medium and short duration systems were 1.74 AUM/ha and 0.72 AUM/ha, respectively. Both medium and short duration systems had variable dormant season stocking rates (medium: SD = 1.72, short: SD = 0.61; Appendix 2: Table 2 and Fig. 7).

Information on dormant season supplemental feeding was collected for 2001-2002, 2002-2003, and 2003-2004. In the winter of 2001-2002, only one long duration system pasture had supplementally fed cattle with hay. No dormant season grazing information was collected from this season, but grazing must have occurred in this long duration system pasture.

In 2002-2003, five of the eight medium duration pastures were supplementally fed. Corn gluten pellets and alfalfa hay were the supplemental feeds. In 2003-2004, three of the eight medium duration system paddocks had animals that were supplementally fed during the dormant season; one with alfalfa hay and the remainder with corn gluten pellets.

No supplemental feed was provided to cattle in short duration system paddocks in 2001-2002. During the 2002-2003 dormant season, one of eight short duration system paddocks had cattle that were supplementally fed with cake to provide additional protein. The following dormant season (2003-2004), two of eight paddocks were supplementally fed in the same manner as above.

Stocking density was highest in rotational grazing systems (Appendix 2: Tables 1 and 2). Long, medium, and short duration systems stocked animals at 0.50, 2.62, and 9.10 animals/ha (this includes all cattle in the herd). Cattle densities were different among grazing systems during both the growing and dormant season (+/- 1 SD; Appendix 2: Tables 1, 2). Medium duration systems were grazed longer in the dormant season than in the growing season (an additional 21 days; Appendix II: Table 2). Short duration systems had smaller herds than medium duration systems in the winter (518 vs 626 head, respectively). Stocking rates on medium duration systems were greater in the dormant season (1.74 AUM/ha) than the growing season (1.32 AUM/ha). Average short duration system stocking rate was 0.72 AUM/ha lower in the dormant season than the growing season.

Vegetation Structure 2002 – Vegetation composition was primarily grass cover (45.5%, SD = 25.9; Table 3). Forbs (8.4%, SD = 10.4) and woody vegetation (7.5%, SD = 11.9) provided additional cover. Approximately 30% (Table 3) of the ground on our study area was exposed. Litter depth (0.08 cm, SD = 0.47) and VOR (0.38 dm, SD = 0.52) were minimal on Sandhills pastures in 2002.

Long duration systems tended to have the most forb cover (9.4%, SE=1.7), woody cover (8.9%, SE = 1.4), and bare soil (33.0%, SE = 7.0; Table 3). Medium duration systems had the most litter cover (14.5%). Although differences among systems are minimal, we found medium duration systems to have the highest VOR (0.44 dm, SE = 0.08) (Table 3). Short duration systems had the lowest vegetation height and density (VOR), but the tallest individual plant height (3.5 dm; SE = 0.46; Table 3). Short duration systems also had the deepest litter (0.11 cm, SE = 0.04; Table 3).

Vegetation Structure 2003 and 2004 - Ground cover on Sandhills pastures was primarily and most often (≥ 97% of frames examined) bare soil (45.5% SD=31.3) and lying litter cover (44.1% SE=30.8; Table 4). Bunchgrass (14.2%, SE=13.3) and rhizomatous grass (10%, SE = 11.9; Table 4) also were common ground cover (present in approximately 93% of frames examined. Forbs (6.4%, SE = 8.0), cactus (5.8%, SD = 1.3), standing litter (4.4%, SD = 5.9), shrubs (4.2%, SD = 9.3), sedges (4.0%, SD = 6.4), cow dung (1.2%, SD = 5.1), and yucca (0.16%, SD = 2.8) added additional structure to study pastures, in minimal amounts (Table 4). Standing litter, sedges, and forbs consistently provided minimal amounts of ground cover, present in 93%, 87%, and 78% of our sampling frames, respectively. There was no amount of measurable litter (< 0.5 cm) in 72% of the samples. Mean litter depths were shallow (0.28 cm, SD = 0.63; Table 4). We found sufficient (>0.25 dm) vegetation to measure VOR in 91% of our samples. Eighty-nine percent of our VOR measurements were ≤ 0.75 dm. Mean vegetation height and density (VOR) was low (0.40 dm, SD = 0.40; Table 4). The tallest plant was much higher than the mean VOR reading (approximately 5 dm; Table 4).

Long duration systems tended to have higher bunchgrass cover (11.1%, SE = 2.0), yucca cover (0.41%, SE = 2.8), and bare soil cover (49.7%, SE=63). Long duration systems had the least lying litter cover (40.2%, SE=5.8; Table 4) and cattle dung cover

(0.80%). Medium duration systems had the least amount of standing litter (3.9%, SE = 0.59) and forb cover (5.7%, SE = 0.91; Table 4), but shrub cover (5.0%, SE = 0.68) and lying litter (47.6%, SE = 5.8) tended to be greatest in this system; Table 4). Short duration systems had greater cactus cover (0.26%; SE=0.03). Litter depths were similar among grazing systems (long: 0.29 cm, SE = 0.07; medium: 0.31 cm, SE = 0.07; short: 0.24 cm, SE = 0.07 SE±. Mean VOR readings ranged from 0.37 (SE=2.8) on medium duration systems to 0.43 dm (SE = 2.9) on short duration systems; short duration systems had the tallest mean plant height (52.0 cm, SE = 2.6).

Our study pastures were dominated by native species (98%, SD=11.7). Most often (94%) native plants comprised 100% of the sampling frame. We did not observe any difference in native plant cover among the grazing systems (Table 4). We found exotic plants in 9% of our samples. Long duration pastures tended to have more exotic grass cover (2.8%, SE = 0.93) than medium (1.5%, SE = 0.92) and short duration systems (0.63%, SE = 0.63; Table 4).

Of the grazing systems examined, large-scale heterogeneity (LSH) was greatest (having the most variation in VOR) on long duration systems during the early- and late-season vegetation sample (early = 74.9, late = 84.1; Table 5). Long duration systems consistently became more heterogeneous as the growing season progressed, although to varying degrees (Table 5).

Small-scale heterogeneity (SSH) was similar among the three grazing systems during the early vegetation sample (Table 5). Difference in SSH between the early-season sample and the late-season sample among grazing systems was similar in magnitude (Table 5). The greatest difference between the early- and late-season sample was 0.33 on long duration systems. Long duration systems become more heterogeneous as the growing season progressed in both 2003 and 2004 (Table 5). Short duration systems consistently (2003 and 2004) became more homogeneous as the growing season progressed (Table 5).

ANOVA assumptions - Tests for homogeneity of variance were performed by plotting residuals against predicted values in SAS (PROC GPLOT); this assumption was met. We assumed that errors were independently distributed. We tested for normality in SAS by creating quartile-quartile plots of the residuals (PROC UNIVARIATE). Despite the lack of normality for most of the variables examined, we performed the ANOVA relying on the robustness of the test (Zar 1999).

Effect of year and grazing system

Early sampling round – Bunchgrass cover varied by year ($P = 0.002$), as did forb cover ($P = 0.009$), bare soil ($P < 0.001$), lying litter cover ($P < 0.001$), and litter depth ($P < 0.001$; Table 6). Differences between 2003 and 2004 in bunchgrass cover and forb cover were less than 10 percentage units; however, mean bunchgrass cover decreased 42% from 19% to 11%. Mean forb cover decreased 44%, from 9% in 2003 to 5% in 2004. Larger differences occurred in bare soil and lying litter cover. Mean bare soil cover increased approximately 25 percentage units on our study sites, from 30.3% in 2003 to 55.0% in 2004, an increase of 82%. Mean lying litter cover decreased 55% from 62% in 2003 to 28% in 2004. Mean litter depth decreased 58% from 0.43 cm in 2003 to 0.18 cm in 2004. We did not detect an effect of grazing system on our selected vegetation composition variables (Table 6).

Grazing systems were variable in the amount of early-season, large-scale heterogeneity each year thus we observed a system/year interaction for LSH ($P < 0.001$; Table 6). Small-scale heterogeneity was significantly affected by year ($P < 0.001$), grazing system ($P = 0.001$), and the interaction ($P = 0.002$).

Late sampling round – Bunchgrass cover was lower in 2004 during the late vegetation sampling round (2003: 18.2 %, 2004: 9.3%, $P = 0.003$; Table 8). The amount of bare soil cover in 2004 (64.8%) was greater ($P < 0.001$) than that recorded in 2003 (32.2%). Conversely, lying litter decreased from 59.3% in 2003 to 27.5% in 2004 ($P < 0.001$). Litter depth was 0.19 cm lower in 2004 (2003: 0.35 cm, 2004: 0.16 cm, $P = 0.047$; Table 8). Visual obstruction readings were higher in 2004 (2003: 0.27 dm, 2004: 0.57 dm, $P = 0.005$; Table 8).

We found that late-season vegetation during 2004 was significantly more homogeneous than 2003 at both spatial scales (Table 8). Large- and small-scale heterogeneity was affected by grazing system ($P < 0.001$; Table 8). Large-scale heterogeneity decreased with decreasing grazing duration (long: 103.7, medium: 84.3, and short: 58.8) as did small-scale heterogeneity (long: 1.7, medium: 1.4, and short: 0.8).

Variation in vegetation structure and composition

Early-season vegetation structure and composition. -Variation in bunchgrass cover was best explained by a 3-factor model that included effects of current growing season grazing (CGsG), dormant season stocking rate (DsSR), and the amount of rest during the previous growing season (PGsR, $w_i = 1.00$). We also found significant linear relationships between bunchgrass cover and ecological site ($P = 0.029$) and range condition ($P = 0.033$; Table 7).

A single-factor model, ecological site (ECO), was selected as the best approximating model for variation in VOR ($AIC = 1241.2$, $w_i = 0.80$, Table 7). As with VOR, variation in large-scale heterogeneity was best explained by ecological site ($AIC = -13595.1$, $w_i = 1.0$, Table 7).

Late-season vegetation structure and composition - Ecological site was selected as the best model ($w_i = 1.00$) to explain variation in bunchgrass, forb, and lying litter cover (Table 9). We also found that bunchgrass cover during the late-season was affected by current growing season rest (CGsR, $P = 0.025$).

Variation in bare soil cover was best explained by cumulative precipitation (PRECIP, $w_i = 0.84$, $\beta = 2.18$, $SE = 0.685$). Growing season stocking rates explained variation in VOR readings ($w_i = 0.82$, $\beta = 0.10$, $SE = 0.023$). Variation in VOR was also related to the amount of rest during the current growing season (CGsR; $P < 0.001$) and cumulative precipitation (PRECIP; $P < 0.001$).

We found that variation in late-season, small-scale heterogeneity was best explained by range condition ($w_i = 1.00$; Table 9). Grazing system also caused variation in small-scale heterogeneity (Table 9). Late-season, large-scale heterogeneity was not sufficiently described by any of our hypothesized causal variables; the null model was selected as the best model (Table 9). However, as with SSH, we found relationships between LSH and range condition and grazing system ($P < 0.001$; Table 9).

DISCUSSION

Cumulative cover of live vegetation on our study plots in 2002 and 2003-2004 was approximately 65% and 45%, respectively. Average total plant cover on dune ridges upper slopes, slopes, and interdunal valleys was 80%, 97%, and 105%, respectively, on Arapaho Prairie in the southwestern Sandhills (Barnes et al. 1984). Vegetative cover on Cresent Lake National Wildlife Refuge (NWR) was 70% (Bragg 1978). Cover on dune slopes ranged from 40-70% grass cover (Bragg 1978). Although in the same grassland region, vegetation cover in our study was noticeable lower than in other studies. However, management treatments varied by study. As Bragg (1998), vegetative cover is substantially reduced by grazing especially as compared to unburned, ungrazed sites on Crescent Lake NWR. Ubiquitous grazing on our study pastures lead to lower amounts of cover. In the Sandhills, variation in vegetation cover measurements may also vary with time of observation as suggested by Smith 1893 (Bragg 1978).

In 2002, variation in vegetation measurements among grazing systems was small. However, some trends were noticeable. Woody and bare soil cover, VOR readings, and litter depth tended to decrease with decreasing grazing duration in 2002 (Table 3). Forb cover tended to be lower on rotational systems. As grazing duration decreased, litter depth and the height of the tallest plant increased (Table 3).

Cover of forbs and bunchgrass decreased from 2003 to 2004 during the early sampling period (Table 6, Figure 9). Lying litter cover, litter depth and small-scale heterogeneity also decreased with year during the same sampling period (Table 6, Figure 9). Bare soil increased with year during the early sampling round (Table 6, Figure 9).

As in June, bunchgrass, bare soil, and lying litter cover and litter depth were lower during the late sampling period in 2004 than in 2003. Unlike the early sampling period, VOR and LSH decreased from 2003to 2004 in the late sampling period (Table 8 and Figures 12 and 13). The structure of plant cover is directly related to standing herbage and the amount of standing herbage is inversely related to stocking rate (Reece et al. 2001). Average growing season stocking rates for the study area increased from 0.90 (SD = 0.50 SD) AUM/ha in 2003 to 1.21 (SD = 0.89) AUM/ha in 2004. This grazing pressure was distributed evenly throughout the growing season; the number of individual grazing events was similar before our vegetation sampling periods. This increased grazing pressure may have been the cause of decreased vegetation cover during our study. In Saskatchewan, standing dead material, such as litter cover and litter depth was reduced by grazing (Bai et al. 2001). In a comparison of continuous grazing and rotational grazed pastures in Texas, litter biomass was generally greater in the continuously grazed system early in the calendar year. The authors contributed this difference in litter biomass to stocking rate and not to grazing system (Heitschmidt et al. 1987). Stocking rates were similar among grazing systems in this study (Figure 6) and may explain why no differences in litter (cover or depth) were detected. In a study of the effects of SDG and HILF grazing systems on forage production and composition, Taylor et al. (1993) found that litter varied significantly among years, but remained similar between grazing systems. The authors also found that the production of forbs was similar among grazing systems (SDG and HILF), but varied among years and levels of fall and winter precipitation.

The influence of limited precipitation may confound the annual effects of grazing on vegetation cover and structure. Bunchgrass cover may have decreased due to a lag effect of drought that began during our first year of study (2002). In 2003 conditions appeared to improve with approximately average monthly rainfall through June (Figure 2). However, drought conditions continued into 2004 (Figure 4) and did not show signs of improvement until September, well past the peak of herbage production for many Sandhills grass species (Reece et al. 2001). If a drought is extended past one to three years, the impact of drought and reduced growth of shoots and roots may cause lag effects of drought (Reece et al. 1991).

A similar, but reverse, relationship may explain the increase in bare soil cover with year. As the amount of vegetative cover and lying litter decreases, it follows that bare soil cover would increase. Litter accumulation rates were most likely lower than decomposition rates. Due to drought conditions, vegetation was not growing and senescing at rates adequate to facilitate litter accumulation.

The amount of precipitation received in the spring (April-May) of 2004 was approximately 38 mm less than that received during the same period in 2003 and of the 30-year average (Figure 3). As the 2004 growing season began, the study area was experiencing moderate drought conditions; the most severe conditions during this time period of all three years of study (Figure 4). Additional precipitation fell during the middle of the growing season (June and July), but relatively high grazing pressure coupled with limited precipitation in the previous two year, may not have allowed the vegetation to fully recover or have comparable measures as in 2003. The amount of available forage later in the growing season has been shown to be reduced by grazing that occurs in May in the Sandhills (Voleskey et al. 2005). If drought stress, in the form of limited soil moisture, occurs early in the growing season, the number of shoots that are produced may be reduced in perennial grasses (Reece et al. 1991). Depth of soil moisture in April on sandy range sites in Colorado was correlated to forage production during the primary growing season (Dahl 1963).

Our study illustrates that LSH and SSH (Tables 6 and 8) increasing with increasing grazing duration. The significant interaction of year and system precludes this main effect of system, thus indicating year, as a surrogate variable for climate, interacts with grazing system (or possibly range condition) to affect heterogeneity. However, we chose to examine the main effects of year and system.

Historically, heterogeneity was a result of grazing variability in both space and time. Rotational grazing systems are designed to improve grazing distribution, control timing of grazing, and optimize harvest efficiency. Plant species that are tolerant or favored by this type of grazing become dominant, leading to homogeneous structure (Vallentine 2001).

Allowing a grazing animal to exhibit grazing preferences will often result in unevenly distributed grazing patterns (Schacht et al. 1996). Pastures managed using a continuous grazing method (long duration system in this study) are often overgrazed in preferred or convenience areas and lightly grazed in others (Schacht et al. 1996, Valentine 2001). This may lead to increased woody vegetation and bare soil in those overgrazed areas, especially around water sources. High VOR readings in long duration systems readings may have been the result of taller, non-grazed plants in the less-preferred patches. Litter may also be deeper in these less-preferred areas providing suitable nesting substrate for some bird species. The absence of dormant season grazing, on long duration systems allows for increased growth of soapweed yucca (*Yucca glauca*) as the crowns of yucca are grazed during the winter (Tolestead 1942).

Selective overgrazing and lack of winter grazing may help to increase structural heterogeneity on long duration systems. The increased cover of woody vegetation, yucca and shrubs added structure within pastures managed with this method. This was evident in the average system vegetative measurements in 2002 and the significant effect of system on small- and large-scale heterogeneity in 2003 and 2004. Fuhlendorf and Engle (2001) suggested that moderate levels of grazing (as occurred in this study) on continuous grazing systems, such as our long duration treatment, can increase heterogeneity levels at some scales unspecified by the authors. Our study supports this hypothesis.

Although rotational systems are more homogeneous at a pasture (large) scale, they may provide heterogeneity at a larger landscape-scale with the pastures acting as landscape patches. Four to five pasture deferred or rest rotation systems would likely provide the greatest landscape-scale heterogeneity. Grazing frequency with these systems is less than shorter duration, higher density systems, allowing for a longer recovery and growth period. Managing for heterogeneity by using a combination of grazing systems across the landscape (this study) may support a universal management goal that enhances biodiversity and supports the ranching enterprise (Fuhlendorf and Engel 2004).

Early in the 20th century, R. J. Pool was the first to realize the relationship between topography and species distribution in the Sandhills (Barnes and Harrison 1982).

Topographic position and aspect are important determinants of plant distribution with interdunal valleys especially distinct from dune tops, and north- and south-facing slopes (Schacht et al. 2000). Soil moisture is the primary limiting factor to plant growth on upland range sites (Reece et al. 2001); adequate amounts are crucial to semi-arid grassland plants (Barnes and Harrison 1982). During dry years within the Sandhills, water availability depends upon soil texture (Tolestead 1942). Soil texture within the Sandhills follows a gradient from fine to coarse from the interdunal valleys to the swales and dune tops (Barnes et al. 1984). Coarse textured ridge soils allow for infiltration and percolation of varying amounts of precipitation (Barnes et al. 1984). This reduces runoff and provides greater soil moisture availability than the finer textured soils of the interdunal valleys. Finer textured soils in low lying areas have greater water holding capacity and increased runoff (Tolestead 1942, Barnes and Harrison 1984). The influence of topography on plant species communities is partly due to a species' ability to utilize available water resources (e.g. morphological characteristic such as root structure; Barnes et al. 1984). The resulting topographically-influenced vegetative community will then influence a site's potential to provide vegetative structure.

In addition to localized topography, regional climate (temperature and climate) further defines plant communities within the Sandhills (King and Stine 1998). Dune tops, slopes, and interdunal valleys vary in micro and macro climates. Ecological sites are classifications of these topographic, edaphic, and microclimaticic variations that differ in their ability to produce a characteristic climax plant community; they serve as the basic unit of range management (King and Stine 1998). The ability to produce different kinds, amounts, and proportions of plant species in the climax plant community varies among and are described by different ecological sites (King and Stine 1998).

Ecological site explained much of the variation in bunchgrass, forb and lying litter cover, VOR, and large-scale heterogeneity in our study (Table 7 and 9). Early season VOR readings were highest on the subirrigated meadows (0.55 dm), blowout areas of the choppy sands range sites (0.52) and choppy sands sites (0.48 dm; Figure 11). Subirrigated meadows are very productive (King and Stine 1998) resulting in high VORs. Cattle grazing pressure on choppy sands tends to be low resulting in much non-grazed standing herbage. Cattle often prefer to graze on relatively flat areas; a slope of 10-30% can decrease herbage use by up to 30% (Reece et al. 2001). The underutilized areas may also provide for variation in VOR through a combination of limited grazing, thus taller and denser vegetation and slippage and blowout areas that may be relatively free of vegetation.

Variation in small-scale heterogeneity was explained best by range condition (Table 9 and Figure 15). Structure was most heterogeneous at this scale for areas in good condition (51-75%). Range in good condition supports a more diverse number of plant species (Reece et al. 2001) and increases the cover, height, and thickness of either live or dead standing plants (Bai et al. 2001). Diverse plant communities are more resilient to disturbances (Tilman and Downing 1994). Smith et al. (1996) concluded that range in good condition provided more wildlife habitat than range in excellent condition which tends to be less diverse in terms of species composition and structure.

Heavy grazing and drought are the main causes for range deterioration (Reece et al 2001). Range condition deteriorates as stocking rate increases (Holechek et al. 1999). No one grazing system appears have a distinct advantage over other systems in influencing forage production (Holechek et al. 1999, Vallentine 2001). Moderate stocking rates (25% harvest of current forage growth), regardless of grazing system, should not be exceeded to improve range condition (Taylor et al. 1993). Grazing regimes that maintain range in good condition will maintain structural diversity of grasslands (Bai et al. 2001) and provide habitat for wildlife.

SUMMARY

Ecological site and year (often a surrogate variable for weather) are the two main driving factors influencing vegetation on private range in the Sandhills. Grazing system was not an important factor in the measurements of vegetation cover that we analyzed. However, grazing system did influence the level of structural heterogeneity at both spatial scales. Land managers cannot control the biological potential (ecological site) of a site nor short-term (yearly) variations in climate. However, stocking rate can be used to improve range condition and manage for drought and wildlife.

Using a variety of grazing systems across the landscape and implementing moderate stocking rates will optimize range condition and heterogeneity at a multitude of spatial scales. The increased diversity in plant species composition and structure increases ecosystem resilience to drought and support habitat for a variety of grassland species. Restoration of heterogeneity at spatial and temporal scales, similar to that in which grassland-wildlife communities evolved, may play a crucial role in the restoration of grassland biodiversity (Fuhlendorf and Engle 2004). Increasing heterogeneity through the use of grazing systems at multiple scales may be an effective goal for ecologically and economically sustainable rangeland and grassland wildlife management.

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Table 1. Ecological site description (%) of three grazing systems (long, medium, and short rotations) used on private lands in the Nebraska Sandhills, 2002-2004.

	Grazing systems			
Ecological Site	Long	Medium	Short	All systems
Sands[a]	64	78	77	74
Sandy	16	17	11	14
Choppy Sands[b]	13	3	10	9
Subirrigated meadow	5	1	1	3

[a] blowouts comprised 1.04%, 0.58%, and 0.39% of sands sites in long, medium, and short duration systems, respectively and 0.7% of such sites in the study area.

[b] blowouts comprised 0.78%, 0.39%, and 0.20% of choppy sands sites in long, medium, and short duration systems, respectively and 0.5% of such sites in the study area.

Table 2. Range condition of private rangeland by ecological site and grazing system (long, medium, and short rotations) in the Nebraska Sandhills, 2002-2004.

		Grazing systems		
Ecological Site	Condition	Long	Medium	Short
Sands	Excellent	50%	12.5%	50%
	Good	50%	62.5%	50%
	Fair	0%	25%	0%
	Poor	0%	0%	0%
Sandy	Excellent	0%	0%	100%
	Good	100%	100%	0%
	Fair	0%	0%	0%
	Poor	0%	0%	0%
Choppy Sands	Excellent	--[a]	0%	--[a]
	Good	--[a]	0%	--[a]
	Fair	--[a]	100%	--[a]
	Poor	--[a]	0%	--[a]
Subirrigated Meadow	Excellent	0%	--[a]	--[a]
	Good	50%	--[a]	--[a]
	Fair	50%	--[a]	--[a]
	Poor	0%	--[a]	--[a]

[a] ecological site was not present on our study sites in this grazing system

Table 3. Mean habitat structure values (±SE) for grazing systems on private lands in the Nebraska Sandhills in 2002.

	Grazing System							
	Long		Medium		Short		Pooled	
	$\bar{x}^a$	SE	$\bar{x}^a$	SE	$\bar{x}^a$	SE	$\bar{x}$	SD
% Cover								
Grass	47.09	6.53	42.38	6.53	47.04	6.53	45.48	25.86
Forb	9.36	1.66	7.71	1.66	8.00	1.66	8.36	10.36
Woody	8.94	1.39	7.52	1.39	5.98	1.39	7.49	11.90
Bare soil	33.02	6.98	29.56	6.98	25.03	6.99	29.22	24.34
Litter	12.68	2.20	14.49	2.20	13.03	2.20	13.40	14.10
Live	46.54	4.36	39.33	4.36	44.82	4.36	43.55	24.09
Dead	10.66	2.43	10.21	2.43	11.45	2.43	10.76	14.06
Total	53.95	6.14	48.83	6.14	53.58	6.14	52.10	23.72
Litter depth (cm)	0.04	0.04	0.08	0.04	0.11	0.04	0.08	0.47
VOR (dm)	0.44	0.08	0.36	0.08	0.34	0.08	0.38	0.52
Tallest plant (dm)	2.95	0.46	3.08	0.46	3.53	0.46	3.19	1.73

[a] Means are least-squares means.

Table 4. Mean habitat structure values (± SE) for grazing systems on private lands in the Nebraska Sandhills in 2003 and 2004.

	Grazing System							
	Long		Medium		Short		Pooled	
	$\bar{x}^{a}$	SE	$\bar{x}^{a}$	SE	$\bar{x}^{a}$	SE	$\bar{x}$	SD
% Cover								
Annuals	1.29	0.31	1.54	0.31	1.85	0.32	1.57	2.77
Bunchgrass	11.06	2.01	15.01	2.01	16.47	2.06	14.22	13.28
Rhizomatous grass	10.19	1.34	9.48	1.34	10.30	1.39	9.98	11.86
Total Grass	21.25	2.78	24.49	2.78	26.86	2.88	24.20	17.58
Sedges	4.48	0.67	3.34	0.67	4.07	0.70	3.95	6.40
Forbs	6.69	0.91	5.74	0.91	6.64	0.92	6.40	7.98
Shrubs	3.82	0.68	4.99	0.68	4.04	0.69	4.27	9.26
Yucca	0.41	0.12	0.08	0.12	0.00	0.12	0.16	2.85
Cactus	0.17	0.03	0.17	0.03	0.26	0.03	0.20	1.13
Bare soil	49.69	6.32	42.29	6.31	44.40	6.35	45.51	31.26
Standing litter	4.53	0.59	3.89	0.59	4.87	0.61	4.41	5.86
Lying litter	40.25	5.84	47.62	5.84	44.53	5.88	44.10	30.80
Cow pie	0.79	0.31	1.20	0.31	1.25	0.32	1.23	5.10
Plant Origin								
Native	96.79	1.02	97.97	1.02	98.71	1.03	97.78	11.72
Exotic	2.83	0.92	1.50	0.92	0.63	0.93	1.68	9.03
Litter depth (cm)	0.29	0.07	0.31	0.07	0.24	0.07	0.28	0.63
VOR (dm)	0.41	0.08	0.37	0.08	0.43	0.08	0.40	0.40
Tallest plant (cm)	46.87	2.52	49.95	2.52	51.96	2.55	49.59	19.94

[a] Means are least-squares means.

Table 5. Habitat heterogeneity as measured by variation in Visual Obstruction Readings (VOR) on private rangelands in the Nebraska Sandhills, 2003 and 2004. See text for further description of sampling protocols and formulas used for calculating heterogeneity. Larger values indicate more heterogeneous habitat structure at both spatial scales. Early- and late-season sampling occurred in mid-June and early August, respectively. Difference = (late – early) heterogeneity values.

			Grazing system					
Scale	Sample	Year	Long		Medium		Short	
			Avg	SD	Avg	SD	Avg	SD
Large-scale	Early-season	2003	88.15	22.32	63.28	20.68	84.93	61.03
		2004	61.65	25.78	72.11	27.85	53.80	17.41
		Pooled	74.90	26.44	67.70	23.19	69.37	44.75
	Late-season	2003	92.48	27.65	80.51	33.66	66.95	39.00
		2004	75.62	16.28	55.35	11.93	54.99	18.82
		Pooled	84.05	22.86	67.93	26.97	60.97	29.06
	Difference	2003	4.32	--	17.23	--	-17.98	--
		2004	13.97	--	-16.76	--	1.19	--
		Pooled	9.15	--	0.23	--	-8.39	--
	Season mean	2003	90.32	--	71.90	--	75.94	--
		2004	68.64	--	63.73	--	54.40	--
		Pooled	79.48	--	67.82	--	65.17	--
Small-scale	Early-season	2003	1.04	0.29	0.94	0.34	1.12	0.24
		2004	0.96	0.26	0.96	0.17	0.86	0.26
		Pooled	1.00	0.26	0.95	0.25	0.99	0.27
	Late-season	2003	1.37	0.33	1.19	0.35	0.91	0.10
		2004	0.98	0.33	0.92	0.28	0.70	0.11
		Pooled	1.17	0.37	1.06	0.33	0.81	0.15
	Difference	2003	0.33	--	0.26	--	-0.20	--
		2004	0.01	--	-0.04	--	-0.16	--
		Pooled	0.17	--	0.11	--	-0.18	--
	Season mean	2003	1.21	--	1.06	--	1.02	--
		2004	0.97	--	0.94	--	0.78	--
		Pooled	1.09	--	1.00	--	0.90	--

Table 6. Effect of grazing system and year (2003-2004) on select vegetation structure variables measured in mid-June ('early') on private rangelands in the Nebraska Sandhills. Heterogeneity is a measure of variation of VOR readings at two spatial scales; see text for further discussion of heterogeneity. $\alpha = 0.05$ significance level.

	Effect		
	System	Year	System*Year
% Cover			
Bunchgrass	0.554	0.002	0.862
Forbs	0.693	0.009	0.705
Bare Soil	0.646	<0.001	0.767
Lying Litter	0.631	<0.001	0.509
Litter Depth	0.480	<0.001	0.232
VOR	0.668	0.168	0.634
Heterogeneity			
large	0.130	0.794	<0.001
small	0.001	<0.001	0.002

Table 7. *A priori* model sets created to explain variation in select vegetation variables measured during the early (mid- to late-June) vegetation sampling round conducted on private rangelands in the Nebraska Sandhills, 2003-2004. Models with lower ΔAIC values and higher Akaike weights have more support given the data and the model set. The slope for dormant season stocking rate (DsSR) is provided for models that included it as a variable.

Variable	Model	k	AIC	ΔAIC	w_i	B_{DsSr}	SE
Bunchgrass	CGsG+DsSR+PGsR	9	16295.1	0.0	1.00	0.62	0.257
	ECO	7	17660.8	1365.7	0.00	--	--
	CGsG+DsSR	5	17706.1	1411.0	0.00	1.1459	0.231
	RCND	6	17712.3	1417.2	0.00	--	--
	CGsG	4	17729.2	1434.1	0.00	--	--
	NULL	1	17734.0	1438.9	0.00	--	--
VOR	ECO	7	1241.2	0.0	0.80	--	--
	NULL	1	1244.0	2.8	0.20	--	--
	CGsG	4	1252.0	10.8	0.00	--	--
	CGsG+DsSR	5	1253.1	11.9	0.00	0.02	0.007
	RCND	6	1254.9	13.7	0.00	--	--
	CGsG+DsSR+PGsR	9	1258.9	17.7	0.00	0.01	0.007
Heterogeneity -large scale	ECO	7	-13595.1	0	1.00	--	--
	CGsG+DsSR+PGsR	9	-12710.6	884.5	0.00	0.96	3.210
	RCND	6	-11914	1681.1	0.00	--	--
	NULL	1	-11792.8	1802.3	0.00	--	--
	CGsG	4	-11622.5	1972.6	0.00	--	--
	CGsG+DsSR	5	-11503.7	2091.4	0.00	-7.46	2.490

[a] Definition of model effects: ecosite (ECO), null model (NULL), current growing season grazing (CGsG), range condition (RCND), dormant season stocking rate (DsSR), previous growing season rest (PGsR).

Table 8. Effect of grazing system and year (2003-2004) on select vegetation structure variables measured in early August ('late') on private rangelands in the Nebraska Sandhills. Heterogeneity is a measure of variation in VOR readings at two spatial scales; see text for further discussion of heterogeneity. $P<0.05$ significance level.

	Effects		
	System	Year	System*Year
% Cover			
Bunchgrass	0.180	0.003	0.321
Forbs	0.682	0.071	0.367
Bare soil	0.757	<0.001	0.798
Lying litter	0.734	<0.001	0.672
Litter depth	0.980	0.047	0.894
VOR	0.808	0.004	0.926
Heterogeneity			
large	<0.001	<0.001	<0.001
small	<0.001	<0.001	<0.001

Table 9. *A priori* model sets created to explain variation in select vegetation variables measured during the late (early August) vegetation sampling round conducted on private rangelands in the Nebraska Sandhills, 2003and 2004. Models correspond to hypotheses listed in text; *k* represents the number of parameters estimated by each model. Models are listed as ranked by AIC values; AIC weight (w_i) is the weight of evidence in favor of the given model from the model set considered. Models have decreasing empirical support as ΔAIC values become larger. Slope (β ± SE) is given for models with continuous variables

	Model	k	AIC	ΔAIC	wi	β	SE
% Cover							
Bunchgrass	ECO	7	17403.80	0	1.00	--[a]	--
	NULL	1	17432.90	29.1	0.00	--	--
	CGsR	5	17438.40	34.6	0.00	--	--
	RCND	6	17440.30	36.5	0.00	--	--
	GsSR	2	17450.80	47	0.00	-1.01	0.660
	PDSI	2	17451.20	47.4	0.00	-1.05	1.050
	PRECIP	2	17452.60	48.8	0.00	-0.54	0.299
Forb	ECO	7	15530.80	0	1.00	--	--
	NULL	1	15565.60	34.8	0.00	--	--
	RCND	6	15576.30	45.5	0.00	--	--
	CGsR	5	15580.20	49.4	0.00	--	--
	PDSI	2	15580.70	49.9	0.00	-0.92	0.559
	GsSR	2	15583.70	52.9	0.00	-0.16	0.356
	PRECIP	2	15583.80	53	0.00	-0.21	0.136
Lying litter	ECO	7	20496.90	0	1.00	--	--
	NULL	1	20656.50	159.6	0.00	--	--
	RCND	6	20660.30	163.4	0.00	--	--
	CGsR	5	20668.30	171.4	0.00	--	--
	GsSR	2	20680.40	183.5	0.00	1.39	1.398
Bare soil	PRECIP	2	20868.30	0	0.84	2.18	0.685
	PDSI	2	20872.10	3.8	0.13	4.14	2.302
	GsSR	2	20875.50	7.2	0.02	-1.24	1.479
	CGsR	5	20877.00	8.7	0.01	--	--
	NULL	1	20878.90	10.6	0.00	--	--

VOR	GsSR	2	1405.40	0	0.82	0.10	0.023
	CGsR	5	1409.30	3.9	0.12	--	--
	SYST	4	1411.10	5.7	0.05	--	--
	PRECIP	2	1415.00	9.6	0.01	-0.04	0.010
	NULL	1	1416.30	10.9	0.00	--	--
	PDSI	2	1419.90	14.5	0.00	-0.01	0.037
	ECO	7	1424.40	19	0.00	--	--
	RCND	6	1426.60	21.2	0.00	--	--
Heterogeneity							
small	RCND	6	-31959.30	0	1.00	--	--
	GsSR	2	-31877.60	81.7	0.00	0.00	0.00
	NULL	1	-31367.70	591.6	0.00	--	--
	SYST	4	-31083.50	875.8	0.00	--	--
large	NULL	1	-24694.50	0	1.00	--	--
	GsSR	2	-24671.30	23.2	0.00	0.00	0.00
	ECO	7	-24638.80	55.7	0.00	--	--
	RCND	6	-24504.10	190.4	0.00	--	--
	SYST	4	-24430.60	263.9	0.00	--	--

[a] Model parameter is categorical.

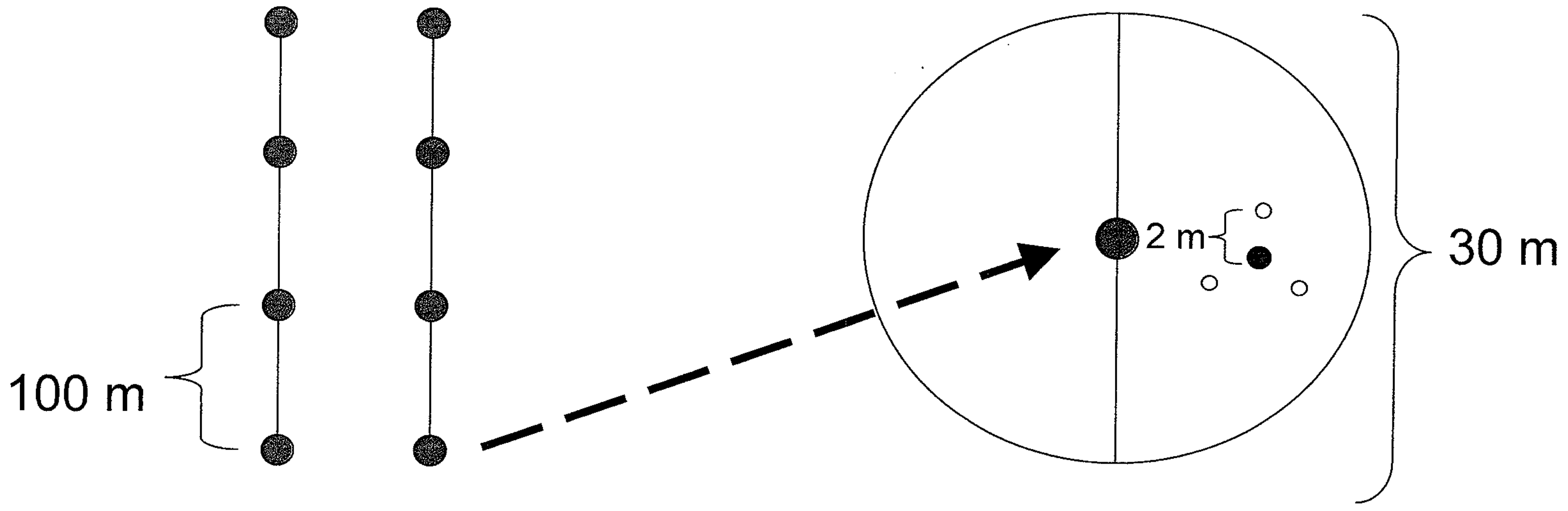

Figure 1. Vegetation sampling design used on private rangelands in the Nebraska Sandhills, 2003-2004. Red dots indicate 100 m increments along sampling transects. The center of the sampling unit (blue dot) is randomly located within 15 m of each 100 m interval. Vegetation measurements were taken at each of the triangle points (yellow dot).

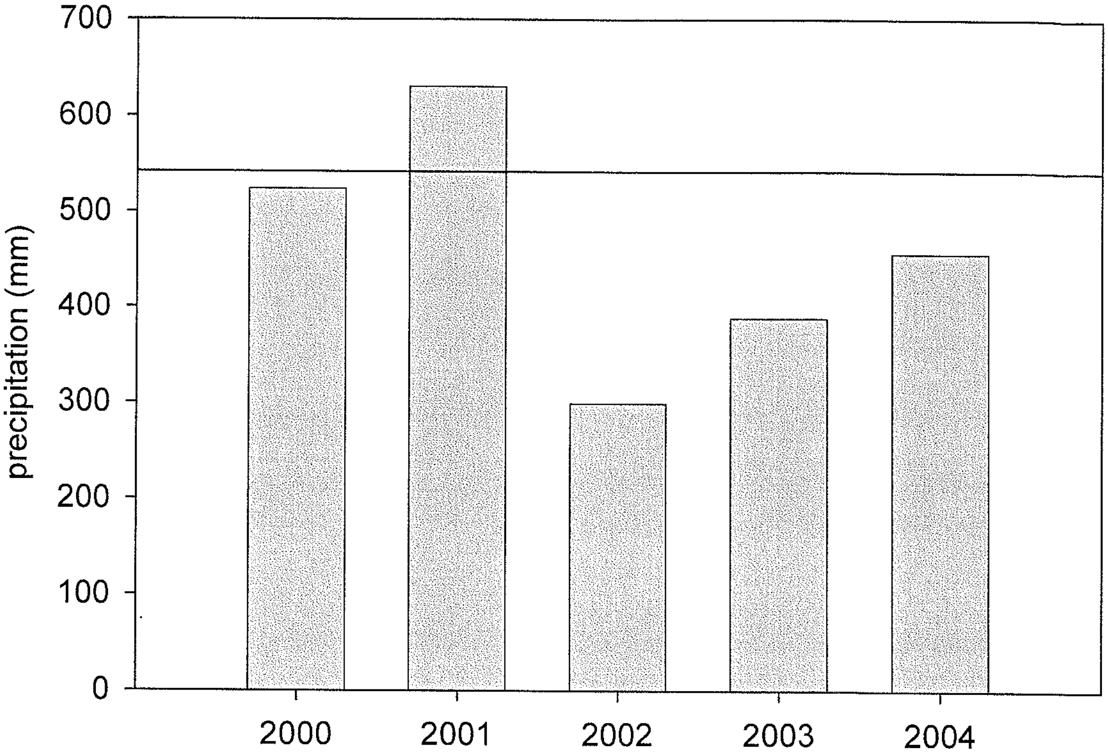

Figure 2. Total yearly precipitation (mm) for study area (region between Valentine and Thedford, Nebraska), 2000-2004. Horizontal line indicates 30-year mean precipitation

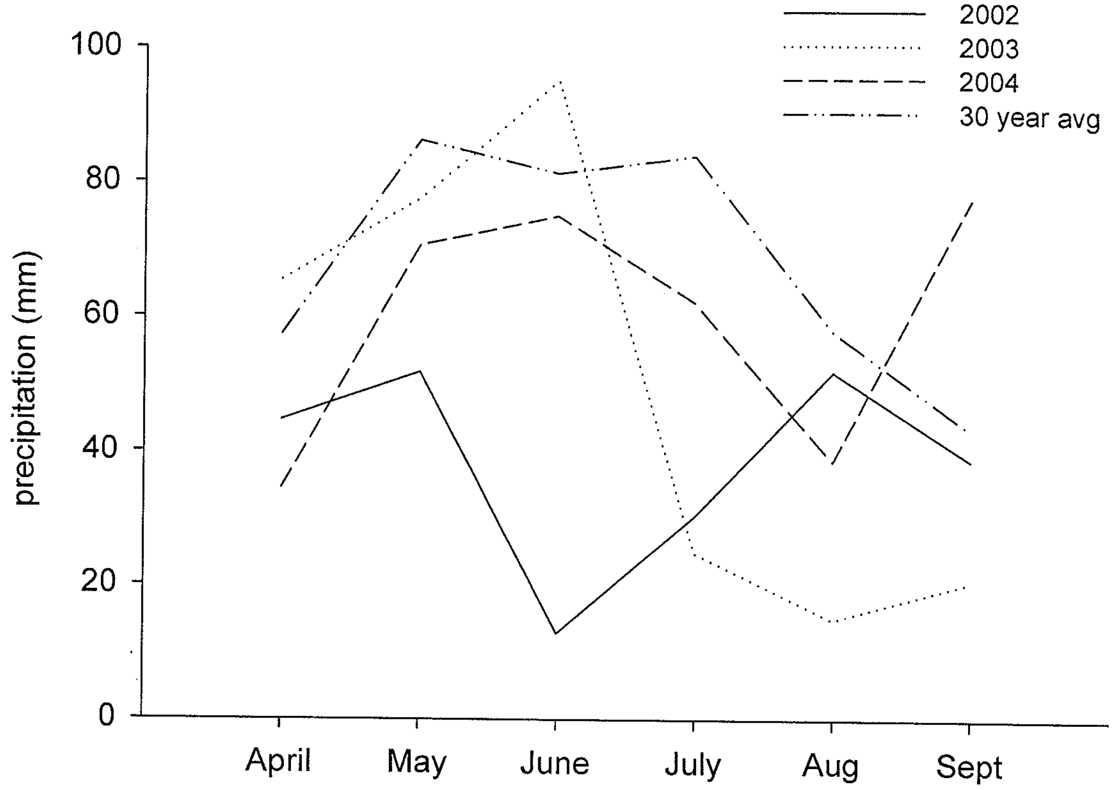

Figure 3. Monthly precipitation totals (mm) for region between Valentine and Thedford, Nebraska. See text for value calculation description.

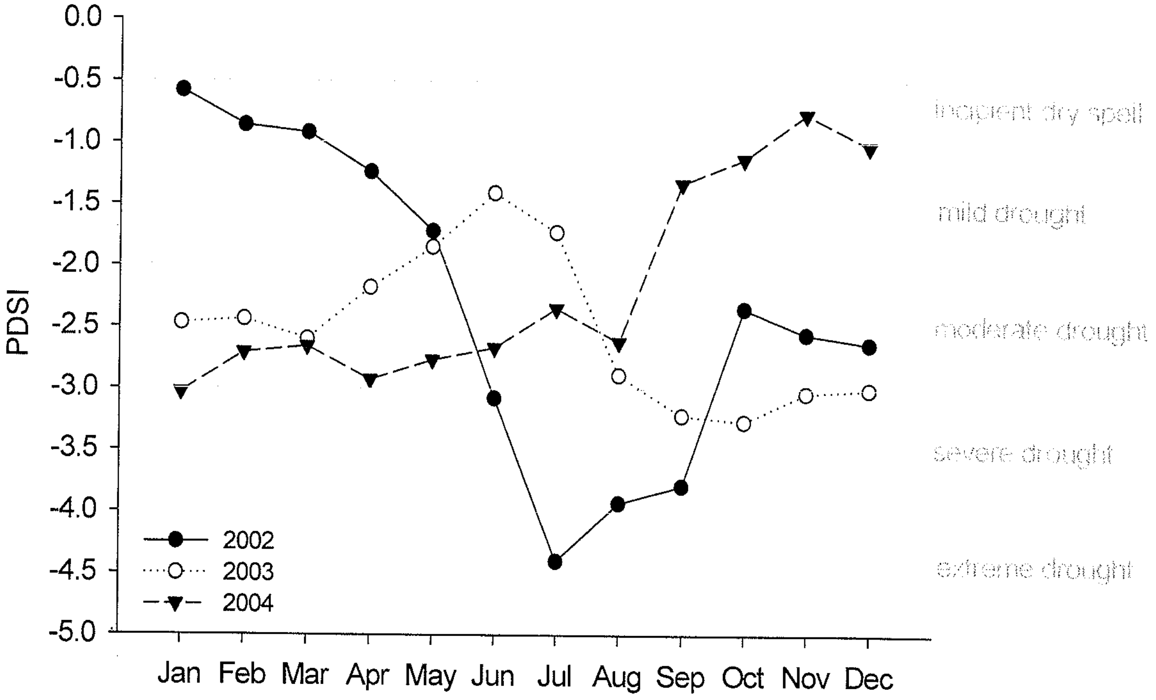

Figure 4. Monthly Palmer Drought Severity Index (PDSI) values for the Sandhills region, 2002-2004. PDSI categories are listed on the right. See text for further information on this index.

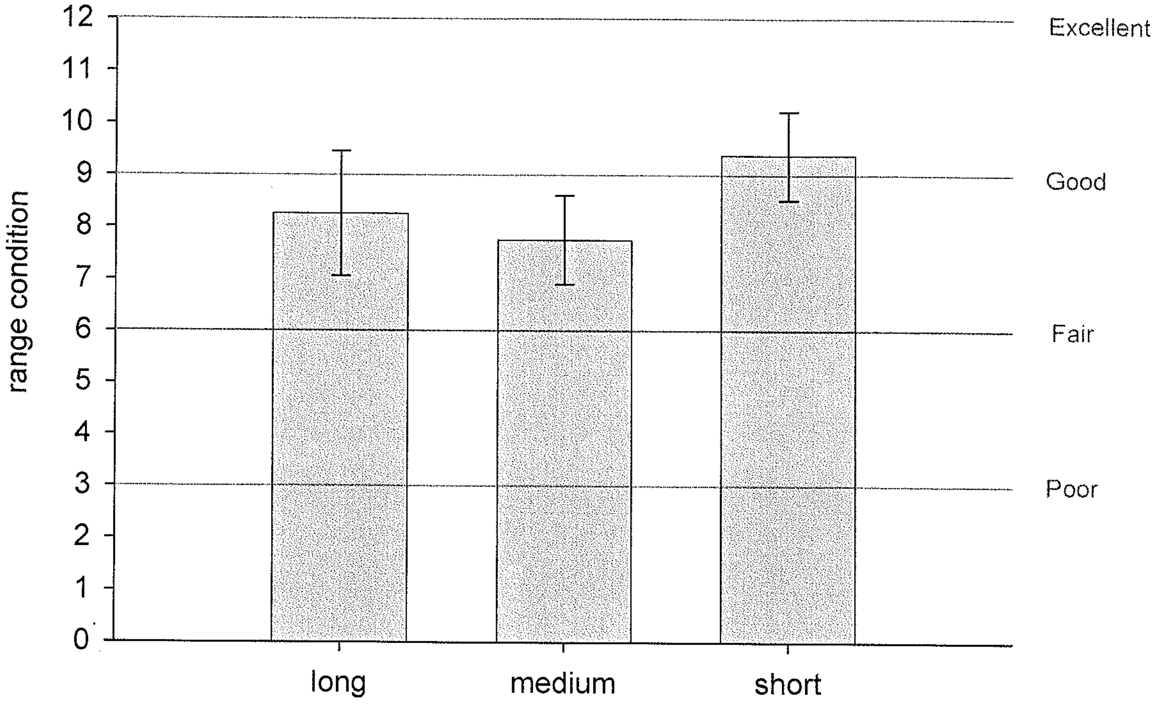

Figure 5. Weighted average range condition (±1 SE) for pastures within three grazing systems (long, medium, and short rotations) on private rangelands in the Nebraska Sandhills, 2002-2004. See text for weighted average methodology.

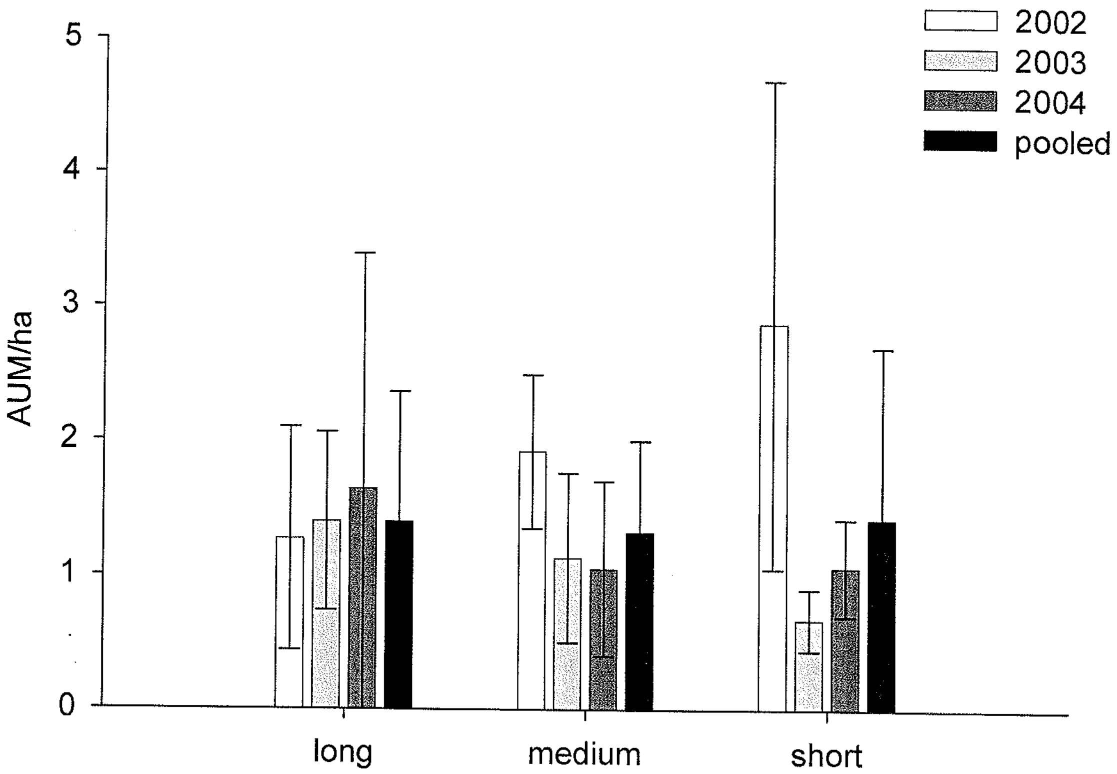

Figure 6. Average growing season (1 May to 30 September) stocking rates (AUM/ha; ±1 SD) for three grazing systems (long, medium, and short rotations) on private rangeland in the Nebraska Sandhills, 2002-2004.

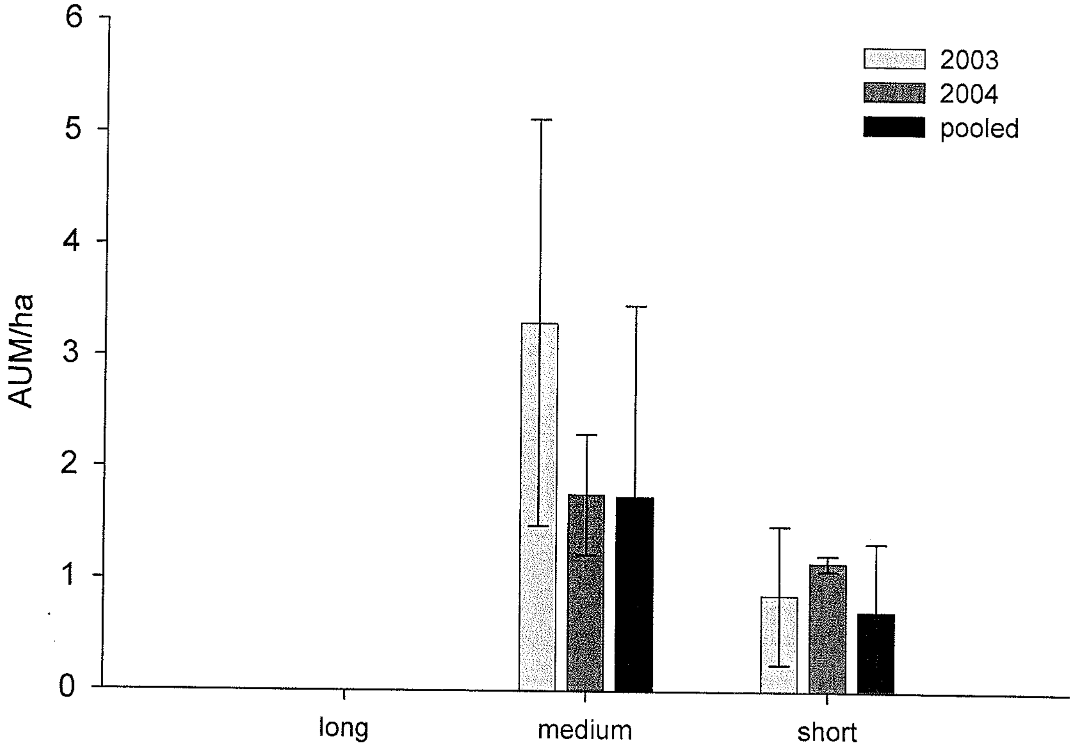

Figure 7. Average dormant season (1 October to 30 April) stocking rates (AUM/ha; ± 1 SD) on of three grazing systems (long, medium, and short rotations) on private rangeland in the Nebraska Sandhills, 2003-2004.

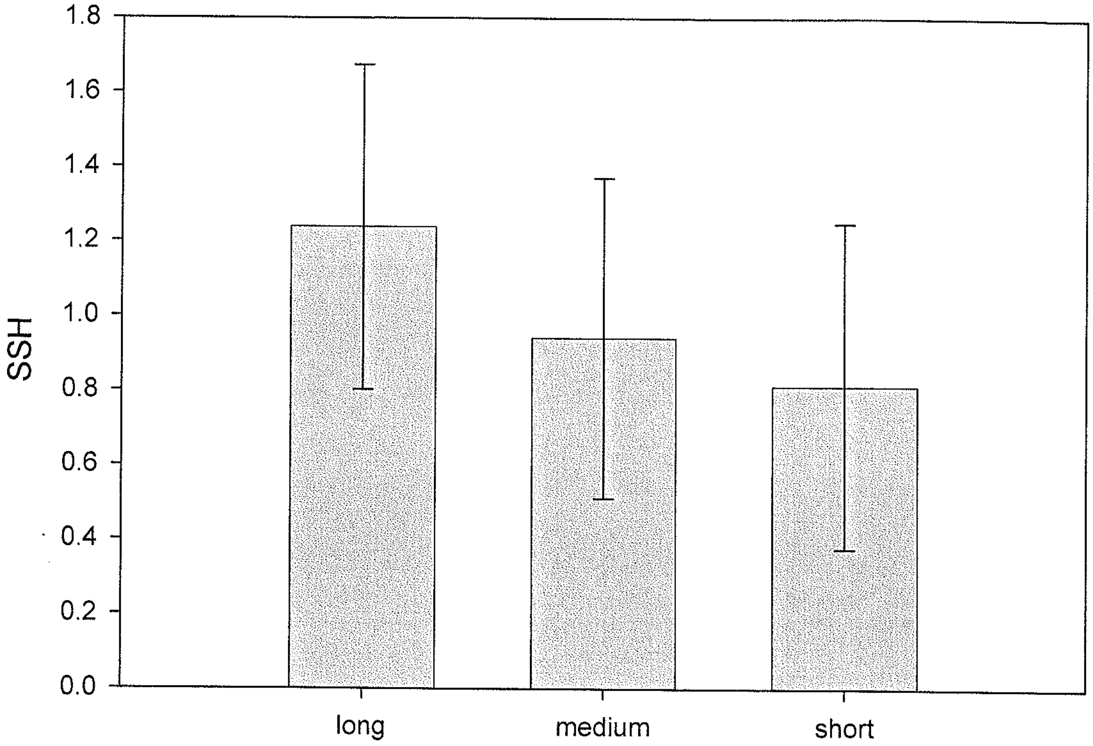

Figure 8. Least squares means (± 1 SE) of small-scale heterogeneity (SSH) by grazing system (P = 0.001) measured in the early season (mid to late-June) on private rangelands in the Nebraska Sandhills 2003-2004.

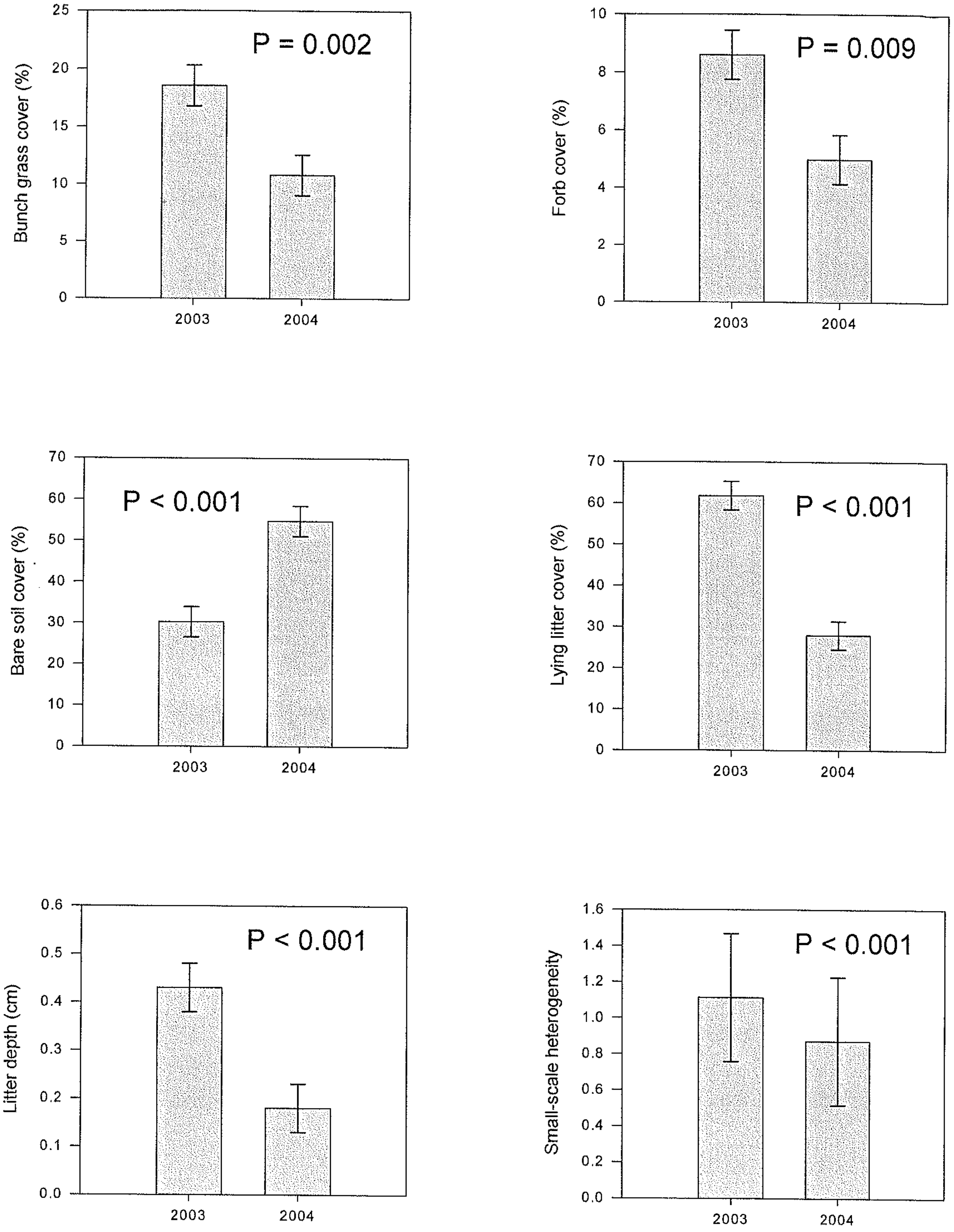

Figure 9. Least squares means (± 1 SE) of vegetation variables by year measured during the early season (mid to late-June) on private rangelands in the Nebraska Sandhills 2003-2004

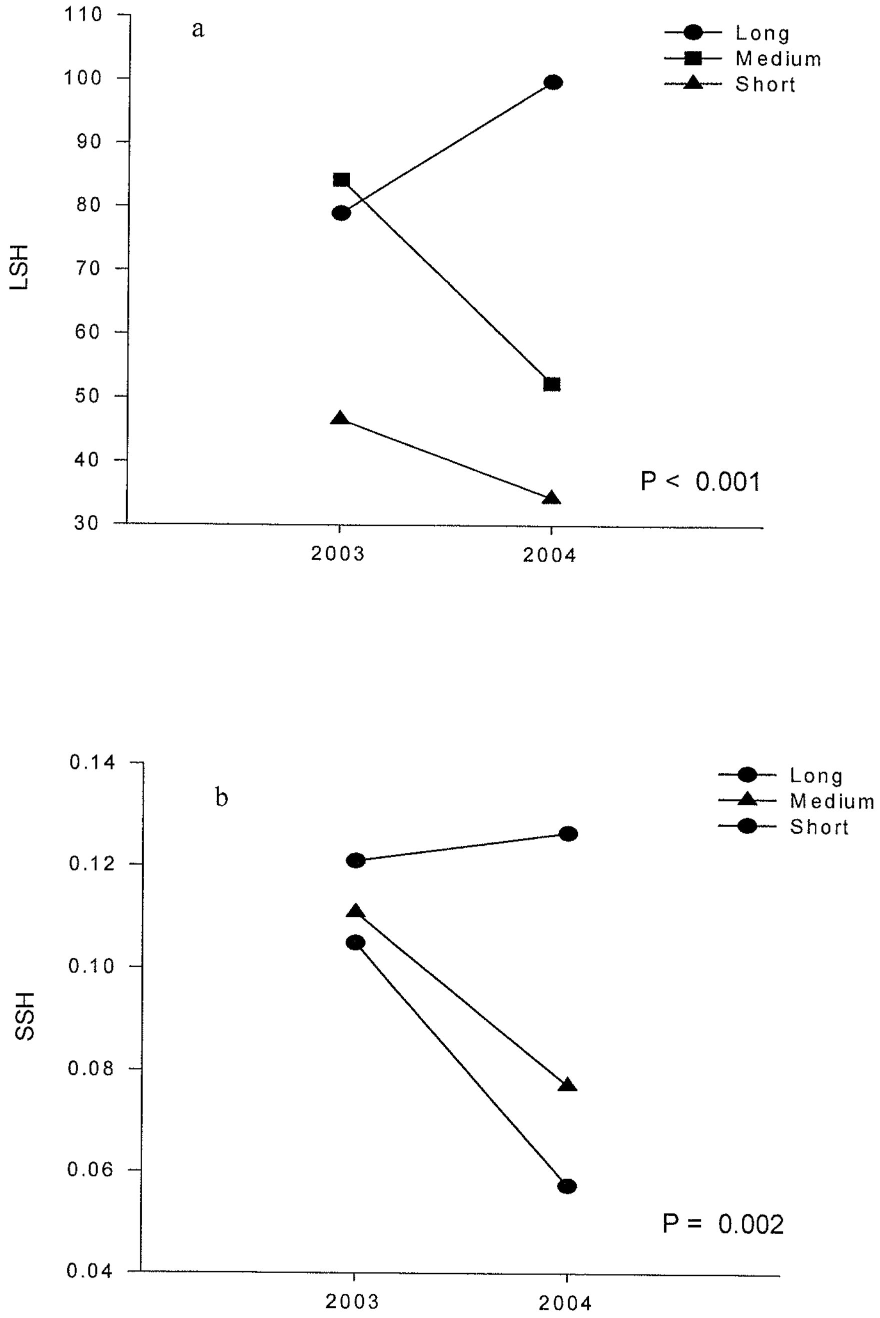

Figure 10. Significant interaction effect of year and grazing system (least squares means) for large- (LSH, a) and small-scale heterogeneity (SSH, b P = 0.002) during the early vegetation sampling round (mid to late-June) on private rangelands in the Nebraska Sandhills 2003-2004.

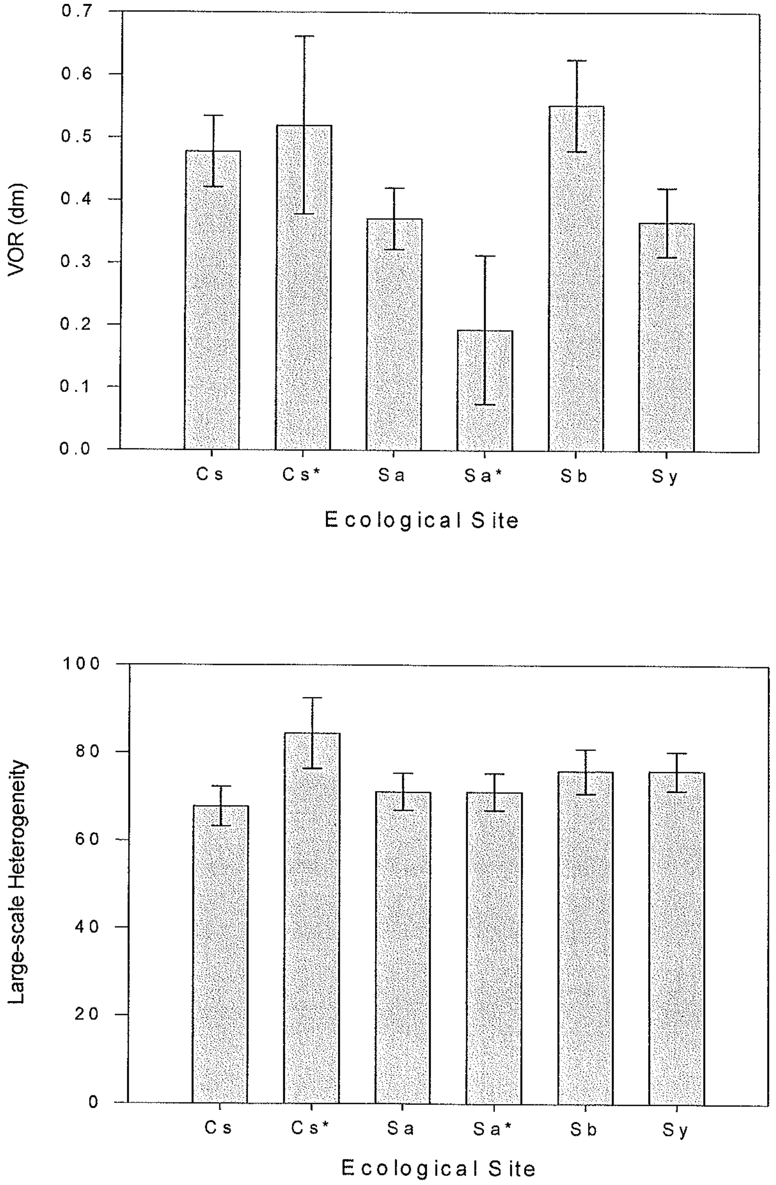

Figure 11. Least squares means (± 1 SE) for best approximating (ΔAIC = 0.0) single factor categorical models selected to explain variation in vegetation measurements during the early vegetation sampling round (mid to late-June) on private rangelands in the Nebraska Sandhills, 2003-2004. Cs = choppy sands, Sa = sands, Sy = sandy, Sb = subirrigated meadow, and * = blowout.

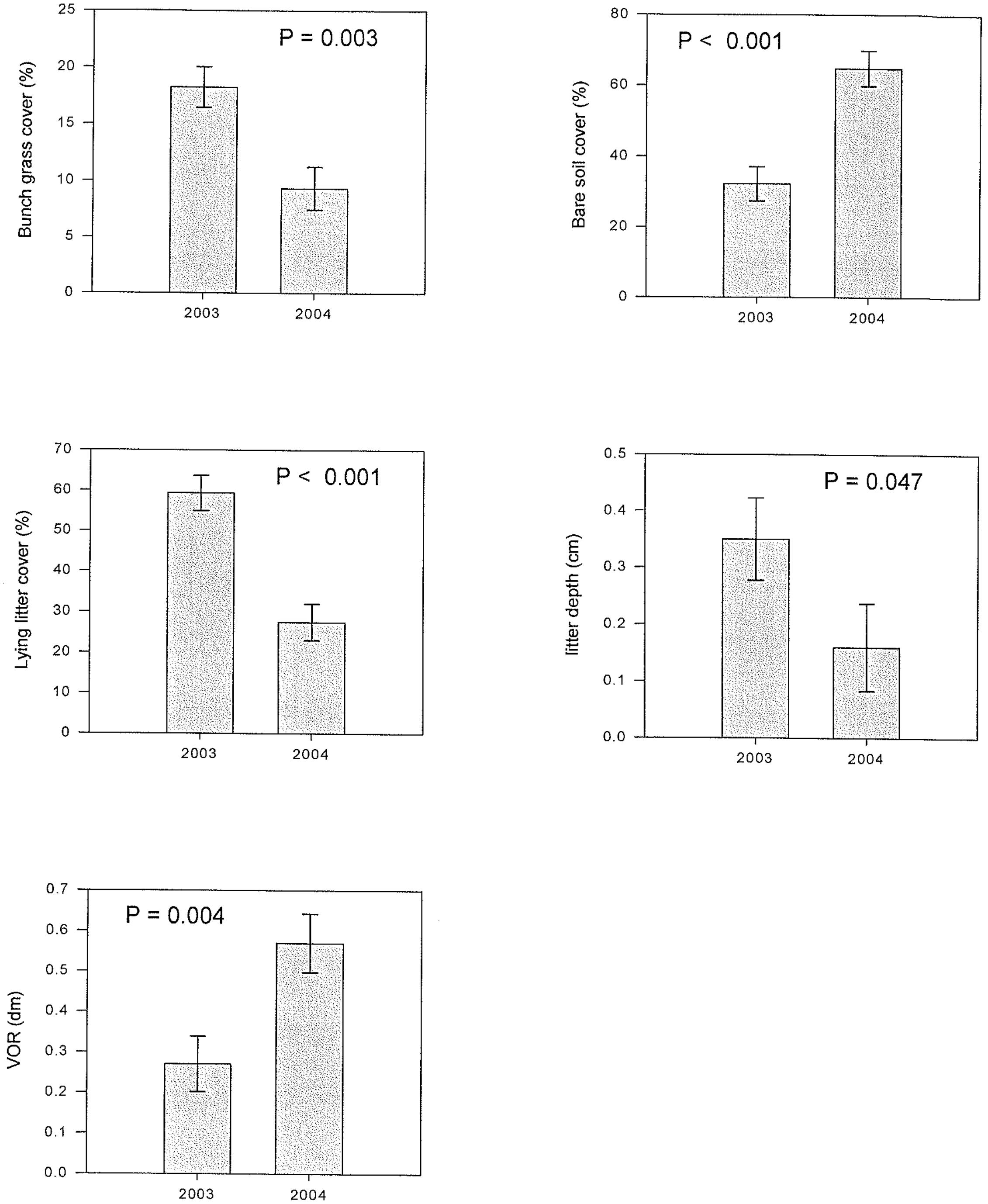

Figure 12. Least squares means (± 1 SE) for vegetation variables with a significant effect of year ($P < 0.05$) during the late vegetation sampling round (early August) on private rangelands in the Nebraska Sandhills, 2003-2004.

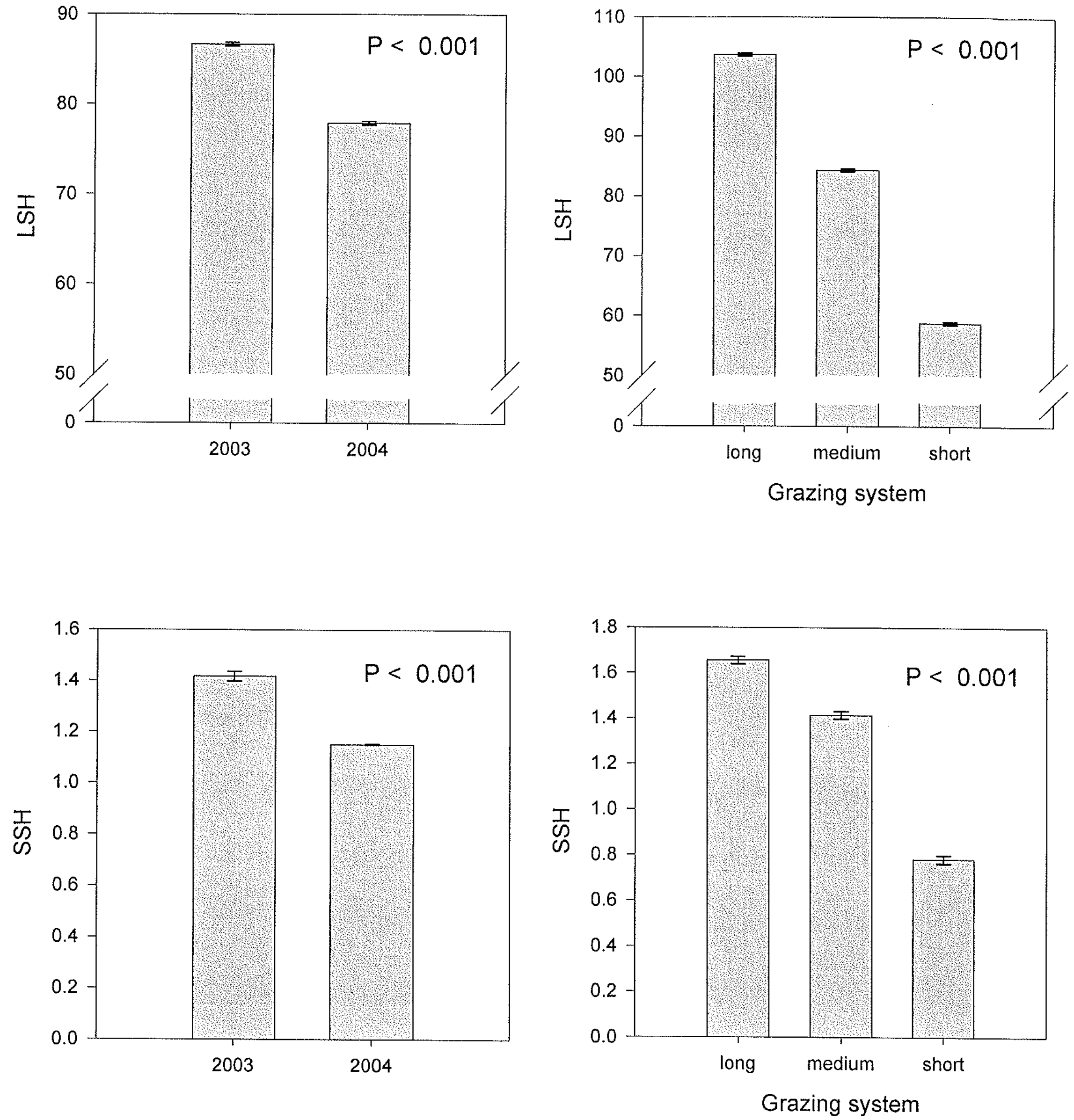

Figure 13. Least squares means (± 1 SE) for large- (LSH) and small-scale heterogeneity (SSH) with significant effect of year and grazing system during the late vegetation sampling round (early August) on private rangelands in the Nebraska Sandhills 2003-2004.

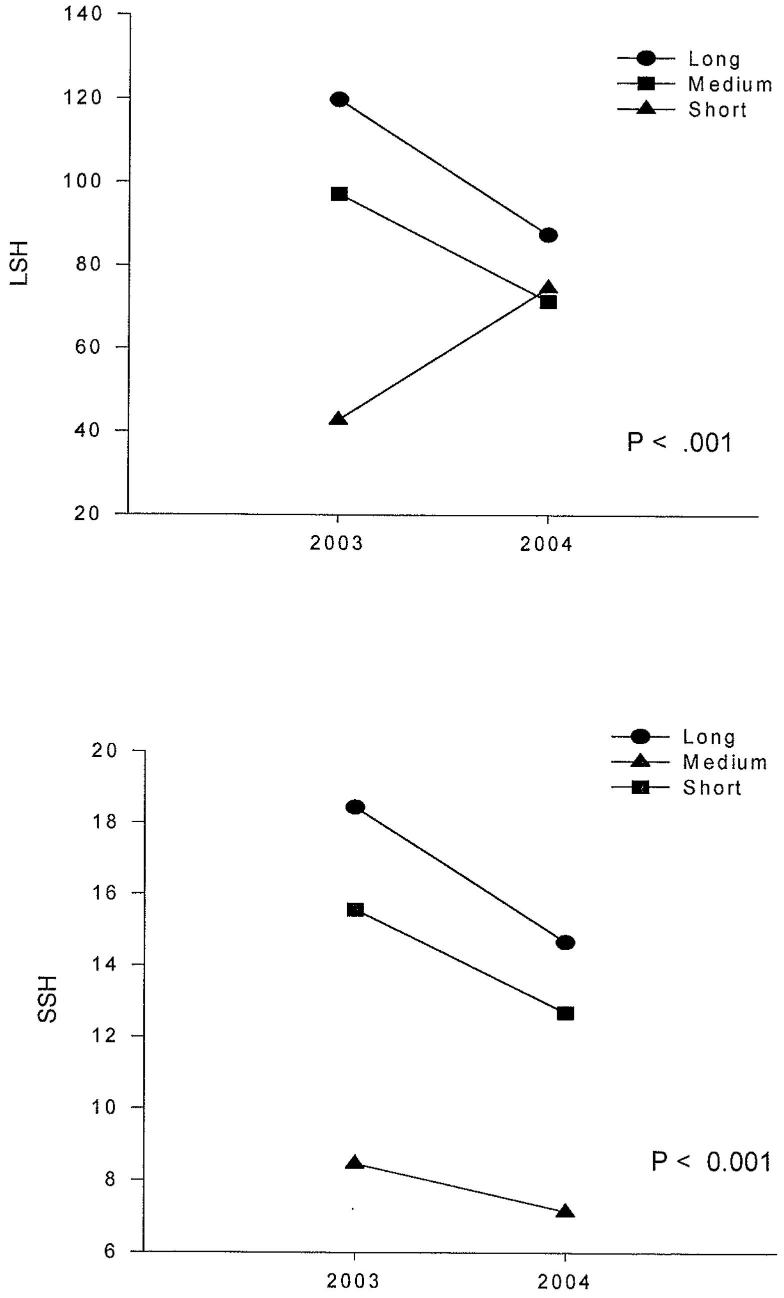

Figure 14. Significant interaction effect of year and grazing system (least squares means) on large- (LSH) and small-scale heterogeneity (SSH) during the late vegetation sampling round (early August) on private rangelands in the Nebraska Sandhills 2003-2004

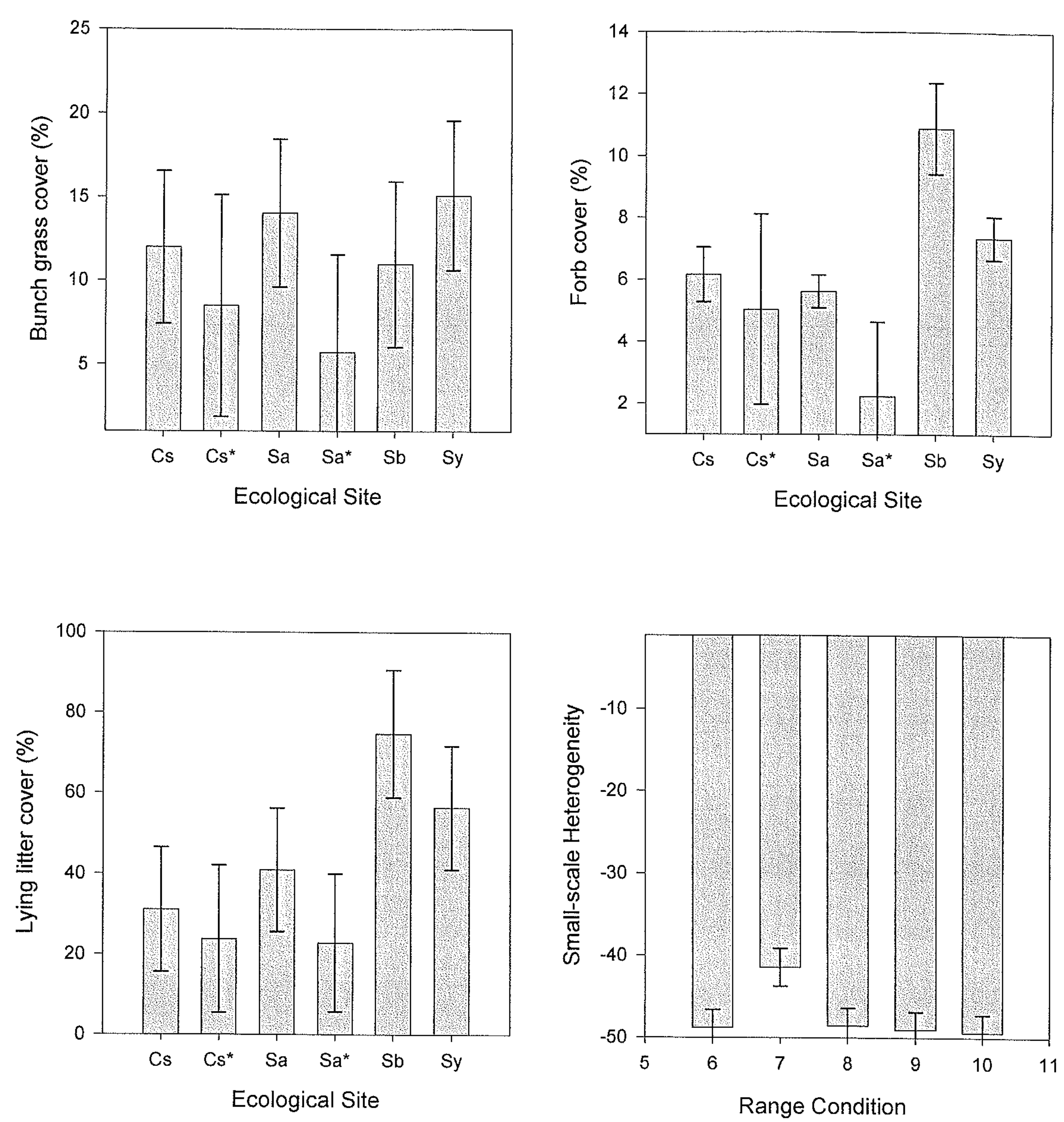

Figure 15. Least squares means (± 1 SE) for best approximating (ΔAIC = 0.0) single factor categorical model selected to explain variation in vegetation during the late vegetation sampling round (early August) on private rangelands in the Nebraska Sandhills, 2003-2004. Ecological sites are: choppy sands (Cs), sands (Sa), sub-irrigated meadow (Sb), and sandy (Sy); * indicates a blowout.

CHAPTER 2: THE INFLUENCE OF GRAZING SYSTEMS ON GRASSLAND BIRD DENSITIES AND SPECIES RICHNESS ON PRIVATE RANGELANDS IN THE NEBRASKA SANDHILLS

Abstract: Grazing is the *de facto* habitat management method used in much of the Nebraska Sandhills, but ranchers use a variety of grazing systems. Our goal was to evaluate the effects of grazing systems on grassland birds. We selected four replicate pastures for each of three grazing treatments; study sites were located on eight private ranches. We estimated densities of grassland bird populations using line transect survey methods and we estimated species richness from our survey data. Sixty species were observed, and long duration systems tended to have highest species richness estimates, as well as the most heterogeneous habitat structure. Differences in species richness among systems were most pronounced in years of limited precipitation. Grasshopper sparrows, western meadowlarks, and brown-headed cowbirds accounted for 70% of our observations. We estimated densities for 14 species and used a model comparison approach to determine the effects of habitat on species' density. Grazing system had a significant effect on the densities of grasshopper sparrow and mourning dove and was useful in explaining variation in the density estimates for vesper sparrow and horned lark. Short duration systems had the highest densities of the most species. Brown-headed cowbird densities were lowest on medium duration systems. The preferred grazing system for grassland bird management will depend on the species for which an area is being managed. Other factors such as drought, grazing intensity, and brown-headed cowbird parasitism rates may be more important factors to consider than grazing system.

INTRODUCTION

Native grasslands are the largest vegetative province on the North American continent, occupying 17% of this landmass (Knopf 1996, 1994). The natural resources found within the continent's midsection were rapidly changed with European settlement. However, the mixed grass prairie, a vegetative province blended of the tallgrass and shortgrass prairies to the east and west, respectively, has remained relatively intact. Mixed grass prairie is a product of grazing, fire, and climate. It follows that sustainable management of this habitat would require a combination of these factors. Grazing influences have changed with the near extirpation of the American bison (*Bison bison*), one of the major native large ungulate grazers, in 1889 (Knopf 1994). Domesticated cattle have replaced replaced bison as the predominate, large ungulate grazer of the mixed grass prairie.

The Sandhills physiographic region is vegetated by a specialized, mixed grass prairie type that originally occupied 7 million ha in Nebraska, South Dakota, and Kansas (Bragg and Steuter 1996). The sandy, erodible substrate of unformed soils has thwarted most efforts to cultivate in the region and has left it relatively unconverted (6-28% conversion rate; Bragg and Steuter 1996). The Sandhills prairie is managed overwhelmingly through cattle grazing (80%; Miller 1998). Thus, grazing remains an ecological factor in the Sandhills. But, the timing, intensity, and duration of this process, through the use of fences that control the movements and behaviors of grazers, have changed the influence grazing has on the biota of the region. Producers in this region (Clark and Coady 1993) have employed rotational grazing systems to improve range utilization and condition, and promote forage and animal production to optimize economic gain (Martin 1978).

Grassland bird populations have declined due to habitat destruction, alteration and fragmentation (Askins 1993, Knopf 1994, 1996, Peterjohn and Sauer 1999, Vickery et al 1999, Vickery and Herkert 2001). Although only 5% of the species in North America are considered grassland endemics (Mengel 1970), evolved within and dependent upon on this habitat for one or more of their life stages, they represent an important component of our continents' biodiversity. However, the cause of population declines is still uncertain, providing justification for studies in the region with the highest diversity (i.e. the Great Plains) for this guild. Informed management of private grassland resources may be crucial to reversing declining population trends and maintaining biodiversity.

The objects of this study were to; 1) estimate and compare species richness among grazing systems, 2) estimate densities of grassland bird species, and 3) determine the causes of variation in grassland bird density.

METHODS

Study Area

We conducted our study on privately owned rangeland in eastern Cherry and northern Thomas counties of the north central portion of the Nebraska Sandhills from 2002 to 2004 (Appendix I: Figure 1). Approximately 432-482 mm of precipitation falls in this semi-arid region (Wilhite and Hubbard 1989). Soils are Valentine-Elsmere-Tryon (Lewis and Kuzila 1998).

We selected participating landowners based upon willingness to cooperate, range management practices, and management history (see Chapter 1 SLFK for study site description). We chose only upland sites to reduce any bias in landscape position, topographical description, or soils associated with wetland and subirrigated meadow sites. We attempted to distribute treatments evenly across the study area. In 2002, we examined three replicates each of long, medium, and short duration grazing systems (see Tables 1 and 2 in Appendix II for a description of grazing treatments). We added an additional replicate per grazing treatment in 2003; thus, a total of twelve study pastures or experimental units were used for the remainder of the study (Appendix I: Figure 2).

Sampling Methods

Bird surveys

We repeatedly surveyed 3,000 meters of transect per pasture to sample for grassland birds. Our design was based on an *a priori* power analysis, which assumed relatively low abundances (10 birds/1,000 m); our goal was to achieve a 0.10coefficient of variance (CV) for our density estimates. We randomly placed one pair of 1500-m, parallel transect lines in each of the long duration pastures, and we placed two pairs of 750–m, parallel transects in medium and short duration pastures (Appendix I: Figure 3). We determined starting direction for transects from each pasture's entrance gate using the spin of a compass. In 2002, we placed parallel transects separated by 125 m in medium and short duration pastures, and transects in long duration pastures were placed 250 m apart. However, in 2003 and 2004, we separated all transects by 250 m in an attempt to increase our sample of independent observations. We marked transects every 50 m with fluorescent surveyor flagging. Geographic coordinates were taken at the starting point of each transect to facilitate relocation of transects between years (see Figure 3 in Appendix I for illustration of study design layout). Each transect pair within the medium and short duration pastures was placed in separate paddocks (a group of paddocks comprises a pasture). In these systems, producers strive to graze a particular paddock during different time periods in subsequent years. Therefore, we divided up the sampling effort between two paddocks by placing each of our transect pairs in paddocks that were temporally separate within the grazing rotation.

Birds were surveyed during three time periods, or rounds, throughout the summer; the rounds were (1) late May to mid-June, (2) late June to early July, and (3) mid-late July (Table 1). During each round, we surveyed all pastures three times on consecutive days, which resulted in nine surveys per pasture per year. We surveyed all treatments during each round, and on a given day, one replicate of each grazing system was surveyed. We varied the order in which pastures were surveyed within the three rounds. Before surveys were conducted, observers were trained in sampling protocol (Anderson 1979) and bird identification (sight and sound). Supplemental training was given in distance estimation.

We conducted surveys within a four to five hour period beginning at sunrise, when conditions were conducive to surveys (< 25 km/hour winds and limited precipitation). Within a survey round, observers were rotated so that no observer surveyed a pasture twice during that round. Observers recorded sighting distance (laser rangefinder) and bearing (hand-held compass) to all individuals or clusters of birds seen and/or heard to the nearest meter and degree, respectively. We recorded measurements to the initial detection location of the individual or center of the cluster and recorded cluster size. We also recorded the method of detection (sight and/or sound) for each bird recorded. Our survey methods followed the recommendations of Buckland et al. (2001);

thus, we assumed that (1) all birds on the transect line were detected, (2) measurements taken were accurate to the nearest meter and degree, (3) birds did not move in response to the observer, and (4) all measurements were made to the initial detection location (Buckland et al. 2001).

Vegetation surveys

2002 vegetation – We measured vegetation structure and composition during three rounds of surveys: 11-19 June, 25 June - 4 July, and 10-18 July. Vegetation structure was measured at 30 points spaced 100-m apart along transects in each pasture. At each point visual obstruction was read (VOR) to the highest decimeter to which the view of the pole was completely obstructed by vegetation. Percent cover of vegetation was estimated into eight cover classes: total, dead, live, grass, forb, woody, bare, and litter using a 20 x 50 m Daubenmire frame (Daubenmire 1959). Cactus and yucca were included in the woody category. Percent cover of vegetation categories was estimated into six cover classes: 1=0-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%. Litter, defined as vegetation forming a horizontal matte covering the ground, was measured to the nearest centimeter in the center of the Daubenmire frame at each point. The tallest plant found within the four meter distance between the Robel pole and the observer was measured and recorded during the second and third rounds of vegetation sampling.

2003-2004 vegetation - At each 100-m transect interval, including zero, a sampling location was randomly selected within a 15-m radius of the interval for a total of thirty-two locations in each pasture. Each random location served as the center of an equilateral triangle with 3.5-m sides (sampling unit). The three nodes of the triangle served as a sampling points resulting in 96 total samples for each pasture (Chapter 1: Figure 1).

We used a 20 x 50-cm Daubenmire frame (Daubenmire 1959) to estimate percent ground cover at each sampling point. Cover classes included estimates of bunch, rhizomatous, and annual grasses, sedges, forbs, shrubs, cactus, yucca, lying (residual vegetation standing ≤45° to the ground) and standing litter (residual vegetation standing at > 45° to the ground), bare soil, and cattle dung. We recorded all percent cover estimates to the nearest 5%, allowing for total cover classes to exceed 100%. Estimated cover of bunch and rhizomatous grass were pooled to create a grass cover category. We recorded visual obstruction readings (VOR) to the nearest quarter decimeter from four directions at right angles (Robel et al. 1970) from a square pole. An average of these four readings was used to describe the vegetation height and density at each sampling point.

We incorporated our VOR means in a modified sampling protocol from Wiens (1974) that allowed us to quantify structural heterogeneity of grassland bird habitat at broad (pasture-level) and fine (patch-level) spatial scales. We refer to these scales as large- and small-scale heterogeneity. Mean small-scale heterogeneity (SSH) for each pasture, *r*, was calculated as:

$$SSH_r = \frac{\left(\sum_{i=1}^{32}\left(Max_{k_i} - Min_{k_i}\right)\right)}{\sum_{i=1}^{32}\bar{x}_{k_i}}$$

where $i = 1, 2, \ldots, 32$ for each sampling unit, $k = 1, 2, 3$ (three sub-samples taken at i), and $\bar{x}_{k_i}$ represents the mean of VOR scores from 3 sub-samples at i. We used the coefficient of variation (CV) to represent large-scale heterogeneity (LSH) for each pasture:

$$LSH = \frac{\sigma}{\bar{x}_i} \times 100$$

$$\text{where} \quad \sigma = SD(\bar{x}_{k_i}).$$

We measured and recorded height of the tallest plant (to the nearest 0.25 dm) located within a 30 cm radius of the sample point, its functional group (grass, forb, shrub, sedge, rush or yucca), and status (alive or dead). Litter depth was measured to the nearest 0.5 cm within 3 cm of the upper right-hand corner of the Daubenmire frame. We also estimated percent cover of all plants based upon origin (native or exotic).

To standardize our vegetation data collection, two of the four observers were trained to measure VOR and the remaining two individuals were trained to estimate percent cover throughout the field season each year. Percent cover observers were rotated such that no observer estimated percent cover on a pasture during both sampling rounds within each year to reduce observer bias.

Statistical Analysis

Species Richness - Estimates of species richness were determined using program SPECRICH2 (White et al. 1978, Rexstad and Burnham 1991). The ability to detect a species depends on the detectability of the species and the skills of the observer. Program

SPECRICH2 uses a closed mark-recapture model to address species detectabilities that are less than one, which is most often the case. Species richness estimates are determined based upon presence-absence data from multiple sites or visits; in this instance, multiple pastures ($i=1, 2 \ldots k$; $k = 3$ in 2002 and $k = 4$ in 2003 and 2004) of each grazing system. The total number of species observed at each pasture for all pastures in each of three grazing systems, $n(i)$ and the total number of species observed at k pastures is recorded. A species is 'captured' and 'marked' when it is initially observed and recorded (determined to be present). Additional detections of the same species are treated as 'recapture' events.

Density - We calculated relative abundance (total number of individuals observed/total survey effort, [birds/m]) for all species observed. We used program Distance (v5.0, Beta 5) to estimate densities for each species with a sample size of ≥ 60 individuals per year. Density estimates were calculated using line transect data analyzed as clusters; cluster size estimation compensated for size bias by regressing the natural log (ln) of cluster size against the estimated detection function, $g(x)$.

We visually inspected the frequency distribution of the observed perpendicular distances to determine the utility of binning the data (Buckland et al. 2001). Frequency histograms of the perpendicular distance data by species within year did not suggest data heaping (i.e. distance measurement rounding errors); therefore, data were not binned. We also used visual inspection to remove outliers through right truncation of the data. We applied species- and year-specific truncation distances (Table 2).

We looked for an observer bias each year for species that had ≥ 60 observations using program Distance V4.1 (release 2) by post-stratifying the data based upon observer and selecting among a five model set using information theoretic selection criteria (AIC) further described below. Chi-Square goodness-of-fit intervals cutpoints were manually determined.

We initially estimated density for each species at three hierarchical levels: sample, strata, and global. The 12 pastures served as our samples. We used the three grazing systems to stratify pastures (long, medium, and short duration grazing). All samples were pooled for a global density estimate (Buckland et al. 2001). We calculated global density estimates as an average of the stratum estimates weighted by total effort in strata, and we treated strata as a fixed effect.

A model selection process was conducted within each of the three levels. We combined three key functions and three adjustment terms to create a five-model set for each of the three detection levels. The five models were created by combining the half normal key function with the cosine and hermite polynomial adjustment terms, the uniform key function with the cosine and simple polynomial adjustment terms and the hazard rate key function with the cosine adjustment term using Distance's conventional distance sampling engine. Program Distance evaluated the models using information criteria (Akaike's Information Criterion, AIC; Buckland et al. 2001). We selected the model with the lowest AIC score as the best model for detection function; when AIC scores were similar (ΔAIC < 2.0), we selected the most parsimonious model (fewest parameters). We evaluated model fit using Kolmogorov-Smirnov goodness-of-fit test ($P>0.05$; Buckland et al. 2001).

Detection of a bird can potentially vary among samples or strata because of habitat features. We used AIC to select the appropriate detection function, g(x), among the sample, strata or global levels to determine density. Selection of a global detection function indicated no difference in detection among strata or samples.

Once we selected the most appropriate level of detection (global, strata, or sample), we evaluated two additional detection function models. These models were created by taking the selected detection function model and adding a single, factor-level covariate. The first covariate accounted for differences in detection of birds based upon our detection method, either auditory or visual. The data were therefore stratified by type of detection: 1) auditory (a), if we observed a bird by sound only or 2) visual (v), if we saw or saw/heard an individual. The model estimated detection functions for each detection type. The second covariate model allowed for differences in detection for birds observed on fences. The 'fence' covariate stratified the data by the initial detection location of a bird as being 1) on a fence or fence post or 2) not on a fence or fence post. We collected this data only during 2003-2004. A basic model selection process was conducted within each of the covariate levels. We combined two key functions and three adjustment terms to create a five model set for each of the covariate models. The five models were created by combining the half normal key function with the cosine, simple, and hermite polynomial adjustment terms and the hazard rate key function with the cosine and simple polynomial adjustment terms. We used Distance's multiple covariates sampling engine for this process. We compared covariate models to the model selected in our initial model selection process using AIC. Key function and expansion terms varied by species and year (Tables 1, 2, 3 in Appendix III). The final detection function model used to estimate densities are found in Table 2 by species and year. Average components of the coefficient of variation can be found in Table 4 of Appendix III.

We used bootstrapping (999 resamples) to determine measures of variance for those species in which the sample or strata level detection functions were used for density estimation (Buckland et al. 2001). Preliminary detection of differences in species density among systems within years and among years within a particular system was done using asymmetric 95% confidence intervals, based on 2.5% and 97.5% quantiles.

To explain variability in density among study sties, we created an *a priori*, limited set of single-factor models based on hypothesized causal mechanisms from literature sources and our observations. We limited our analysis to the most abundant species for which we had at least two years of density estimates. Model components included grazing system (SYST), vegetation structural components, and growing season stocking rate (GsSR) and stocking density (SDEN). We used information theoretic methods to select the best approximating model(s) using AICc values generated in PROC MIXED (SAS Institute 2006). Pasture-level yearly density estimates of the selected species were linearly regressed on the same set of vegetation and grazing variables used in the model selection process, treating year as a random effect. For the remaining species in which we did not construct model sets, effect of system also was tested for using linear regression methods as described above. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Species Richness - We recorded 60 species during our study; twenty-eight species were observed in all three years (Table 3). Three additional species were observed in association with the survey effort (recorded enroute to or from survey transects: warbling vireo [*Vireo gilvus*], wood duck [*Aix sponsa*], and European starling [*Sturnus vulgaris*]. The number of species observed varied among years with 32, 53 and 49 species observed in 2002, 2003, and 2004, respectively. Long, medium, and short duration systems had 35, 34, and 28 observed species (Figure 1a).

Average species counts and species richness estimates tended to decrease as grazing duration decreased (Figure 1a, b). Short duration system species richness estimates (15±4.48, 95% CI) were significantly lower than long duration systems in 2002 (Figure 1b). This was the only significant difference of species richness estimates detected among grazing systems during our study.

Species counts were noticeably higher in 2003 and 2004 than in the first year of our study, on all grazing systems (Figure 1a). Species counts were most similar between 2003 and 2004 (Figure 1a). The greatest number of species was observed on medium duration pastures (2003: 41 and 2004: 42). Species richness estimates in 2003 exhibit a similar positive trend with grazing duration as seen the previous year, although to a lesser degree (Figure 1b).

Abundance and density - We recorded 31,685 observations of 60 species by sampling 890,100 m of transect (Table 4). Three species accounted for approximately 75% of our observations: grasshopper sparrow (*Ammodramus savannarum*; 31.6%), western meadowlark (*Sturnella neglecta* 30.3%), and brown-headed cowbird (*Molothrus ater*; 10.4%; Table 4). Other species comprising up to 10% of the total sample included lark sparrow (*Chondestes grammacus*; 7.6%), upland sandpiper (*Bartramia longicauda;* 3.5%), horned lark (*Eremophila alpestris;* 3.1%), mourning dove (*Zenaida macroura*; 2.4%), vesper sparrow (*Pooecetes gramineus;* 1.5%), lark bunting (*Calamospiza melanocorys;* 1.4%), and red-winged blackbird (*Agelaius phoeniceus*; 1.0%; Table 4). Relative abundances (# individuals observed/survey effort) can be found in Table 4.

We did not detect a consistent observer effect on detection (Table 2). Thus we combined data from observers for density estimation. We estimated densities of fourteen species for which a sufficient sample size (n ≥ 60) was available in at least one year. Species with three years of sufficient data for density estimates included brown-headed cowbird, grasshopper sparrow, lark sparrow, mourning dove, upland sandpiper, and western meadowlark. In addition, common night hawk (*Chordeiles minor*), field sparrow (*Spizella pussila*), horned lark, lark bunting, red-winged black bird, sharp tailed grouse (*Tympanuchus phasianellus*) and vesper sparrow had sufficient data in two of the three years. Density of killdeer (*Charadrius vociferous*) could only be estimated for one year.

We found that grazing system affected densities of grasshopper sparrows, horned larks, and mourning doves (Table 5 and 6; Figures 2, 3, and 4). Densities of species on private rangeland in the Nebraska Sandhills ranged from approximately 90 grasshopper sparrows/100 ha to only one killdeer/100 ha (Table 5). Short duration grazing systems had the highest densities (birds/100 ha) of the most species (7) among grazing systems evaluated, including brown-headed cowbird (33.4), common nighthawk (3.4), lark bunting (9.4), mourning dove (6.8), red-winged black bird (2.2), sharp-tailed grouse (4.1), and western meadowlark (42; Table 5). Field sparrows (3.8), killdeer (1.5), lark sparrow (24.2), upland sandpiper (5.7), and vesper sparrow (3.6) were most abundant on long duration systems (Table 5). Medium duration systems supported highest densities of only two species, grasshopper sparrow (114.6) and horned lark (9.6; Table 5).

Brown-headed cowbird - Private rangelands supported 20.6 brown-headed cowbirds/100 ha, our third most dense species overall. Brown-headed cowbird densities ranged widely from 6.2 (medium duration systems) to 33.4 birds/100 ha (short duration systems; P = 0.111; Table 5 and 6).

Medium duration systems tended to have the fewest and short duration systems the most brown-headed cowbirds in all three years. In 2002, density of brown-headed cowbirds on medium duration pastures (1.1 birds/100 ha, 95% CI = 0.44-2.60; Figure 2) were significantly lower than the other grazing systems examined (long: 12.7 birds/100 ha, 95% CI = 6.9-23.4; short: 12.1 birds/100 ha, 95% CI = 5.7-26.1). In 2003, medium duration systems contained significantly fewer brown-headed cowbirds (3.9 birds/100 ha, 95% CI = 1.23-12.07) than short duration systems (58.7 birds/100 ha, 95% CI = 16.0-215.07; Figure 2). No significant difference among systems was detected in 2004, however, the lowest density was found on medium duration systems (long: 27 birds/100 ha, 95% CI = 16.0-64.1; medium: 13.8 birds/100 ha, 95% CI = 15.4-64.1; short: 29.4 birds/100 ha, 95% CI = 16.0-64.1; Figure 2).

Variation in brown-headed cowbird densities was explained best by two models: tallest vegetation height (AICc = 235.3, $w_i = 0.611$) and bunchgrass cover (ΔAICc = 0.9, $w_i = 0.389$). However, model coefficients were not significantly different from zero (Table 6).

Common Nighthawk - This species occurred at a density of 2.9 birds/100 ha in the Nebraska Sandhills. Medium duration pastures had the lowest nighthawk density (1.9 birds/100 ha, P = 0.211; Table 5). Densities were not calculated for 2002. Density of this species tended to be higher in 2003 than in 2004 (Figure 2).

Field Sparrow - Our study sites averaged 1.6 field sparrows/100 ha (Table 5). Throughout the duration of the study, only one field sparrow was observed on short duration grazing systems. Overall field sparrow density was greatest on long duration systems (3.8 birds/100 ha, P = 0.174; Table 5). This was evident in both 2002 and 2003 in which long duration systems had 5.0 birds/100 ha (95% CI = 1.01-24.35; Figure 2) and 2.6 birds/100 ha (95% CI = 0.52-12.51; Figure 2), respectively. We could not calculate densities for field sparrows in 2004.

Grasshopper Sparrow - This was the most dense species (90 birds/100 ha) found during our study (Table 5). Overall grasshopper sparrow density was highest on medium duration systems (114.6 birds/100 ha) and lowest on long duration systems (56.9 birds/100 ha, P = 0.047; Table 5 and 6, Figure 3). There was significant variability among years within short duration systems; this system had significantly greater grasshopper sparrow densities in 2004 (121.0 birds/100 ha, 95% CI = 92.5-158.4) than the previous year (75.5 birds/100 ha, 95% CI = 62.3-79.8; Figure 2). Densities were similar between 2004 and 2002 (95.5 birds/100 ha, 95% CI = 85.9-118.3; Figure 2). Shrub cover was the best approximating model explaining variation in density of this species with 65% of the weight in the model set (AICc = 246.1; Table 6). The single factor, early large-scale heterogeneity model also had substantial empirical support (ΔAICc = 1.2, w_i = 0.35; Table 6). Grasshopper sparrow densities showed a significant linear relationship with early large scale heterogeneity (β=-0.745, SE = 0.31; Table 6), VOR (β=196.9, SE = 51.58; Table 6), system (P=0.047; Table 6, Figure 3), and litter depth (β=266.65, SE = 61.12).

Horned Lark - Private rangeland in the Nebraska Sandhills supported 7.1 horned larks/100 ha (Table 5). Medium duration pastures had the greatest average density of horned larks (9.6 birds/100 ha, P = 0.501; Table 5 and 6). This trend was consistent in both 2003 and 2004 (Figure 2). The density of horned larks tended to be greater in 2004 than in 2003. Densities were not estimated for this species in 2002 ($n<60$). The grazing system model was selected as the best approximating model (AICc = 157.1, $w_i = 0.74$; Table 6), with some support for the VOR model (ΔAICc = 3.0, $w_i = 0.164$; Table 6).

Killdeer - Private rangeland in the Nebraska Sandhills supported 0.89 killdeer/100 ha (Table 5). Densities decreased with grazing duration (long: 1.53 birds/100 ha, 95% CI = 0.33-7.14; medium: 0.90 birds/100 ha, 95% CI = 0.36-2.27; short: 0.24 birds/100 ha, 95% CI = 0.11-0.52). We could only calculate densities of killdeer in 2003.

Lark Bunting - Lark bunting density was 4.4 birds/100 ha (Table 5). Short duration systems had the highest density of lark buntings (D = 9.4 birds/100 ha, P = 0.193; Table 5). An abundance of only 16 individuals was observed in 2003; densities were estimated only for 2002 and 2004. Long duration systems had consistently lower densities than short duration systems in both 2002 (long: 0.11 birds/100 ha, 95% CI = 0.02-0.57; short: 13.6 birds/100 ha, 95% CI = 5.5-33.2; Figure 2) and 2004 (long: 0.18 birds/100 ha, 95% CI = 0.03-0.90; short: 5.3 birds/100 ha, 95% CI = 1.1-25.8; Figure 2). Bunting abundance was variable among years on medium duration pastures. Density estimates on medium duration pastures ranged from less than one individual/100 ha (95% CI = 0.02-0.57) in 2002, and almost seven individuals/100 ha (95% CI = 1.4-34.8) in 2004. Variability also was observed on short duration pastures (2002: D = 13.5 birds/100 ha, 95% CI = 5.54-33.16; 2004: D = 5.3 birds/100 ha, 95% CI = 1.09-25.79; Figure 2).

Lark Sparrow - We estimated 18.1 lark sparrows/100 ha on private rangelands in the Nebraska Sandhills (Table 5). Although grazing system did not significantly affect densities of this sparrow (P = 0.151; Table 5 and 6), long duration pastures supported the highest density (24.21 birds/100 ha). The shrub model provided the best explanation in variation of densities of lark sparrows (AICc = 192.5, w_i = 0.917; Table 6). Lark sparrow densities varied with the amount of lying litter (β = -0.566, SE = 0.24), bare soil (β = 0.537, SE = 0.17), and growing season stocking rate (β = -5.728, SE = -2.42; Table 6).

Mourning Dove - Mourning dove density in the Nebraska Sandhills was 5.6 birds/100 ha (Table 5). Medium duration systems supported the lowest density of mourning doves (3.72 birds/100 ha, P = 0.010; Table 5, Figure 4). In 2002, medium duration systems had significantly fewer birds/100 ha (1.3 birds/100 ha, 95% CI = 0.73-2.32) than long (3.5 birds/100 ha, 95% CI = 2.65-4.58) and short duration systems (3.8 birds/100 ha, 96% CI = 2.83-5.18; Figure 2). We estimated significantly fewer mourning doves for both long and short duration grazing systems in 2002 (long: 3.48, 95% CI = 2.65-4.58; short: 3.83, 95% CI = 2.83-5.18; Figure 2), than in 2004 (long: 7.8, 95% CI = 5.61-10.84; short: 9.0, 95% CI = 5.70-14.24; Figure 2). Medium duration systems had significantly greater densities in 2003 (5.77 birds/100 ha, 95% CI = 2.94-11.3) and 2004 (4.1 birds/100 ha, 95% CI = 2.86-5.87) than in 2002 (1.30 birds/100 ha, 95% CI = 0.73-2.32; Figure 2). The grazing system model was selected as the best model (AICc = 154.7, w_i = 0.996; Table 6).

Red-winged Blackbird - Red-winged blackbird density was 1.1 birds/100 ha (Table 5). Short duration pastures had the highest density of this species (2.21 birds/100 ha, P = 0.384). In 2003, short duration systems had greater density of this species (4.20 birds/100 ha, 95% CI = 1.01-17.42) than long duration systems (0.3 birds/100 ha; 95% CI = 0.15-0.67; Figure 2). Density estimates were not calculated for 2002.

Sharp-tailed Grouse - We estimated 3.0 sharp-tailed grouse/100 ha on private Nebraska Sandhills rangeland (Table 5). Short duration systems supported the highest overall density of this species (4.1 birds/100 ha, P = 0.238; Table 5). In 2003, long duration systems had significantly fewer grouse (0.77 birds/100 ha, 95% CI = 0.42-1.42) than did short duration systems (5.1 birds/100 ha, 95% CI = 1.86-13.96; Figure 2). We did not estimate densities for 2002.

Upland Sandpiper - Upland sandpiper densities were similar among grazing systems (long: 5.7, medium: 5.2, short: 5.5 birds/100 ha; P = 0.899) and averaged 5.5 birds/100 ha on private rangelands in the Nebraska Sandhills (Table 5). On both long and short duration systems, we recorded fewer birds in 2002 (long 1.16 birds/100 ha, 95% CI = 0.40-3.37; short: 2.04, 95% CI = 1.10-3.78) than in 2004 (long: 7.0 birds/100 ha, 95% CI = 3.76-13.02; short: 6.32 birds/100 ha, 95% CI = 4.30-9.28; Figure 2). The shrub model was selected as best explaining variation in upland sandpiper density (AICc = 133.3, $w_i = 0.917$; Table 6). Density decreased with increasing shrub cover ($\beta = -1.06$; SE = 0.47).

Vesper Sparrow - Average vesper sparrow density was 2.5 birds/100 ha on our Nebraska Sandhills study site. Vesper sparrows were most abundant on long duration grazing systems (3.6 birds/100 ha) and lowest on medium duration systems (1.5 birds/100 ha, P = 0.365; Table 5). This trend was observed during years in which densities were estimated (2003 and 2004).

Western Meadowlark - Private rangelands in the Nebraska Sandhills support 36.8 western meadowlarks/100 ha (Table 5). Western meadowlark densities increased as grazing duration decreased (long: 29.1, medium: 39.3, and short: 42.0 birds/100 ha; P =

0.065; Table 5). This average trend was most apparent in 2004. Within grazing, western meadowlark densities tended to increase with year (Figure 2). This trend was significant in medium (2003: 34.76 birds/100 ha, 95% CI = 28.53, 38.61; 2004: 63.31, 95% CI = 49.12, 81.61) and short duration systems during the last two years of our study (2003: 32.91, 95% CI = 28.53-38.58; 2004: 70.52, 95% CI = 61.83-80.43; Figure 2). The bunchgrass model (AICc = 195.2; $w_i = 0.731$) explained most of the variation in western meadowlark densities. As bunchgrass cover in pastures increased, densities increased ($\beta = 1.52$, SE = 0.59; Table 6). Meadowlark densities increased with VOR ($\beta = 54.52$, SE = 15.15), litter depth ($\beta = 54.86$, SE = 17.20), and late-season, large-scale heterogeneity ($\beta = -0.27$, SE = 0.11).

DISCUSSION

Species Richness - Species richness decreased with grazing duration. This trend was most apparent in 2002, a year of limiting precipitation. As drought conditions were ameliorated, the relationship between species richness and grazing system changed as systems became more similar. This suggests that precipitation may be a factor effecting bird species richness in the Nebraska Sandhills. Short duration grazing systems may not be as resilient (maintaining bird species richness) in times of drought as compared to long and medium duration systems.

Bird species richness is affected by vegetation structure (Wiens 1974, Cody 1985). In habitats with multiple levels of vegetation structure such as forests, the relationship between habitat structure and species richness is readily apparent (MacArthur and MacArthur 1961). Although vegetation structure in grasslands may not be as diverse as that found in forests (Cody 1985), it would still be reasonable to expect lower species richness in grasslands that have less variation in their vegetation canopy. In Argentina, bird species richness was primarily influenced by vegetation structure and secondarily by the first climatic factor (precipitation gradient, humidity, frost occurrence, and amplitude; Cueto and de Casenave 1999). Bohning-Gaese (1997) showed that species diversity at a given scale is related to the spatial heterogeneity at that scale.

Although grazing systems were similar in average percent vegetative cover values (Chapter 1, SLFK), systems were different in structural heterogeneity (variability in height and density as measured by VOR). Rotational systems were relatively more homogeneous as compared to long duration systems at both a small- and large spatial scale (Chapter 1, SLFK). In short duration grazing systems cattle are forced to graze all plants by reducing the selective grazing behaviors of cattle. This increases the competitive advantage of some plant species and results in decreased plant species composition. Evenly grazed pastures, such as those found in short duration grazing systems, may have both lower plant species diversity and lower bird species richness, especially during times of water stress. However, Schneider (1998) showed that species richness was higher on rotational systems in North Dakota suggesting that other factors may influence species richness other than grazing system.

In a North Dakota study examining the effects of drought on grassland birds, species richness decreased during severe drought. Bird species richness was affected by decreasing the abundance of common species and removing several less common species (George et al. 1992). Species richness exhibited a greater decline on pastures in fair relative to good condition. The authors recommend adjusting grazing intensity to promote higher condition range and manage for drought to help maintain range production and bird species richness (George et al. 1992).

Dependent on species, densities of our most abundant birds were similar to, lesser, or greater than densities reported from the Nebraska Sandhills, the Great Plains region, and other grassland habitat types. Faanes and Lingle (1995) reported 18 pairs of grasshopper sparrows/km^2 on uplands near the Platte River in Nebraska. Grasshopper sparrow densities ranged from 4.0 to 7.5 territories/42 ha on grazed areas in the Nebraska Sandhills (Anderson 1992). In a regional study of the use of CRP by grassland birds, Johnson and Schwartz (1993) reported approximately 20-22 indicated breeding pairs/100 ha. Although different measures of bird density were used, grasshopper sparrow densities reported were all lower than the 89.7 birds/100 ha recorded on our study area. Our pooled density estimate for brown-headed cowbirds was 20.6 birds/100 ha. Faanes and Lingle (1995; 5.6 pairs/ km^2) and Johnson and Schwartz (1993; 4-7 indicated breeding pairs/100 ha) reported lower densities of cowbirds. Our meand lark sparrow density was 18.3 birds/100 ha. This was lower than Walcheck's (1970) lark sparrow density estimate in Montana of 18 pairs/40 ha, but greater than densities reported by Faanes and Lingle (1995; 4.2 pairs/ km^2) and Anderson (1992; 1.2 to 4.8 territories/42 ha). We observed western meadowlarks at a density of 36.8 birds/100 ha. Anderson (1992) reported a range of 4.0 to 7.5 territories/42 ha; thus our study supported numbers similar to that found at the high range of Anderson (1992). Similar density of meadowlarks was observed by Faanes and Lingle (1995) (19 pairs/km^2). George et al. (1992) reported a range of meadowlark densities from 20-35 birds/km^2 in a North Dakota study; this was also similar to those observed during our study.

Although short duration systems supported the highest densities of the most species (seven; Table 5), species components of rangeland avifauna in the Nebraska Sandhills responded differently or not at all to grazing systems examined in this study (Figure 5). Of the species responses that were statistically significant, the actual relationship varied. Medium duration systems examined in this study supported both the highest densities of grasshopper sparrows and horned larks and the lowest densities of mourning doves.

In a North Dakota study, Schnieder (1998) reported no difference in grasshopper sparrow densities between rotational and season long grazing regimes, although relative grasshopper sparrow abundances were higher on rotational systems. Messmer (1985) also working in North Dakota had grasshopper sparrows in greatest abundance on twice-over rotational systems. Anderson (1992) reported a significant effect of grazing system on grasshopper sparrow density; highest densities were on long duration systems. Messmer (1985) recorded higher horned lark densities on twice-over and short duration grazing systems than long duration systems. Anderson (1992) reported the highest densities of horned larks (species was absent from short duration systems) on long duration systems.

Both grazing (Saab et al. 1995, Kantrud and Kologoski 1982) and grazing system (Salo et al. 2002) may elicit different responses from different grassland birds. These responses also may vary depending on grassland types (Wiens and Dyer 1975) making the interpretation of the relationships between grazing and wildlife complex (Kirsch et al. 1978).

Direction grazing duration trends - Excluding the three species discussed above, we detected no effect of grazing system effect on the densities of the remaining 11 species for which we calculated densities (Figure 5). There were some noticeable trends, however. Some of these trends were significant depending on year. Four species exhibited a negative trend with grazing duration. Sharp-tailed grouse and red-winged blackbird densities were highest on short duration systems, both significantly so in 2003. Rotational systems always had the highest densities for lark buntings. Western meadowlarks tended to have highest densities on short duration systems and lowest densities on long duration systems, except in 2003, in which rotational systems were similar, but still had higher densities than long duration systems. Killdeer increased as grazing duration increased during the year in which abundances were sufficient to calculate densities.

Other grazing duration trends - We observed other types of trends among grazing systems; for some species, a particular grazing system consistently had higher or lower densities estimates (Figure 5). Lark sparrows were consistently most dense on long duration systems while medium duration systems consistently had the lowest densities of this species. Medium duration systems consistently had the lowest densities of brown-headed cowbirds in all three years of this study, which may have important implications for host species' productivity. Short duration systems supported the highest overall densities of the nest parasite. Common nighthawks were least dense on medium duration systems.

Precipitation - Our study was initiated during a drought year in which annual precipitation was approximately half of the 30 year average. Total annual precipitation increased with each year (Chapter 1: Figure 2). Annual density trends (significant and non significant) were noted for some species, some trends were universal among treatments and other yearly trends were specific to systems. Densities of the horned larks increased from an insufficient sample size in 2002 (< 60) to highest densities calculated in 2004. Western meadowlark and horned lark densities increased with year. For the meadowlark, this increase was significant on medium and short duration systems. Vesper sparrows, absent from surveys in 2002, increased in density with year on long and medium duration systems.

The impact of grazing systems on a particular species may vary with year (i.e. precipitation and temperature). Under precipitation limiting conditions, medium duration systems provide the highest densities of grasshopper sparrows. As moisture conditions improve, short duration systems become more similar to medium duration systems. Long duration systems supported the lowest average densities in this study, but still supported much higher densities than reported on upland prairie in the Nebraska Sandhills region by Faanes and Lingle (1995) and on long duration systems in the Nebraska Sandhills (7.5 territories/42 ha; Anderson 1992). Therefore, rotational systems, particularly medium duration, have greater densities of grasshopper sparrows, especially under drought conditions.

In mixed grass prairie of North Dakota, George et al. (1992) showed that during a severe drought, densities of several of the common species found in a North Dakota grassland decreased significantly. Four of the six species which experienced declines, increased to pre-drought densities the year following drought (George et al. 1992). Grasshopper sparrow density significantly decreased during drought and recovered to pre-drought densities the following year (George et al 1992). Western meadowlark densities did not vary throughout the duration of the pre- and post-drought study in North Dakota. Major declines in migratory bird species in Michigan and Wisconsin corresponded with severe drought years (Blake et al.1992). Igl and Johnson suggested that trends (1967 to 1992-93) in some North Dakota bird populations probably decreased due to drought conditions (Igl and Johnson 1997). The density of grassland birds commonly found in east-central North Dakota was most correlated with the amount of spring (April May) precipitation (Cody 1985). However, a species response to weather will depend on the respective species' ecology (Cody 1985). Grasshopper sparrow density was correlated with yearly precipitation while western meadowlarks showed no correlation with precipitation or temperature variables (Cody 1985). A reflection of the variability in grasslands climate, the resources of grassland birds, should also be somewhat unpredictable (Cody 1985). The response of grassland birds to drought may depend on drought conditions, the composition of the bird community, overall climate and vegetation of a site.

Vegetation structure - Vegetation structure (shrub cover, grass cover, VOR, and litter depth) was more important to explaining variation in species densities than grazing system. Grassland birds are known to respond to habitat structure (Cody 1985, Rotenberry and Wiens 1980, Bock et al. 1993). The responses of grassland bird density to vegetation measures depend on region, year, and species (Winter et al. 2005). Management should address this by provide variation in vegetation structure (Winter et al. 2005). Grasshopper sparrow densities increased with shrub cover, VOR and litter depth, but decreased with early large-scale heterogeneity. In North Dakota, Schneider

(1998) also found that grasshopper sparrow densities were positively associated with these same measurements, among others. Rottenberry and Wiens (1980) found grasshopper sparrow abundance positively correlated with litter depth. The authors also reported an inverse relationship with variation in forb and/or shrub heights. This measure could be interpreted as a measure of heterogeneity which would support our inverse relationship with early large-scale heterogeneity. However, in aWest Virginia study, Whitmore (1981) recommends managing habitat for grasshopper sparrows that has low vegetation density, letter depth, litter and shrub cover as found in early grassland successional stages suggesting that responses of this species may vary with region.

Western meadowlark density increased with bunchgrass cover, VOR and litter depth and decreased with large scale heterogeneity during August. This response is similar to grasshopper sparrows by having a positive relationship with VOR and litter depth. Schneider (1998) also reported a positive relationship between meadowlark densities and grass cover and litter depth. Suitable habitat for western meadowlarks encompasses a wide range of vegetation heights and densities, avoiding extremes (Dechant et al. 1999).

Brown-headed cowbird density was positively related to tallest plant height. Densities of this species decreased with bunchgrass cover. This may reflect both their breeding and foraging habits, respectively. Taller vegetation proves perch sites to search for host nests and reduced grass cover facilitates ground foraging behavior. Johnson and Schwartz (1993) also showed a negative relationship between cowbird densities and grass cover. However, Schneider(1998) examining the effects of rotational and traditional season long grazing systems on grassland birds, reported that brown-headed cowbird densities were positively related to grass cover, litter depth and shrub cover

Lark sparrow density was positively related to shrub cover, bare soil, and lying litter. Densities of this sparrow had an inverse relationship with growing season stocking rate. The feeding and breeding habitat of this species may be reflected by the availability of bare ground (feeding sites) and shrubs (nesting substrate; Martin and Parrish 2000) Nests of this species are often found near or at the base of shrubs. Two keys to management for lark sparrow habitat include providing a shrub component and allowing moderate grazing (Dechant et al. 1999). Although lark sparrows tend to select grazed areas (Lusk et al. 2003), our data suggest high levels of grazing could reduce lark sparrow densities. Lusk et al. (2003) recommended that management for this species include moderate levels of litter accumulation and bare ground.

Upland sandpiper densities were inversely related to amount of shrub cover. One component of suitable habitat for upland sandpipers is low woody cover (Dechant et al. 1999).

SUMMARY

Although our data illustrate that under some conditions long duration systems provide the greatest species richness and that the highest densities of some species may be found on rotational grazing systems, it more strongly suggests that there is not an ideal grazing system treatment for the conservation and management of all grassland birds. At a local level, managers should have site specific goals that target a particular suite of specific grassland species. These goals, however, should be framed within a landscape context. Therefore, to most appropriately place the conservation of grassland birds into a larger context, managers should not operate solely within the confines of their property boundaries. It is acceptable and even desirable for different wildlife management areas or ranches to provide different types of habitat for different suites of grassland birds using a variety of grazing systems. This helps to emulate the historical large-scale landscape heterogeneity grassland birds most likely evolved with and supports grassland bird biodiversity at a larger scale.

To reach a level of compatibility between grassland bird conservation and profitable range management one common goal must be obtained, healthy grasslands. This is often done by preventing overgrazing and managing for drought. This can be particularly important in a semi-arid region such as the Nebraska Sandhills. The concept of maintaining landscape heterogeneity (providing variable types and stages of habitat structure) increases the resilience of an ecosystem, helping to recover bird populations and maintaining healthy, harvestable grasslands. Grasslands, by nature, are expansive. Thus proper management of this ecosystem should occur on a landscape scale which provides a matrix of various habitat structures supporting a variety of different grassland birds. Given the size and continuity of the Nebraska Sandhills, landscape management is possible, theoretically. None of the grazing system treatments we examined proved detrimental to grassland birds; all systems appeared to support grassland bird community and individual species populations. This is due in part to appropriate grazing pressure for the region (Chapter 1, SLFK). Therefore, it is advisable to maintain a matrix of grassland habitat types for grassland birds on private Nebraska Sandhills rangeland through the use of a variety of grazing systems.

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Table 1. Dates during which birds were surveyed, by round, on private lands in the Nebraska Sandhills, 2002-2004.

Year	Round 1	Round 2	Round 3
2002	4-19 June	23 June-6 July	7-22 July
2003	26 May-13 June	25 June-10 July	11-28 July
2004	20 May-7 June	22 June-10 July	12-27 July

Table 2. Data filter (right truncation distance in meters) and sample size (n) used in selected density function model with covarites (if applicable) to determine densities of birds in program Distance (v5.0 Beta 5) on private rangeland in the Nebraska Sandhills, 2002-2004. Results of observer effect test also are listed.

Species	Truncation distance (m)	n	Observer bias	Detection function[b]	Covariate[c]
Brown-headed cowbird					
2002	138	156	yes	strata	-
2003	168	321	no	strata	-
2004	146	809	no	sample	-
average	151				
Common nighthawk					
2002	--[a]		--[a]	.	.
2003	216	88	no	global	-
2004	211	119	no	global	-
average	214				
Field sparrow					
2002	299	68	yes	global	-
2003	262	104	yes	global	av
2004	--[a]		--[a]	.	.
average	281				
Grasshopper sparrow					
2002	170	2,585	no	sample	-
2003	122	3,448	yes	sample	-
2004	98	3,610	yes	strata	-
average	130				
Horned lark					
2002	--[a]	.	--[a]	.	.
2003	246	297	no	sample	-
2004	201	433	yes	global	-
average	224				
Killdeer					
2002	--[a]	.	--[a]	.	.
2003	250	43	no	strata	-
2004	--[a]	.	--[a]	.	.
average	250				
Lark bunting					
2002	129	120	no	global	-
2003	--[a]	.	--[a]	.	.
2004	160	172	yes	global	-
average	145				

Lark sparrow					
2002	199	499	yes	strata	-
2003	204	741	yes	sample	-
2004	240	727	no	global	-
average	214				
Mourning dove					
2002	106	62	no	strata	-
2003	305	188	yes	global	-
2004	245	341	no	global	av
average	219				
Red-winged blackbird					
2002	--[a]	.	--[a]	.	.
2003	274	58	no	strata	-
2004	234	41	no	strata	-
average	254				
Sharp-tailed grouse					
2002	--[a]	.	--[a]	.	.
2003	230	46	no	sample	-
2004	174	74	no	sample	-
average	202				
Upland sandpiper					
2002	166	57	no	strata	-
2003	none	442	yes	sample	av
2004	288	451	yes	global	-
average	227				
Vesper sparrow					
2002	--[a]	.	--[a]	.	.
2003	298	221	yes	strata	-
2004	163	210	no	strata	-
average	231				
Western meadowlark					
2002	249	1,270	no	sample	-
2003	277	3,000	yes	sample	-
2004	196	4,447	yes	strata	-
average	241				

---

[a]: data insufficient (n<60) to calculate density

[b]: sample= pasture level, strata = grazing system level, global = pooled

[c]: av = auditory/visual clues, fence = initial observation location (on or off of a fence)

Table 3. List of sixty species observed on private lands by year and grazing system in the Nebraska Sandhills, 2002-2004.

AOU code	Common name	Scientific name	Study[a]	2002[b]	2003	2004
AMCR	American crow	*Corvus brachyrhynchos*	x	L	L, M, S	L ,M
AMGO	American goldfinch	*Carduelis tristis*	x	L, S	L, M	L ,M
AMKE	American kestrel	*Falco sparverius*			L, M, S	L ,M
AWPE	American white pelican	*Pelecanus erythrorhynchos*			S	S
BANS	Bank swallow	*Riparia riparia*			S	M, S
BARS	Barn swallow	*Hirundo rustica*			L, M, S	L, M, S
BEVI	Bell's vireo	*Vireo bellii*	x	L	L	L
BHCO	Brown-headed cowbird	*Molothrus ater*	x	L, M,	L, M, S	L, M, S
BLGR	Blue grosbeak	*Guiraca caerulea*				L, M
BOBO	Bobolink	*Dolichonyx oryzivorus*			M, S	M, S
BRTH	Brown thrasher	*Toxostoma rufum*	x	L	L, M	L, M, S
BWTE	Blue-winged teal	*Anas discors*		S	M	
CAGO	Canada goose	*Branta canadensis*				S
CHSW	Chimney swift	*Chaetura pelagica*			L, M	
CLSW	Cliff swallow	*Petrochelidon pyrrhonota*			L, S	L, M
COGR	Common grackle	*Quiscalus quiscula*		M		L, S
CONI	Common nighthawk	*Chordeiles minor*	x	L, M	L, M, S	L, M, S
COSN	Common snipe	*Gallinago gallinago*			L	
COYE	Common yellowthroat	*Geothlypis trichas*			M	
DICK	Dickcissel	*Spiza americana*	x	L, M	M, S	M, S
EAKI	Eastern kingbird	*Tyrannus tyrannus*	x	L, M	L, M, S	L, M, S
FISP	Field sparrow	*Spizella pusilla*	x	L, M,	L, M	L, M
GADW	Gadwall	*Anas strepera*			S	
GBHE	Great blue heron	*Ardea herodias*			L	
GHOW	Great horned owl	*Bubo virginianus*				M
GPCH	Greater prairie chicken	*Tympanuchus cupido*	x	L, M,	M, S	L, M, S
GRCA	Gray catbird	*Dumetella carolinensis*		L		
GRSP	Grasshopper sparrow	*Ammodramus savannarum*	x	L, M,	L, M, S	L, M, S
GRYE	Greater yellow legs	*Tringa melanoleuca*			S	

HOLA	Horned lark	*Eremophila alpestris*	x	L, M,	L, M, S	L, M, S
INBU	Indigo bunting	*Passerina cyanea*		L		
KILL	Killdeer	*Charadrius vociferus*	x	L, M	L, M, S	L, M, S
LARB	Lark bunting	*Calamospiza melanocorys*	x	L, M,	M	L, M, S
LASP	Lark sparrow	*Chondestes grammacus*	x	L, M,	L, M, S	L, M, S
LBCU	Long-billed curlew	*Numenius americanus*	x	L	M, S	L, M, S
LOSH	Loggerhead shrike	*Lanius ludovicianus*			L, M	M, S
MALL	Mallard	*Anas platyrhynchos*	x	L	L, M, S	L, M
MODO	Mourning dove	*Zenaida macroura*	x	L, M,	L, M, S	L, M, S
NOBO	Northern bobwhite	*Colinus virginianus*			M, S	
NOFL	Northern flicker	*Colaptes auratus*			L, M, S	L, S
NOHA	Northern harrier	*Circus cyaneus*	x	L	L, M, S	M
NOPI	Northern pintail	*Anas acuta*				M
NRWS	Northern rough-winged swallow	*Stelgidopteryx serripennis*			L, M, S	L, M, S
OROR	Orchard oriole	*Icterus spurius*	x	L	L, S	L, M
RPHE	Ring-necked pheasant	*Phasianus colchicus*	x	M, S	L	S
RTHA	Red-tailed hawk	*Buteo jamaicensis*			L, M, S	L, M
RWBL	Red-winged blackbird	*Agelaius phoeniceus*	x	L, M	L, M, S	L, M, S
SEOW	Short-eared owl	*Asio flammeus*			L, S	
SPTO	Spotted towhee	*Pipilo maculatus*	x	L	L, M	L
STGR	Sharp-tailed grouse	*Tympanuchus phasianellus*	x	L, M,	L, M, S	L, M, S
SWHA	Swainson's hawk	*Buteo swainsoni*			M, S	L, M, S
TRES	Tree swallow	*Tachycineta bicolor*			M	L, M, S
TUVU	Turkey vulture	*Cathartes aura*			L, M, S	L, M, S
UPSA	Upland sandpiper	*Bartramia longicauda*	x	L, M,	L, M, S	L, M, S
VESP	Vesper sparrow	*Pooecetes gramineus*			L, M, S	L, M, S
WEKI	Western kingbird	*Tyrannus verticalis*	x	L, M	M, S	L, M, S
WEME	Western meadowlark	*Sturnella neglecta*	x	L, M,	L, M, S	L, M, S
WILL	Willet	*Catoptrophorus semipalmatus*	x	L	L, M, S	L, M, S
WIPH	Willson's phalarope	*Phalaropus tricolor*			L, S	M
YHBL	Yellow-headed blackbird	*Xanthocephalus xanthocephalus*			M, S	L, M

[a]: x=present during all three years of the study (28 species)

[b]: species presence, by year on L=long, M=medium, and/or S=short duration grazing systems. Initial indicates presence on that system. Thirty-two, 53, and 49 species were seen during 2002, 2003, and 2004, respectively.

Table 4. Relative abundance (number of individuals per meter of transect) of species observed on private rangeland in the Nebraska Sandhills, 2002-2004. See Table 3 for species codes. N = total number of individuals (2002-2004), n = yearly total number of individuals, l = yearly effort expended to survey for individuals (meters walked), and L = total effort expended to survey for individuals (meters walked, 2002-2004). Species are listed in decreasing order.

Species	N	%	n/l[a] 2002	n/l[b] 2003	n/l[c] 2004	N/L pooled
GRSP	10,010	31.6%	0.010733	0.011209	0.011668	0.011246
WEME	9,590	30.3%	0.005510	0.010516	0.014983	0.010774
BHCO	3,306	10.4%	0.001305	0.004663	0.004575	0.003714
LASP	2,393	7.6%	0.002267	0.002848	0.002845	0.002688
UPSA	1,100	3.5%	0.000288	0.001543	0.001640	0.001236
HOLA	978	3.1%	0.000156	0.001187	0.001718	0.001099
MODO	771	2.4%	0.000350	0.000761	0.001359	0.000866
VESP	482	1.5%	0.000000	0.000702	0.000788	0.000542
LARB	436	1.4%	0.000568	0.000049	0.000871	0.000490
UNKN	429	1.4%	0.000000	0.000331	0.000995	0.000482
RWBL	312	1.0%	0.000037	0.000739	0.000198	0.000351
FISP	299	0.9%	0.000329	0.000377	0.000300	0.000336
CONI	259	0.8%	0.000016	0.000340	0.000448	0.000291
STGR	192	0.6%	0.000086	0.000226	0.000303	0.000216
KILL	178	0.6%	0.000033	0.000195	0.000331	0.000200
EAKI	87	0.3%	0.000012	0.000114	0.000145	0.000098
SPTO	74	0.2%	0.000041	0.000062	0.000136	0.000083
BARS	68	0.2%	0.000000	0.000056	0.000154	0.000076
BEVI	58	0.2%	0.000049	0.000040	0.000102	0.000065
LBCU	56	0.2%	0.000004	0.000087	0.000083	0.000063
WILL	54	0.2%	0.000008	0.000096	0.000065	0.000061
AMCR	51	0.2%	0.000016	0.000087	0.000059	0.000057
AMGO	50	0.2%	0.000103	0.000059	0.000019	0.000056
DICK	40	0.1%	0.000012	0.000031	0.000083	0.000045
GPCH	38	0.1%	0.000037	0.000022	0.000068	0.000043
NRWS	34	0.1%	0.000000	0.000015	0.000090	0.000038
CLSW	28	0.1%	0.000000	0.000043	0.000043	0.000031
WEKI	28	0.1%	0.000008	0.000025	0.000056	0.000031
AMKE	27	0.1%	0.000000	0.000037	0.000046	0.000030
BRTH	25	0.1%	0.000037	0.000022	0.000028	0.000028
MALL	23	0.1%	0.000004	0.000053	0.000015	0.000026

TUVU	19	0.1%	0.000000	0.000025	0.000034	0.000021
OROR	18	0.1%	0.000004	0.000022	0.000031	0.000020
RTHA	18	0.1%	0.000000	0.000037	0.000019	0.000020
BANS	15	0.0%	0.000000	0.000009	0.000037	0.000017
YHBL	15	0.0%	0.000000	0.000028	0.000019	0.000017
AWPE	14	0.0%	0.000000	0.000012	0.000031	0.000016
SWHA	13	0.0%	0.000000	0.000012	0.000028	0.000015
NOFL	11	0.0%	0.000000	0.000022	0.000012	0.000012
COGR	10	0.0%	0.000008	0.000000	0.000025	0.000011
RPHE	10	0.0%	0.000025	0.000003	0.000009	0.000011
TRES	10	0.0%	0.000000	0.000003	0.000028	0.000011
BOBO	8	0.0%	0.000000	0.000015	0.000009	0.000009
BLGR	7	0.0%	0.000000	0.000000	0.000022	0.000008
GADW	7	0.0%	0.000000	0.000022	0.000000	0.000008
LOSH	6	0.0%	0.000000	0.000006	0.000012	0.000007
NOHA	5	0.0%	0.000004	0.000009	0.000003	0.000006
WIPH	4	0.0%	0.000000	0.000009	0.000003	0.000004
BWTE	3	0.0%	0.000004	0.000006	0.000000	0.000003
GBHE	3	0.0%	0.000000	0.000009	0.000000	0.000003
NOBO	2	0.0%	0.000000	0.000006	0.000000	0.000002
SEOW	2	0.0%	0.000000	0.000006	0.000000	0.000002
CAGO	1	0.0%	0.000000	0.000000	0.000003	0.000001
CHSW	1	0.0%	0.000000	0.000003	0.000000	0.000001
COSN	1	0.0%	0.000000	0.000003	0.000000	0.000001
COYE	1	0.0%	0.000000	0.000003	0.000000	0.000001
GHOW	1	0.0%	0.000000	0.000000	0.000003	0.000001
GRCA	1	0.0%	0.000004	0.000000	0.000000	0.000001
GRYE	1	0.0%	0.000000	0.000003	0.000000	0.000001
INBU	1	0.0%	0.000004	0.000000	0.000000	0.000001
NOPI	1	0.0%	0.000000	0.000000	0.000003	0.000001
	31,685					

[a]: l = 243,000 m

[b]: l = 323,400 m

[c]: l = 323,700 m

Table 5. Density estimates (birds/100 ha) for select species on three grazing systems (long, medium, and short duration) on private rangeland in the Nebraska Sandhills, 2002-2004. Sandhills density estimate is derived from all data, pooled across grazing systems. P-values is from ANOVA test for effect of grazing system on species' density estimates

	Grazing System				
Species	Long	Medium	Short	Sandhills	P-value
Brown-headed Cowbird	22.17	6.24	33.40	20.58	0.111
Common Nighthawk	3.41	1.91	3.42	2.91	0.212
Field Sparrow	3.78	0.86	0.00	1.55	0.174
Grasshopper Sparrow	56.98	114.64	97.34	89.67	0.047
Horned Lark	4.90	9.57	6.94	7.14	0.501
Killdeer	1.54	0.90	0.24	0.89	0.575
Lark Bunting	0.14	3.54	9.43	4.37	0.193
Lark Sparrow	24.21	12.62	17.57	18.13	0.151
Mourning Dove	6.35	3.72	6.83	5.64	0.010
Red-winged Blackbird	0.28	0.69	2.21	1.06	0.384
Sharp-tailed Grouse	1.08	3.23	4.12	3.02	0.238
Upland Sandpiper	5.74	5.21	5.48	5.47	0.899
Vesper Sparrow	3.62	1.46	2.48	2.52	0.365
Western Meadowlark	29.14	39.34	41.95	36.81	0.065

Table 6. *A priori* candidate model set to explain variability in densities of grassland birds observed on private rangeland in the Nebraska Sandhills, 2002-2004; k = 2 for all models (intercept plus parameter). Models with lower ΔAIC values and higher Akaike weights have more support given the data and the model set. β = linear regression coefficient.

Species	Model	AICc	Δ AICc	Wi	β	SE
Brown-headed Cowbird	Tallest plant	235.3	0.0	0.611	-1.15	1.48
	Bunchgrass cover	236.2	0.9	0.389	-0.04	1.30
	Litter depth	312.9	77.6	0.000	11.59	33.61
	VOR	314.6	79.3	0.000	-24.78	37.29
	SYST	315.0	79.7	0.000	-	-
	GsSR	316.1	80.8	0.000	-3.02	6.24
	Forb cover	320.4	85.1	0.000	1.02	2.49
	SDEN	321.5	86.2	0.000	0.88	1.04
	NULL	333.4	98.1	0.000	-	-
Grasshopper Sparrow	Shrub cover	246.1	0.0	0.646	4.11	6.47
	E-LSH	247.3	1.2	0.354	-0.74	0.31
	VOR	325.2	79.1	0.000	196.90	51.58
	SYST	332.3	86.2	0.000	-	-
	Litter depth	332.6	86.5	0.000	266.65	61.12
	GsSR	346.4	100.3	0.000	13.22	10.18
	NULL	354.6	108.5	0.000	-	-
Horned Lark	SYST	157.1	0.0	0.733	-	-
	VOR	160.1	3.0	0.164	-11.35	10.14
	E-SSH	161.8	4.7	0.070	0.15	6.63
	GsSR	163.8	6.7	0.026	-0.86	2.24
	Bare soil cover	167.2	10.1	0.005	0.08	0.09
	NULL	167.9	10.8	0.003	-	-
Lark Sparrow	Shrub cover	192.5	0.0	0.917	1.63	1.91
	Lying litter cover	197.3	4.8	0.083	-0.57	0.24
	SYST	254.0	61.5	0.000	-	-
	GsSR	257.4	64.9	0.000	-5.73	2.42
	Bare soil cover	262.7	70.2	0.000	0.54	0.17
	NULL	268.6	76.1	0.000	-	-
Mourning Dove	SYST	154.7	0.0	0.996	-	-
	GsSR	166.8	12.1	0.002	-0.41	0.55

	NULL	167.9	13.2	0.001	-	-
Upland Sandpiper	Shrub cover	133.3	0.0	0.973	-1.06	0.47
	E-LSH	140.5	7.2	0.027	0.02	0.03
	SYST	180.7	47.4	0.000	-	-
	VOR	181.3	48.0	0.000	-0.39	4.63
	GsSR	184.3	51.0	0.000	0.64	0.73
	NULL	186.2	52.9	0.000	-	-
	Bare soil cover	189.8	56.5	0.000	-0.04	
Western Meadowlark	Bunchgrass cover	195.2	0.0	0.731	1.52	0.59
	Shrub cover	198.4	3.2	0.148	0.26	1.99
	L-LSH	198.8	3.6	0.121	-0.27	0.11
	VOR	255.9	60.7	0.000	54.52	15.15
	Litter depth	257.9	62.7	0.000	54.87	17.20
	SYST	258.2	63.0	0.000	-	-
	GsSR	270.2	75.0	0.000	1.31	2.85
	Forb cover	272.1	76.9	0.000	0.35	1.19
	NULL	274.3	79.1	0.000	-	-

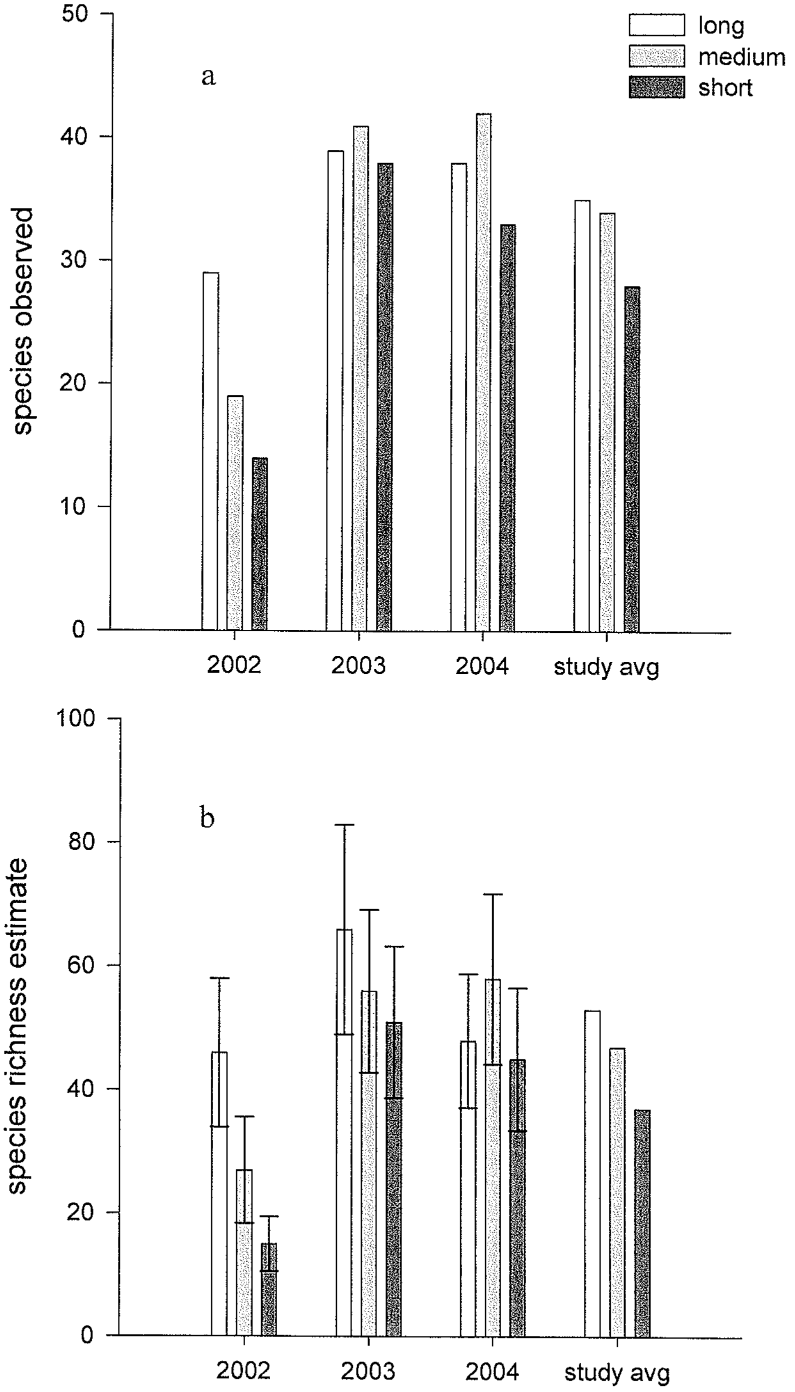
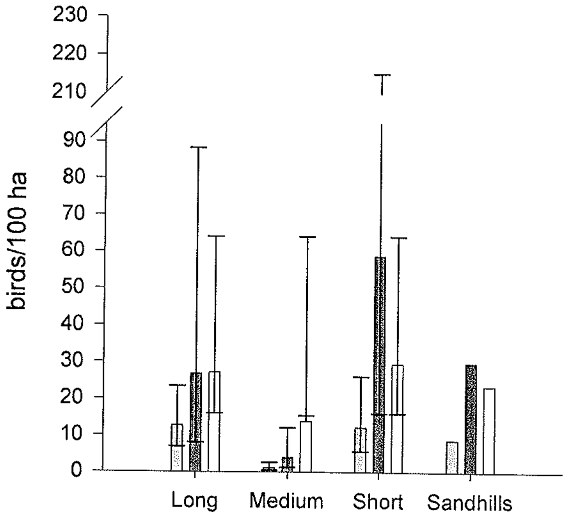
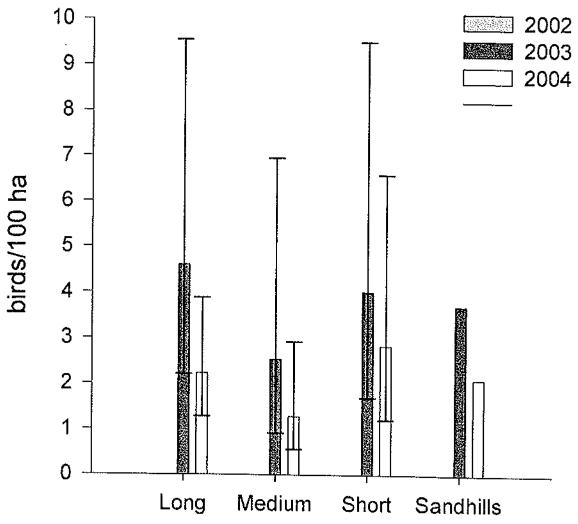


Figure 1. Bird community species richness in three grazing systems (long, medium, and short duration) on private lands in the Nebraska Sandhills, 2002-2004. Species richness

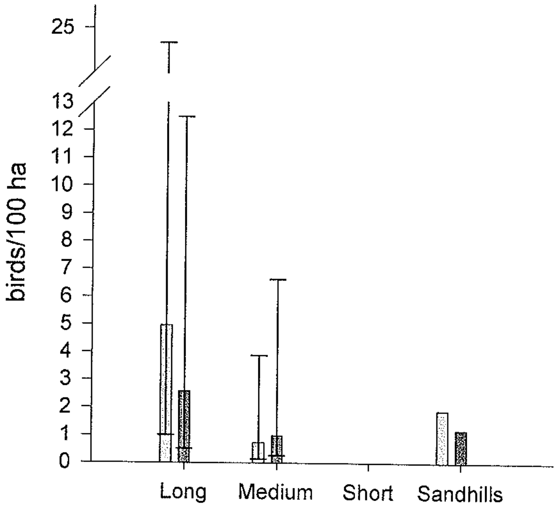
is expressed as: (a) raw count of species observed during bird surveys and (b) species richness estimates (95% CI) from program SPECRICH2.



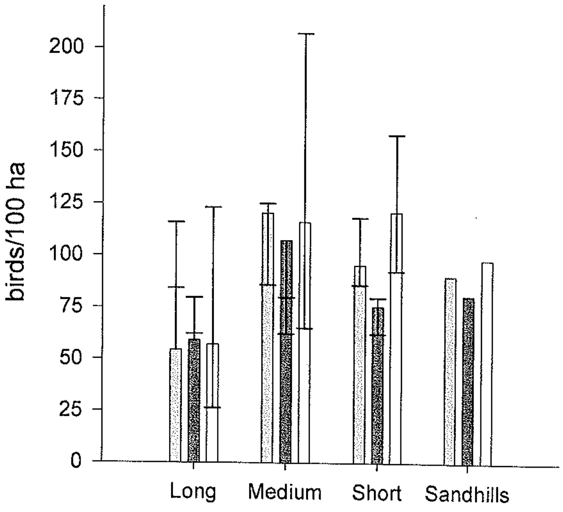
Brown-headed cowbird



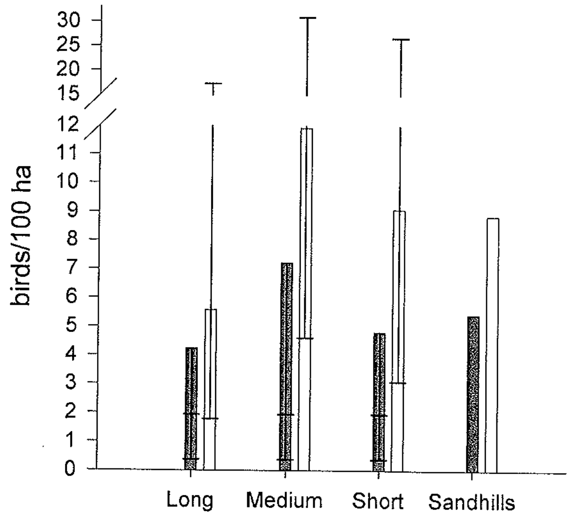
Common nighthawk

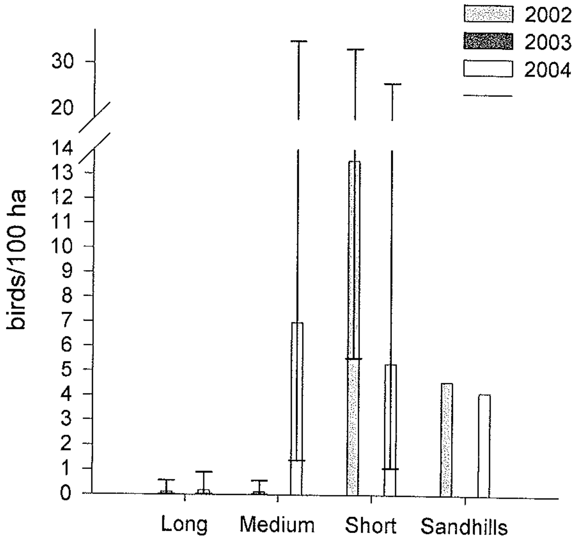


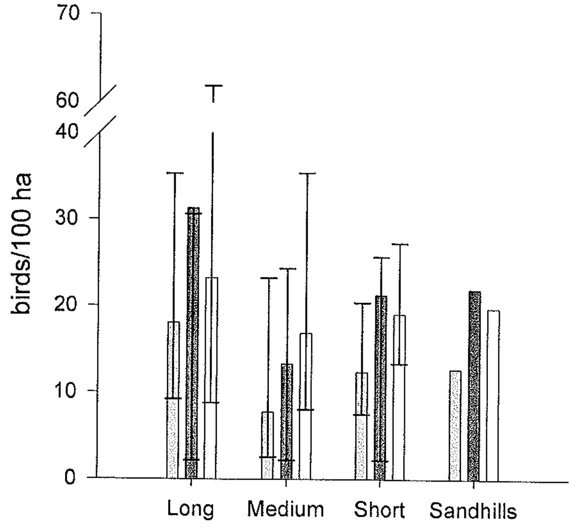
Field sparrow

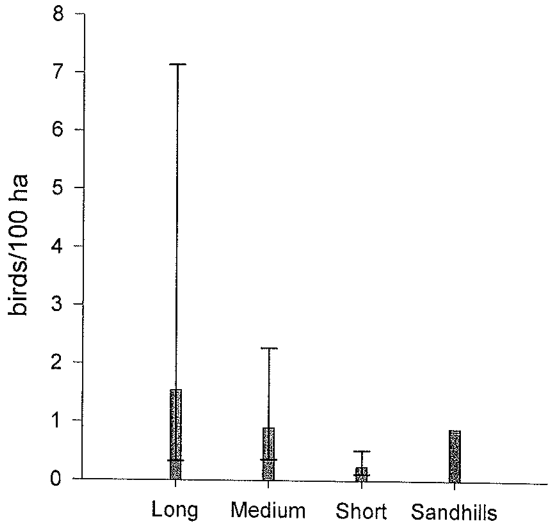


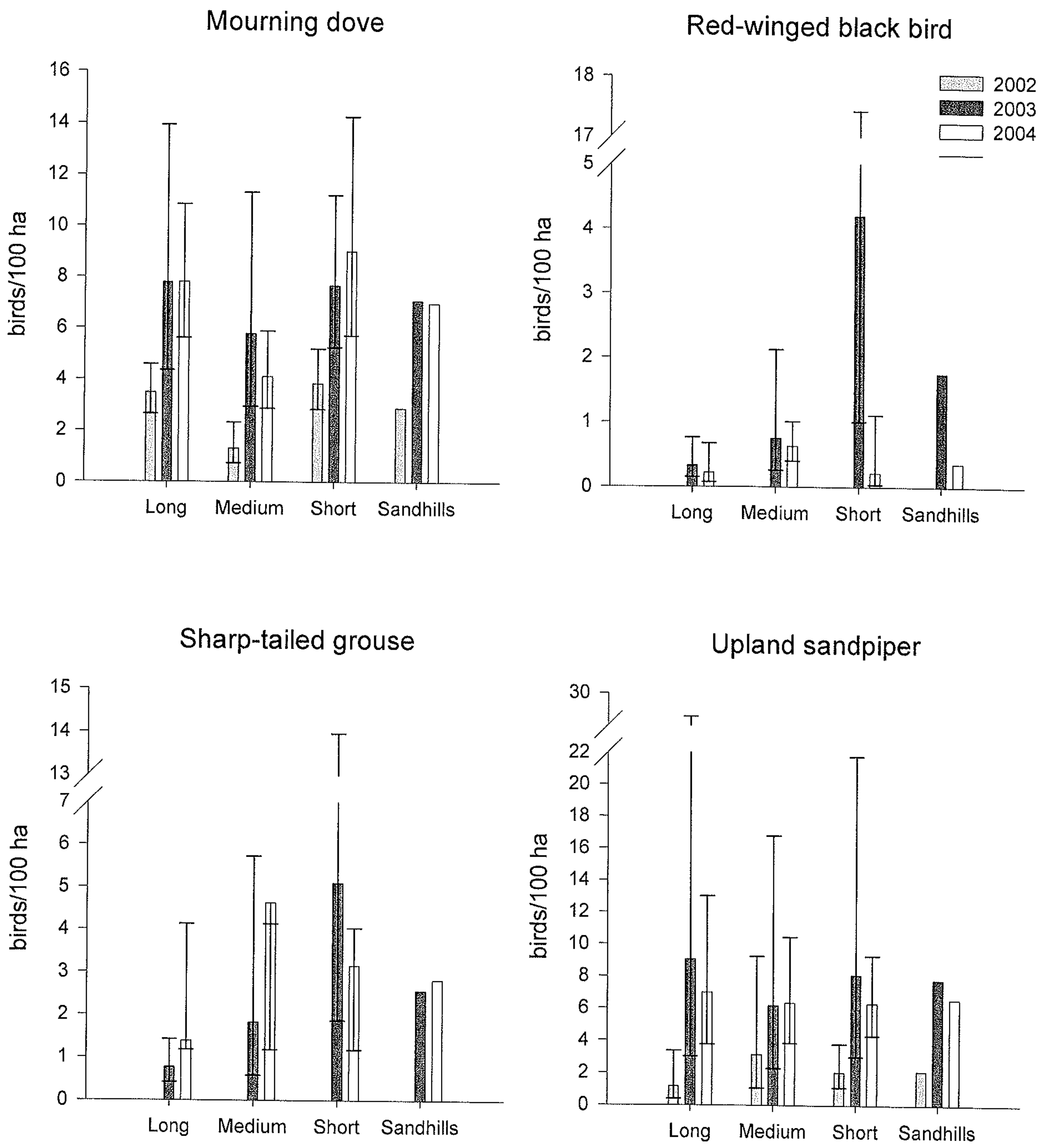
Grasshopper sparrow


Horned lark


Lark bunting


Lark sparrow


Killdeer



Mourning dove

Red-winged black bird

Sharp-tailed grouse

Upland sandpiper

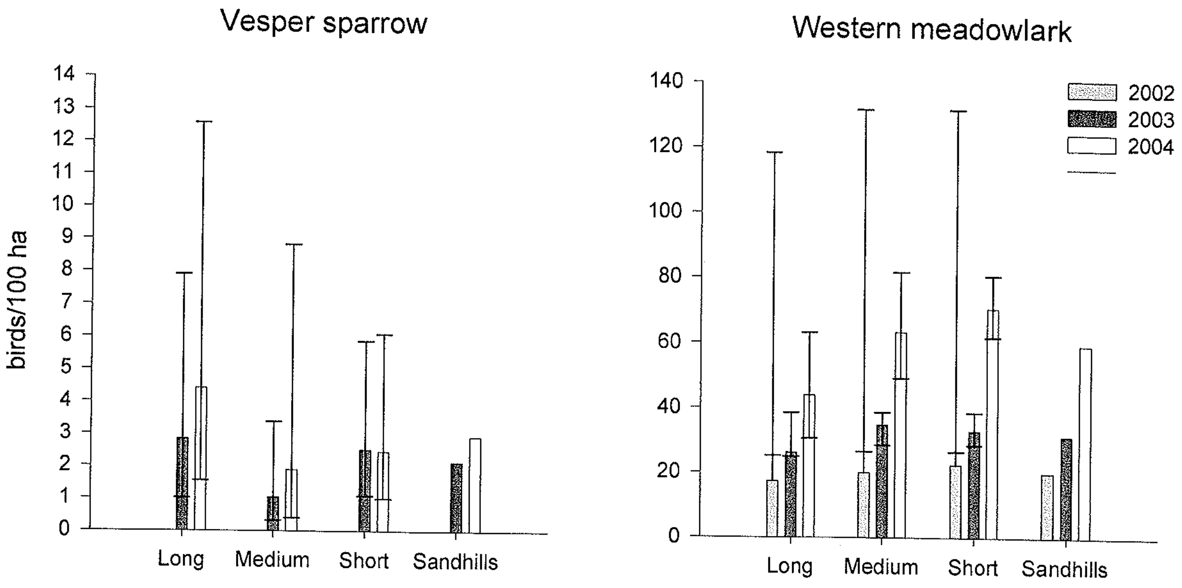


Figure 2. Density estimates (and 95% confidence interval) for fourteen species of grassland birds found in three grazing systems (long, medium, and short duration) on private rangelands in the Nebraska Sandhills, 2002-2004. Sandhills density estimate is derived from data pooled across all grazing systems

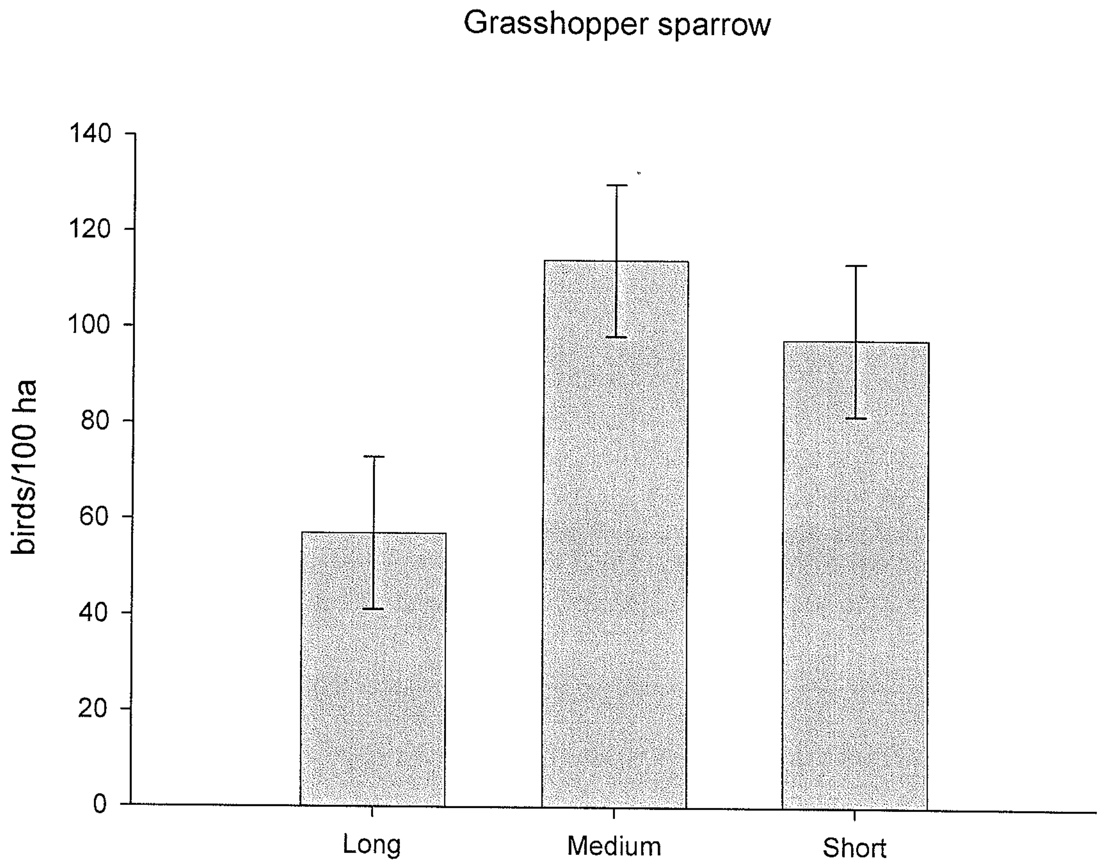


Figure 3. Least squares means (± 1 SE; P = 0.047) of grasshopper sparrow densities found on three grazing systems (long, medium, short duration) used on private rangelands in the Nebraska Sandhills, 2002-2004.

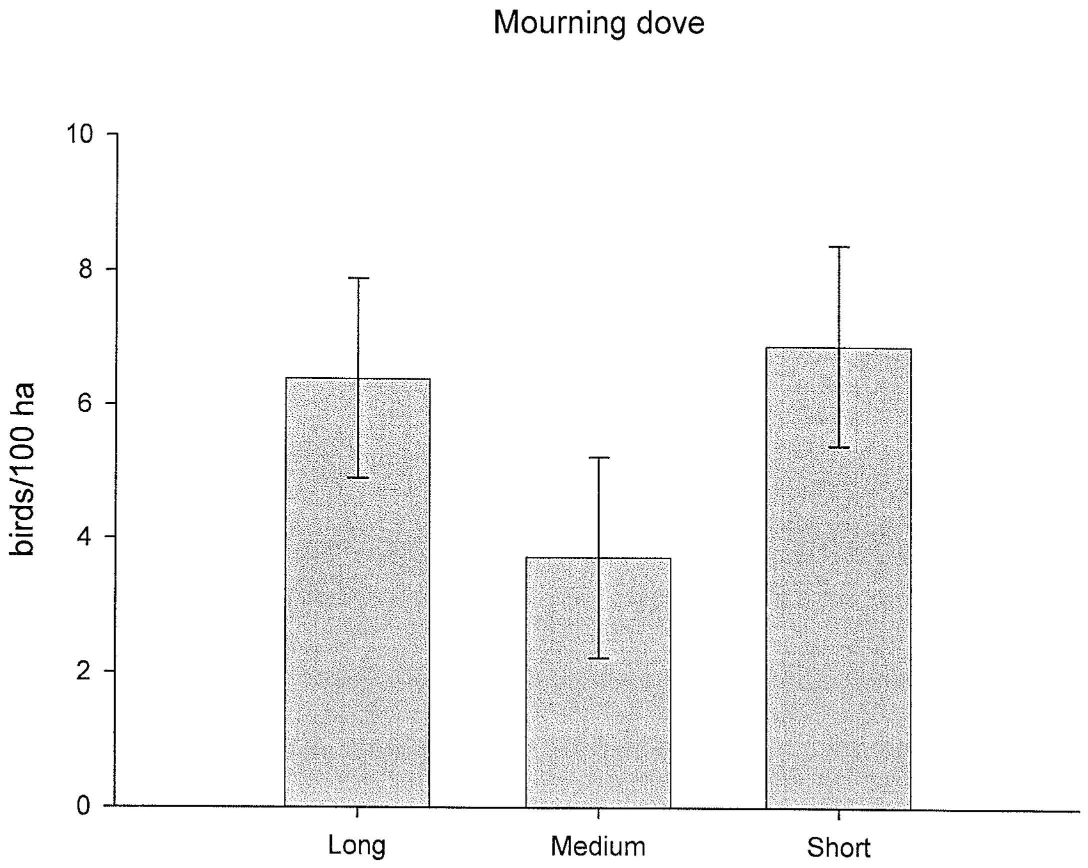


Figure 4. Least squares means (± 1 SE; P = 0.010) of mourning dove densities found on three grazing systems (long, medium, and short duration) used on private rangelands in the Nebraska Sandhills, 2002-2004.

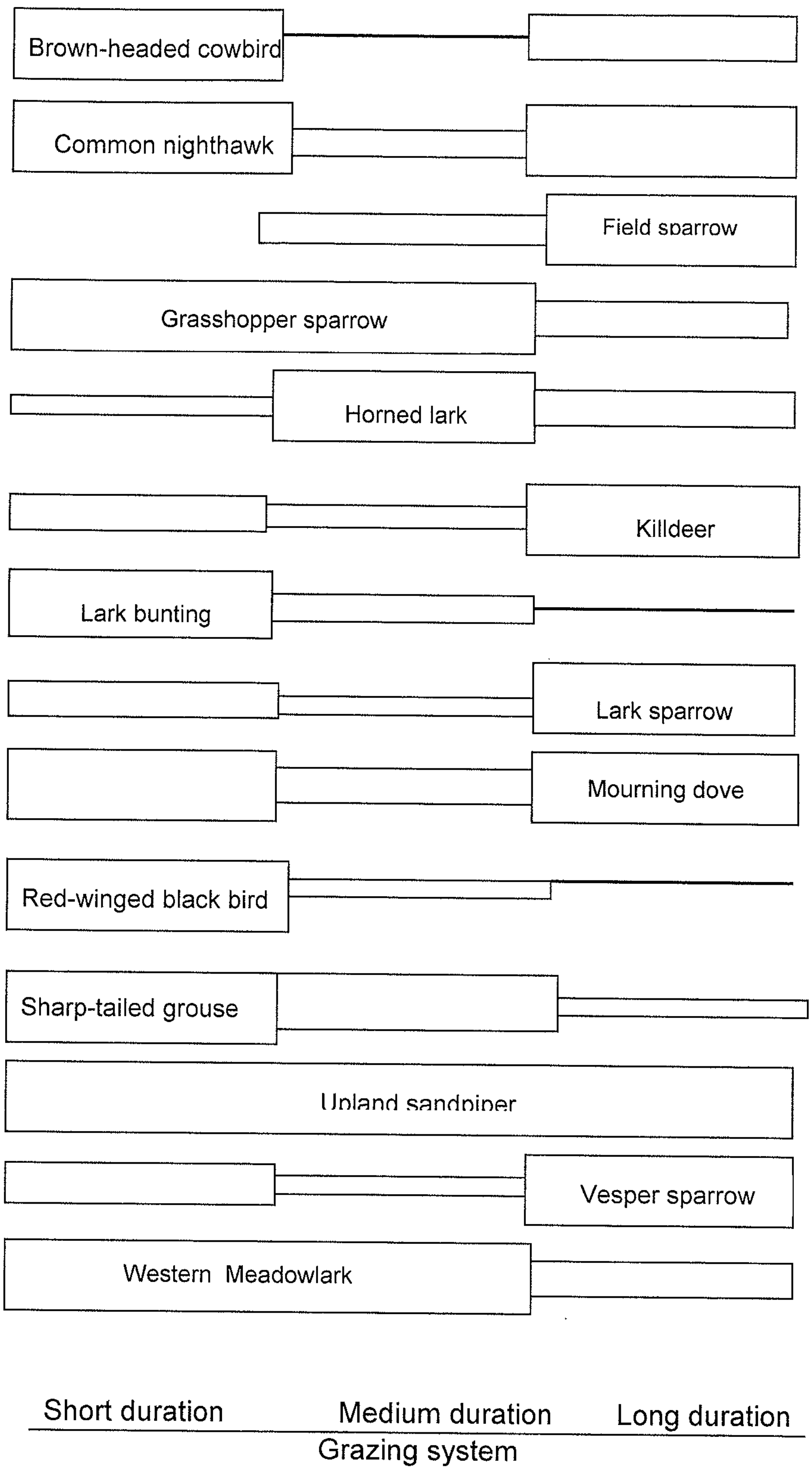


Figure 5. Relative densities of select grassland birds on three grazing systems (long, medium, and short duration) used on private rangeland in the Nebraska Sandhills, 02-04.

CHAPTER THREE: SOURCES IN VARIATION OF GRASSLAND BIRD NEST SURVIVAL IN THE SEMI-ARID NEBRASKA SANDHILLS[2]

Abstract: We observed seventeen species of ground nesting birds on private rangeland in the Nebraska Sandhills from 2002-2004. We monitored 287 nests, and grasshopper sparrows, western meadowlarks, lark sparrows, and mourning doves made up approximately 80% of our sample. Of nests with known outcome, 47% were lost to predation. Ten nests (3.5%) were lost due to cattle disturbance. Daily nest survival, for all species was 0.931 (SE = 0.078; 95% CI = 0.921-0.940). Brown-headed cowbird parasitism level was 16% (n = 287). We used a model selection approach to assess variation in daily nest survival rates; variation was best explained by models with weather-related variables (year and weekly Palmer Drought Severity Indices) and cattle stocking density. However, the linear relationship between daily nest survival and stocking density was weak. Therefore, indirect influences of stocking density, such as increased brown-headed cowbird density and/or parasitism rates may impact daily nest survival rates of grassland birds more than direct mortality from trampling. Grassland bird populations could benefit from proactive management for drought by maintaining range in higher condition; and we encourage biologists to consider the influence of cattle on the breeding and foraging behavior of brown-headed cowbirds.

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[2] Kempema and Powell. To be submitted to The Auk.

INTRODUCTION

Avian productivity estimates can serve as an important indicator of habitat quality and effective management. Ecologists recognize that density may not always be the most appropriate indicator of habitat quality (VanHorne 1983, Pullium 1988). This disjunct relationship between density and habitat quality has been documented for grassland avifauna (Vickery et al. 1992). For grassland birds, measures of reproductive success such as fledging weight, nestling growth rate, and nesting success may serve as more suitable predictors of habitat quality than density (Maurer 1986). Ricklefs and Bloom (1977) recognized nesting success as an important component of avian productivity. Vickery and Herkert (2001) call for additional research into the productivity of grassland bird habitats to avoid ecological traps or population sinks. In this chapter, we attempt to better understand the daily nest survival rates (DNS) of grassland birds nesting on private rangelands managed by one of three grazing systems in the semi-arid Nebraska Sandhills.

The grasslands of North American, once covering much of the continent, have now become one of the most endangered ecosystems. Grasslands have become increasingly modified and fragmented with the onset of agriculture, increasing woody vegetation, and fire control. Grassland bird populations have declined, commensurate with the loss of habitat. In fact, grassland nesting species have experienced the steepest, most consistent and geographically widespread declines of any nesting guild in the US and southern Canada (Peterjohn and Sauer 1999). For example, the grasshopper sparrow, a wide-ranging grassland species, has steadily declined throughout most of its extensive range (Peterjohn and Sauer 1999).

METHODS

Study Area

Our study was conducted from 2002-2004 on private rangelands in eastern Cherry and northern Thomas county in the Nebraska Sandhills (Appendix I: Figures 1 and 2). See Chapter 1 (SLFK) for further study area descriptions.

Sampling Methods

In 2002, we examined three replicates of long, medium, and short duration grazing systems for a total of nine study pastures. See Tables 1 and 2 in Appendix II for a description of grazing treatments. We added an additional replicate per grazing treatment in 2003. Thus, a total of twelve study pastures or experimental units were used for the remainder of the study. We sampled for grassland bird nests along randomly placed line transects used in a concurrent study of grassland bird density (Appendix I: Figure 3; see also Chapter 2, SLFK).

Nest searches - We geographically organized our 12 pastures into four groups of three pastures. Each group had one representative from each of the three grazing system treatments. We searched all treatments within a group at least three times throughout the breeding season. All grazing systems were searched continually throughout the breeding season to avoid temporal biases and provide comparable samples from each grazing system treatment.

We systematically searched for nests using a weighted rope drag. Aluminum cans were spaced at 1-m intervals along the rope to facilitate flushing adults from the nest site. Searches were conducted using a crew of at least two, and most often three individuals. The third observer flagged nests and marked areas already searched. We searched for nests from mid-morning to early afternoon. Our sample was supplemented with additional nests found by using clues from adult behavior and unexpected flushes during research-related activities.

Nest locations were recorded using a GPS receiver and marked on an aerial photo. A minimal amount of blue flagging was tied to vegetation five meters to the north and south of the nest to facilitate relocation. When a nest was first found, we candled two eggs to determine incubation stage (Klett et al. 1986, Lokemone and Koford 1996). Nestling age was estimated by comparing nestling size and/or absence or length of down or feather development to published descriptions and photographs of nestling development (Scott 1979, Hanson and Kossack 1957, Baicich and Harrison 1997). Nest initiation date was determined by backdating from estimated age when first found using methods described above or backdating from hatch or fledging dates. We used average laying, incubation, and nestling stage lengths published in Baicich and Harrison (1997), Ehrlich et al. (1988), and Tacha and Braun (1995).

During each nest visit, we recorded date, time, and observer, length of visit, and presence or absence of cattle in the pasture. Initial method of location (systematic search or behavior) was also recorded.

We collected nest-specific habitat and nest features, including dominant plant functional group providing nest concealment (e.g., grass, forb, shrub, or open), orientation of nest opening, and the method used for locating each nest. In 2003 and 2004, ecological site information was determined within a 15.24-m radius of each nest. We recorded the dominant (covering >50% of the ocularly estimated area) ecological site within this radius. We also recorded nest site elevation. In 2004, additional information on nest placement (slope location and slope direction) was taken.

Nests were revisited approximately every three to five days with nest checks occurring throughout the day. We recorded the number of eggs, both host and parasite (brown-headed cowbird, *Molothrus ater*), nestling development, and additional notes on nest contents and/or potential influences to the nest. Nests were categorized as successful if ≥1 egg hatched or ≥1 nestling fledged (either host or parasite) depending on breeding biology (precocial or altricial nestlings). We attempted to verify the cause of nest failures as either predation, abandonment, or cattle-induced disturbance. We categorized nests as predated when we observed disturbed nest contents, egg shell fragments, predator sign (e.g., tracks, fur), earlier partial predation, presence of adult feathers to indicate a struggle, punctured eggs, or nestling parts. We categorized nests as abandoned using the following criteria: 1) nest has a complete or partial clutch with cold eggs on the second visit after an adult was not attending during a previous check, 2) eggs and/or nestlings present, motionless, and cold, and/or 3) nest is early in the laying or incubation stage and no additional signs indicate active status. Nest outcome was categorized as a cattle-induced failure if nest and/or contents were apparently trampled (nest structure and contents damaged and/or hoof prints or fresh cattle feces nearby) or if the nest site at time of check was in area recently (within one or two days) heavily grazed or trampled by cattle. We categorized nest outcome as unknown if we lacked physical or chronological evidence to determine the reason for the failed outcome.

Pasture-specific habitat - We quantified the variability of vegetation height and density (Visual Obstruction Reading-VOR) within each pasture early in the growing season (mid- to late-June). We calculated large-scale (pasture-level) heterogeneity as the coefficient of variation for VOR readings along our transect lines. We also used sub-samples of VOR readings at each vegetation survey point to calculate small-scale (5 m^2) heterogeneity for each pasture (Wiens 1974). See Chapter 1 (SLFK) for further description of methods.

Grazing – We developed several nest-specific covariates to relate nest survival to grazing pressure. We used information provided by each producer to calculate growing season (1 May to 30 September) and dormant season (1 October to 30 April) stocking rates (AUM/ha; King and Stine 1998) and growing season stocking density (number of animals/ha) for each paddock (Appendix II: Tables 1 and 2). See also Chapter 1, SLFK for further information on system and season specific averages. We defined nesting stocking rate as the intensity of grazing that occurred during the active phase of each nest. The active phase of a nest was defined as the period between and including the date on which the first egg was laid and our estimated or known date of success or failure. Grazing pressure (stocking rate [AUM/ha]) for each pasture or paddock was calculated as the sum of the stocking rates (AUM/ha) from every grazing event during a particular season. We also assigned a stocking density (# animals/ha) to each nest monitoring interval. Stocking density values were calculated as the average stocking densities of all the grazing events that occurred during the growing season within a particular pasture or paddock.

Climate - Weekly drought severity information (Palmer Drought Severity Index-PDSI) was gathered from cooperative weather stations near the towns of Valentine, NE and Purdum, NE to represent the northern and southern reaches of the study area, respectively. The corresponding weekly PDSI values from the closest weather station were assigned to each nest. Climate data was provided by the High Plains Regional Climate Center (HPRCC) at the University of Nebraska in Lincoln. The PDSI is a standardized meteorological drought index calculated using a soil moisture algorithm that takes into account available water holding capacity, precipitation, and temperature to measure the moisture departure from climatological averages. These standardized index values are designed to be comparable across time frames and geographic regions. This is possible by incorporating temporal variations (dry or wet spells) and cumulative effects of past precipitation values so that drought conditions are not indexed to be relieved by short rounds of average or above average precipitation. The PDSI scale runs from approximately +6 to -6; 0.49 to -0.49 is considered near normal; >4.0 is extremely wet, and <-4.0 is extreme drought (Hayes 2005).

Statistical Analysis

Use of information theoretic methods.—Information theoretic methods allow for model comparison among a set of biologically relevant *a priori* models (Burnham and Anderson 2001). We start with the premise that there is some unknown reality of patterns of variability in nest survival in grassland birds on our study area. We developed *a priori* hypotheses to explain anticipated variability in survival, which led to nest-specific and pasture-specific covariates that we collected in the field. Information theoretic methods estimate Kullback-Leibler (K-L) distances, which measure the distance between unknown reality and the model used to explain this unknown reality. Distances are minimized using maximum log-likelihood methods and available data.

The estimate of relative expected K-L distances, known as Akaike's Information Criterion (AIC) provides us a measure of how suitable a model is given the data and the model set (Burnham and Anderson 2002). The model with the lowest AIC value is the model with the most support within the set. The AIC values of the model set are relative and it is only the distance, as measured by ΔAIC that allows comparison of the competing models, as more than one model can be supported by the data. ΔAIC values estimate the relative expected K-L differences between the process represented by the data (truth or reality) and the set of candidate models created to best approximate this process. The larger the ΔAIC for a given model, the less plausible it is that this model is the best model to represent the actual biological process. Those models with ΔAIC values ≤ 2 have substantial empirical support. As ΔAIC values increase, the level of empirical support decreases. Models with larger ΔAIC values are less suitable as a best approximating model of the K-L best model (Burnham and Anderson 2002).

Akaike weights, denoted as $w_{i,}$ provide the relative likelihood of a model, given the set of R (total # of models) and the data. Akaike weight is the weight of evidence that a model is the K-L best model assuming that one of the models being evaluated is the K-L best model and given the data. Akaike weights can be interpreted as a percent and will sum to 1 (Burnham and Anderson 2002).

Logistic exposure nest survival.—We used Shaffer's (2004) logistic exposure method to assess variation in nest survival. Logistic exposure uses logistic regression methods, but uses the nest monitoring interval as the binomial trial (success or failure at end of interval). The method allows for varying visitation intervals and does not assume that dates of nest loses are known. The logistic exposure link function uses an interval, time-related exponent to account for the probability of surviving an interval; thus, survival is dependent on the length of the interval. We assumed that all nests were independent of one another and that those nests with the same explanatory variables have the same DNS rates (Shaffer 2004). We determined the length of the nest visitation interval and the outcome of this interval for each nest.

We developed four basic, single-factor, *a priori* models to examine the effects of species (SP), grazing system (SYST), cowbird parasitism status (PARA), and year (YEAR) in addition to a model with no effects (NULL). We used AICc values and model weights (w_i) to select the best approximating model(s) within an information theoretic framework. Models were run using nest monitoring data from 2002-2004.

We created a second set of 27 *a posteriori* models. These models included single-factor models of growing (GsSR) and dormant season (DsSR) stocking rate, nesting stocking rate (NSR), growing season stocking density (SDEN), presence or absence of cattle (CATT), large-scale (LSH) and small-scale (SSH) heterogeneity measurements for pastures taken in mid- to late-June, and weekly PDSI values. The *a posteriori* models also included models with year effect, and year interaction effect. Last, we considered four additional models. Models included a parasitism effect, and parasitism interaction effect with stocking density, growing season stocking rate, and system. Models were run using data from 2003 and 2004.

We were unable to include 2002 in the initial *a posteriori* analysis, as we did not collect vegetation heterogeneity covariates in 2002. After we determined that the best approximating models from 2003-2004 did not contain variables that were absent from

2002, we applied our top models from the *a posteriori* analysis to the entire data set (2002-2004).

RESULTS

We found 287 nests representing seventeen breeding bird species on private rangeland in the Nebraska Sandhills (Table 1). Nest sample size increased with study year (2002: n = 58, 2003: n = 90; 2004: n = 139). Approximately one-third of the nests were located on each of the grazing systems (Table 1). We found nests from ten species in 2002 and twelve species in 2003 and 2004. We documented 14, 11, and 13 nesting species on long, medium, and short duration grazing systems, respectively (Table 1). Seventy percent of our sample's nests were of passerine species; the composition of nests on long, medium, and short duration systems varied from 57.6%, 75.3%, and 75.7% passerine species, respectively. Grasshopper sparrow (*Ammodramus savvanarum*) and western meadowlark (*Sturnella neglecta*), nests comprised almost 50% of our nest sample (Table 1).

We found our first nests in mid-May during 2002-2004 (May 11-19). The last nests that were monitored to completion were found in mid- to late-July (July 10-23). The mean nest monitoring interval during our study was 3.5 days (SD = 1.0). A majority of the nest checks were at the incubation (54%) and nestling stages (34.5%). The remainder included visits during hatch day (7%), stages unknown due to difficulty in finding the nest (4%), and during the laying stage (0.5%).

Overall, 180 (62.7%) of the 287 nests in our sample failed; 10 nests (3.5%) had unknown outcomes. Of nests with known outcomes (n = 277), 130 nests (47.0%) failed due to predation; additional causes of failure included 14 (5.2%) abandoned nests, 10

(3.5%) cattle-induced failures, and 33 (11.8%) nests with unknown cause of failure. Nine of the 10 nest losses attributed to cattle were due to trampling. Cattle-induced losses were not exclusive to any grazing system (Table 3), medium duration systems had the least number of nests disturbed by cattle.

Raw nest success (# successful nests/ total # of known fate nests) of our most common nesting passerines were 31.3% (n = 80), for grasshopper sparrow, 31.1% (n = 53) for western meadowlark and 45.2% (n = 42) for lark sparrow (*Chondestes grammacus*; Table 2). Nest success rates for other species varied (Table 2).

Seven species and 46 (16%) of the 287 nests were parasitized by brown-headed cowbirds (*Molothrus ater;* Table 4). Fourty-six (23%) of 201 passerine nests were parasitized. Passerine nests found on long, medium, and short duration systems had 21.1%, 20.3%, and 25.6% parasitism rates. The daily nest survival rate estimate (DNS) for our study during 2002-2004 (n = 271) was 0.931 (CI =0.078; 95% CI = 0.921-0.940).

A priori assessment of nest survival - We selected the null survival model as the best model (AICc = 849.29, w_i = 0.39; Table 5). Although the null model was the most parsimonious choice, the year-specific survival model (ΔAICc = 0.85, w_i = 0.26) and the parasitism status model (ΔAICc = 1.24, w_i = 0.21; Table 5) also had substantial empirical support and were useful in explaining variation in daily nest survival (Figure 1 and 2). Although there was no difference in DNS among years, DNS estimates tended to be highest in 2002 (DNS = 0.945, 95% CI = 0.924-0.961, Fig. 1). Nests parasitized by brown-headed cowbirds tended to exhibit lower DNS rate estimates (DNS = 0.921 (95% CI = 0.891-0.943) than those free of parasitism (DNS = 0.933, 95% CI = 0.922-0.943; Fig. 2).

System (△AICc = 3.46, w_i = 0.06) and species models (△AICc = 5.60, w_i = 0.65; Table 5) did not have substantial support. Medium duration systems had the highest DNS point estimate (DNS = 0.936, 95% CI = 0.917-0.951); DNS varied little among systems (Figure. 3). The daily nest survival rate for common nighthawk (*Chordeiles minor*) (DNS = 0.982, 95% CI =0.947-0.994) was higher than all other species excluding field sparrow (DNS = 1, n = 1). Horned larks had the lowest point estimates (DNS = 0.861, 95% CI = 0.573-0.966; 22-day nest success = 3.7%). Daily nest survival rates for grasshopper sparrow (DNS = 0.918, 95% CI = 0.894-0.936; 21-day nest success = 16.6%), western meadowlark (DNS = 0.925, 95% CI =0.898-0.946; 25-day nest success = 14%) lark sparrow (DNS = 0.948, 95% CI = 0.923-0.965; 22-day nest success = 31%), and mourning doves (*Zeniadia macroura*; DNS = 0.908, 95% CI =0.869-0.936; 28-day nest success = 6.7%; Table 6, Figure 4), our four most frequently nesting species, did not vary significantly.

Initial a posteriori assessment of nest survival. - Six of the 27 models had substantial empirical support (△AICc < 2.0; Table 7), and AIC model weights were similar for the best three models ([$w_i \geq 10$] SDEN, AICc = 673.7; PARA, △AICc = 0.48; SDEN*YEAR, △AICc = 0.52; Table 7). The null model and the PARA*SDEN and PDSI models also had △AICc scores < 2.0. Of the best six models, the null model was the most parsimonious. Because of model selection uncertainty, model averaged estimates were calculated (Table 8).

Secondary a posteriori assessment of nest survival - With the inclusion of data from a drought year (2002; Chapter 1: Figure 2) in our secondary *a posteriori* analysis, the drought model (PDSI) was selected as the best model (w_i = 0.78; Table 9). The remaining models showed considerably less empirical support (AICc ≥ 5.6) and very little weight ($w_i < 0.05$). Drought conditions during the course of this study (PDSI values of-1.03 to -4.46), caused considerable variation in daily nest survival rate estimates (Fig. 5).

DISCUSSION

Evaluation of our *a priori* set of single-effect models indicated that none of the initial factors we evaluated, including the effect of grazing system, were causing variation in nest survival. We also found considerable uncertainty in the model selection process for our initial *a posteriori* analysis. Although effects of stocking density, parasitism status, year (often a surrogate value for climate) and interactions of these variables had support, none caused DNS estimates to vary meaningfully (Table 8).

Drought severity had the most plausible influence on variation in daily nest survival rates of ground nesting birds on private rangeland in the Sandhills. In north-east Colorado, lark bunting DNS was lower in 2002 (DNS = 0.908; a severe drought) than in the two years proceeding (both years DNS = 0.933; Yackel-Adams, et al. 2006). The authors stated that realistic population models should incorporate survival estimates that account for ecological conditions, among other factors. Variability in sharp-tailed grouse production on Valentine National Wildlife Refuge, located within the geographic boundaries of the study area, was primarily influenced by cumulative precipitation (January -July) which was used as an index of drought conditions (Flanders-Wanner et al. 2004). Under drought conditions in a North Dakota study, vesper sparrow nesting success, number of young fledged, and percent of eggs hatched were significantly lower than pre- and post-drought (George et al. 1992). Nest sample size and yearly total precipitation, as well as familiarity with the study area and nesting habitats of individual species, increased with each progressive year of our study (Chapter 1: Figure 2). George et al. (1992) observed that the number of horned lark and western meadowlark nests found was greater during years pre- and post-drought.

Drought is a natural occurrence and can not be controlled, but it can be managed for. George et al. (1992) speculated that maintenance of range in good condition will help to mediate effects of drought on grassland bird populations by helping to ensure recovery after drought conditions are alleviated. Flannders-Wanner (2004) recommended that by insuring adequate vegetative cover, moderate ground level temperatures that are important to young-of-the-year, especially during high temperatures, can be maintained through proper management. As range condition increases so does the amount of cover and height and thickness of live or dead standing vegetation (Bai et al. 2001). In addition, species richness increases as range condition improves (Reece et al. 2001) along with the ability to be more resilient to disturbances such as drought (Tilman and Downing 1994). Smith et al. (1996) concluded that range in good condition provided more wildlife habitat than range in excellent condition due to increased plant species and structural diversity. Therefore, adequate cover, as found on higher condition range can help to mediate drought impacts (i.e. disturbance) on both plants and wildlife.

Our initial *a posteriori* analysis of nest survival, using data from only 2003-2004 in which total annual precipitation was nearer to the 30-year average (Chapter 1: Figure 2). This suggests that during times of more abundant precipitation, parasitism and stocking density may be the source of variation in DNS rates. Passerine nests often fail due to parasitism and predators (Martin 1992, Brittingham and Temple 1983). Brown-headed cowbirds have a well-known commensal foraging relationship with grazing ungulates (Goguen et al. 2005). Increased densities of nest parasites increase the incidence and intensity of parasitism (McGeen 1972). However, this correlation between parasite abundance and increased parasitism frequency is questionable (Chance 2005). Densities of this nest parasite were highest in pastures grazed under a short duration rotation (Chapter 2, SLFK). However, in a North Dakota study, cowbird densities did not differ significantly among continuous, twice-over, or short duration grazing system treatments; densities did tend to be higher on grazed than idle areas (Messmer 1990).

Parasitized nests tended to have lower DNS (DNS = 0.921) than unparasitized nests (DNS = 0.933; Figure 2) Parasitism rates for grasshopper sparrows, western meadowlarks, and lark sparrows on our study sites averaged 21%, 9.3%, and 40.5%, respectively. Parasitism of passerine nests by brown-headed cowbirds during our study was greatest (26%) on short duration grazing systems. Parasitism rates also were highest for the three most abundant nesting host species on short duration systems (grasshopper sparrow: 26.9%, western meadowlark: 16.7%, lark sparrow: 40.5%; Table 4). In a summary of parasitism rates of Great Plains aviafauna, Shaffer et al. (2003) reported a range of parasitism rates; grasshopper sparrow parasitism rates ranged from 0 to 58%; western meadowlark parasitism rates ranged from 7-46%; and lark sparrow parasitism rates ranged from 6-82% (Shaffer 2003). Parasitism rates for all of these species recorded during our study were at the low to middle range of those reviewed by Shaffer et al. (2003) when pooled across systems. Species parasitism rates noticeably increased and were highest on short duration systems.

Cowbirds are unique in that they breed in the morning and forage in the afternoon with both activities often occurring in different areas (Rothstein et al 1984). Their distribution is thought to be limited to breeding areas that are within commuting distance (15 km) of feeding areas (Chance et al 2005). However, if these areas overlap, such as in grazed rangeland, the commuting requirement would be eliminated (Dufty 1982). Increased foraging efficiency may increase cowbird productivity and result in a greater impact on host populations.

Shaffer et al. (2003) reported that suitable perch sites (structures that exceed the height of surrounding vegetation) are a crucial component to brown-headed cowbird habitat and are often associated with higher parasitism rates. To facilitate increased utilization of forage, rotational systems use multiple, smaller pastures delineated by fences. Higher densities of brown-headed cowbirds (this study), increased availability of potential perches (fence posts), and theorized increased foraging opportunities (higher stocking densities) and efficiency, and improved breeding success suggest that rotational grazing systems may influence (increase) the impact of parasitism on grassland birds in short duration grazing systems. The effects of grazing system on daily nest survival of grassland birds may not be direct mortality due to trampling or grazing system effect on vegetation, but how herd size and movement facilities, distribution, and duration of grazing affect the behavior of cowbirds and parasitism rates of host species. Therefore, a potential relationship between parasitism rates and stocking density/grazing system may exist. This may have critical management implications as the effects of stocking density and therefore parasitism can be influenced through herd size management.

Stocking density had a slight negative effect on daily nest survival. Trampling of nests by livestock is a recognized concern of some wildlife managers (Jensen et al 1990, Paine et al. 1996). In this study, only ten nest failures were due to cattle; nine were a result of trampling. Increased stocking density may increase nest failure as a result of increased trampling rates. In central South Dakota, trampling of long-billed curlew nests served as a significant source of mortality in 2005 (75%) and 2006 (37%; Clarke 2006). Authors suggested that trampling was dependent on the density of livestock within a pasture (Clarke 2006). Trampling rates of passerine nests on Wisconsin pastures was 29% (14 of 54 nests; Nack 2002). Pasture sizes on Nebraska Sandhills ranches are quite large (Appendix II: Tables 1 and 2). This may have decreased the risk of trampling loss. We found that more nests were lost due to predation than any other factor.

Despite the subsequent habitat alterations brought about by current agricultural activities, pasture and rangelands often serve as the best breeding habitat remaining for some grassland bird species (Herkert 1995, Johnson 1996). Even these remaining habitats are diminishing. National Resources Inventory data report that between 1982 and 1997, approximately 10.5 million ha of pasture and rangeland were lost in the US (Vickery and Herkert 2001). The sandy, erodible substrate of unformed soils has thwarted most efforts to cultivate in the and has left it relatively uncoverted (6-28% conversion rate; Bragg and Steuter 1996). The Nebraska Sandhills prairie is managed overwhelmingly through cattle grazing (80%; Miller 1998).

Relative lack of conversion and continuity of habitat suggests that rangeland in the Nebraska Sandhills should support a productive suite of grassland birds. Overall nest survival rate on Nebraska Sandhills pastures (0.931) is higher than many studies' estimates of nest survival in other grazed habitats. In a study on the effects of cattle and predation on Wisconsin pastures, Nack (2002), reported a 0.884 daily survival rates for nests. Depending on management treatments, DNS rates varied from 0.45 to 0.98 on a tallgrass prairie preserve in Oklahoma (Churchill 2005).

Individual species DNS rates of the most frequently nesting species were lower than that found in other habitats, excluding the lark sparrow. Reproductive success of the four most abundant species nesting on our study site ranged from 0.948 (31.1% nest success) for the lark sparrow to 0.908 for the mourning dove (6.7% nest success). Grasshopper sparrow and western meadowlark DNS rates were 0.918 (16.6% nest success) and 0.925 (14.0% nest success), respectively.

Pastures on our study area had a consistent history of grazing (Chapter 1, SLFK) and increased amounts of bare soil. Lusk et al. (2003) reported that lark sparrow nests in Oklahoma were located more frequently in grazed areas, especially those moderately grazed. The authors concluded that moderate amounts of bare ground and litter are optimal habitat conditions for lark sparrows. Private rangeland in the Nebraska Sandhills has adequate amounts (<85%) of bare soil suggesting that habitat is suitable for successful nesting lark sparrows, as indicated by DNS rates for this species. Daily nest survival of lark sparrows in Illinois was 0.931 (22.3% nest success rate; Martin and Parrish 2000). Average mourning dove nest success throughout the species geographical distribution average 48% according to Sayre and Silviey (1993; Mirarchi and Baskett 2001). Reproductive success of mourning doves is primarily influenced by weather and predators (Mirarchi and Baskett 2001).

Grasshopper sparrow reproductive success has been shown to vary throughout its range. Grasshopper sparrow nests had 16% success rate in grassed strips in agricultural areas (Vickery 1996). Reproductive rates of grasshopper sparrows in Conservation

Reserve Program fields in southeastern Nebraska as determined by a ranking system indicated that 52% of territories observed successfully fledged at least one brood (Delise and Savidge 1996). Grasshopper sparrows in CRP fields of northcentral Missouri successfully fledged at least one young 30% to 58% of the time (McCoy et al. 1999). Western meadowlarks on both grazed and ungrazed areas in Montana had similar nest success rates (26%; Fondell and Ball 2004). Reported nesting success of meadowlarks in a British Columbia study was 42%.

Forty-seven percent of the nests with known outcomes in this study failed due to predation. Predation was also the primary source of mortality on grazed and ungrazed plots in a Montana study (Fondell and Ball 2004). Reproductive failure in songbirds is often caused by nest predation (Martin 1992). Failure of open cup passerine nests, such as those of many grassland birds, is largely attributed to predation (Lack 1954). Miller and Knight (1993) concluded that ground-nesting passerines suffer greater predation rates than do other species in other types of habitats. Small mammals have been document as nest predators in the Great Plains (Pietz and Granfors 2000). In a study concurrent with ours, Fricke (2005) sought to determine the relationship between the small mammal community, DNS, and vegetation structure. He found no relationship between the abundance of small mammals and nest survival rates. The author suggested that a different suite of predators or other unknown causes could be the primary source of nest failure on private range in the Nebraska Sandhills.

SUMMARY

We found no significant direct effect of grazing system on the productivity of grassland birds nesting on private rangeland in the Nebraska Sandhills. The Nebraska Sandhills is an ecosystem with variable disturbance and climate. We found that drought conditions can significantly affect production of grassland birds in this region. While it is impossible to control for yearly climatic conditions, it is feasible to manage for rangelands in higher condition, resulting in range that is more resilient to drought. This also may help grassland birds recover from inevitable impacts of limiting precipitation.

We found evidence to suggest that the number of cattle (stocking density) may affect productivity of grassland birds. Specifically, we encourage biologists to consider the influence of cattle on the breeding and foraging behavior of brown-headed cowbirds. Additional research is needed to further understand the impacts of stocking density on grassland bird production in the region, as well as the effects of various grazing systems on brown-headed cowbird breeding and feeding behavior on private rangeland.

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Table 1. Number of nests, by species, found on three grazing systems (long, medium, and short duration rotations) on private rangelands in the Nebraska Sandhills 2002-2004.

	Grazing systems				
Species	Long	Medium	Short	Pooled	% of all nests
Blue-winged Teal[a]	2	0	1	3	1.0%
Common Nighthawk	5	2	5	12	4.2%
Field Sparrow[b]	1	0	0	1	0.3%
Gadwall[c]	0	0	1	1	0.3%
Grasshopper Sparrow	24	35	26	85	29.6%
Horned Lark	1	0	1	2	0.7%
Lark Bunting	0	2	10	12	4.2%
Lark Sparrow	16	11	15	42	14.6%
Long-billed Curlew[d]	0	1	0	1	0.3%
Mallard[e]	1	1	2	4	1.4%
Mourning Dove	18	11	12	41	14.3%
Sharp-tailed Grouse[f]	5	1	1	7	2.4%
Upland Sandpiper	8	4	3	15	5.2%
Vesper Sparrow	2	1	2	5	1.7%
Western Meadowlark	14	16	24	54	18.8%
Willet[g]	1	0	0	1	0.3%
Wilson's Phalarope[h]	1	0	0	1	0.3%
Total	99	85	103	287	100.0%

a: *Anas discors,* b: *Spizella pusilla*, c: *Anas strepera*, d: *Numenius americanus*, e: *Anas platyrhynchos* , f: *Tympanuchus phasianellus*, g: *Catoptrophorus semipalmatus*, h: *Phalaropus tricolor*

Table 2. Proportion of successful nests of bird species found on three grazing systems (long, medium, and short duration rotations) on private rangelands in the Nebraska Sandhills, 2002-2004 (n = 277).

	Grazing system			
	Long	Medium	Short	Pooled
Blue-winged Teal	0.0%	--[a]	0.0%	0.0%
Common Nighthawk	50.0%	50.0%	100.0%	72.7%
Field Sparrow	100.0%	--[a]	--a	100.0%
Gadwall	--a	--a	0.0%	0.0%
Grasshopper Sparrow	29.2%	31.3%	33.3%	31.3%
Horned Lark	0.0%	--[a]	0.0%	0.0%
Lark Bunting	--a	0.0%	20.0%	16.7%
Lark Sparrow	43.8%	45.5%	46.7%	45.2%
Long-billed Curlew	--a	0.0%	--a	0.0%
Mallard	0.0%	100.0%	100.0%	75.0%
Mourning Dove	17.6%	36.4%	41.7%	30.0%
Sharp-tailed Grouse	60.0%	0.0%	0.0%	42.9%
Upland Sandpiper	37.5%	50.0%	0.0%	33.3%
Vesper Sparrow	0.0%	100.0%	50.0%	50.0%
Western Meadowlark	14.3%	40.0%	37.5%	32.1%
Willet	0.0%	--[a]	--a	0.0%
Wilsons Phalarope	0.0%	--[a]	--a	0.0%

[a] no nests recorded

Table 3. Number of nest failures attributed to abandonment due to cattle activity or trampling on three grazing systems (long medium, and short duration rotations) used on private rangeland in the Nebraska Sandhills, 2002-2004.

		Grazing system			
		Long	Medium	Short	Pooled
2002	abandoned	1	0	0	1
	trampled	2	1	0	3
2003	abandoned	0	0	0	0
	trampled	2	0	1	3
2004	abandoned	0	0	0	0
	trampled	0	0	3	3
	System	5	1	4	10

Table 4. Brown-headed cowbird (*Molothrus ater*) parasitism rate by host species and grazing system (long, medium, and short duration rotations) on private rangeland in the Nebraska Sandhills, 2002-2004

	Grazing systems			
	Long	Medium	Short	Pooled
Blue-winged Teal	0.0%	--[a]	0.0%	0.0%
Common Nighthawk	0.0%	0.0%	0.0%	0.0%
Field Sparrow	100.0%	--[a]	--[a]	100.0%
Gadwall	--[a]	--[a]	0.0%	0.0%
Grasshopper Sparrow	16.7%	20.0%	26.9%	21.2%
Horned Lark	100.0%	--[a]	0.0%	50.0%
Lark Bunting	--[a]	0.0%	10.0%	8.3%
Lark Sparrow	31.3%	45.5%	46.7%	40.5%
Long-billed Curlew	--[a]	0.0%	--[a]	0.0%
Mallard	0.0%	0.0%	0.0%	0.0%
Mourning Dove	0.0%	0.0%	0.0%	0.0%
Sharp-tailed Grouse	0.0%	0.0%	0.0%	0.0%
Upland Sandpiper	0.0%	0.0%	0.0%	0.0%
Vesper Sparrow	50.0%	100.0%	50.0%	60.0%
Western Meadowlark	7.1%	0.0%	16.7%	9.3%
Willet	0.0%	--[a]	--[a]	0.0%
Wilsons Phalarope	0.0%	--[a]	--[a]	0.0%

[a] no nests found in grazing treatment

Table 5. Comparison of models in an *a priori* assessment of variation in daily nest survival rates for 271 grassland bird nests on private rangelands in the Nebraska Sandhills, 2002-2004. Models correspond to hypotheses listed in text; *k* represents the number of parameters estimated by each model. Models are listed as ranked by AICc values; AIC weight (w_i) is the weight of evidence in favor of the given model from the model set considered. Models have decreasing empirical support as ΔAICc values become larger.

Model	k	AICc[a]	Δ AICc	w_i
Null	1	849.3	0.00	0.39
Year	3	850.2	0.85	0.26
Parasitism status	2	850.5	1.24	0.21
Grazing system	3	852.8	3.46	0.07
Species	16	852.9	3.60	0.07

[a] Effective sample size for computing AICc: 2363.

Table 6. Daily nest survival (DNS) rate estimates and 95% confidence intervals (CI) for bird species nesting on private rangelands in the Nebraska Sandhills, 2002-2004.

		95% CI	
Species	DNS	lower	upper
Blue-winged Teal	0.961	0.768	0.995
Common Nighthawk	0.982	0.947	0.994
Field Sparrow	1.000	--	--
Gadwall	0.000	--	--
Grasshopper Sparrow	0.918	0.894	0.936
Horned Lark	0.861	0.573	0.966
Lark Bunting	0.903	0.828	0.947
Lark Sparrow	0.948	0.923	0.965
Long-billed Curlew	0.871	0.441	0.983
Mallard	0.968	0.806	0.996
Mourning Dove	0.908	0.870	0.936
Sharp-tailed Grouse	0.951	0.876	0.981
Upland Sandpiper	0.948	0.905	0.972
Vesper Sparrow	0.957	0.843	0.989
Western Meadowlark	0.925	0.898	0.946
Willet	0.920	0.598	0.989

Table 7. Comparison of models in the initial *a posteriori* assessment of variation in daily nest survival rates for 213 grassland bird nests on private rangelands in the Nebraska Sandhills, 2003-2004. Models and acronyms correspond to hypotheses listed in text; *k* represents the number of parameters estimated by each model. Models are listed as ranked by AICc values; AIC weight (w_i) is the weight of evidence in favor of the given model from the model set considered. Models have decreasing empirical support as ΔAICc values become larger.

Model	k	AICc[a]	ΔAICc	w_i
SDEN	2	673.66	0.00	0.13
PARA	2	674.14	0.48	0.10
SDEN*YEAR	3	674.17	0.52	0.10
NULL	1	674.40	0.74	0.09
PARA*SDEN	3	674.96	1.30	0.07
PDSI	2	675.00	1.34	0.07
GsSR	2	675.66	2.01	0.05
YEAR	2	675.68	2.02	0.05
PARA*YEAR	4	675.80	2.15	0.04
DsSR	2	676.16	2.50	0.04
NSR	2	676.20	2.54	0.04
CATT	2	676.21	2.55	0.04
SSH	2	676.24	2.58	0.04
LSH	2	676.31	2.65	0.03
PARA*GsSR	3	676.65	3.00	0.03
PDSI*YEAR	3	676.73	3.07	0.03
DsSR*YEAR	3	677.02	3.36	0.02
SSH*YEAR	3	677.38	3.73	0.02
NSR*YEAR	3	678.12	4.47	0.01
SYST	3	678.28	4.62	0.01
CAT*YEAR	4	678.99	5.34	0.00
PARA*SYST	6	681.95	8.30	0.00
SYST*YEAR	6	682.91	9.25	0.00
SP	15	683.38	9.72	0.00
SP*YEAR	23	687.16	13.50	0.00
LSH*YEAR	24	692.25	18.59	0.00
GsSR*YEAR	38	692.73	19.08	0.00

[a] Effective sample size for computing AICc: 1805.

Table 8. Model averaged regression coefficients (β) estimated during the initial *a posteriori* assessment of variation in daily nest survival rates of grassland birds nesting on private rangeland in the Nebraska Sandhills, 2003-2004. Mean, SD, and minimum and maximum values of continuous model effects are presented. Model acronyms are defined in the text.

	Logit-scale parameter		Model effects		
Parameter	β	SE	Mean (SD)	Min	Max
CATT:absent	-0.0030	0.0103	--	--	--
CATT:present	0.0000	0.0000	--	--	--
DsSR	-0.0008	0.0025	0.88 (1.91)	0.00	8.07
GsSR	-0.0055	0.0135	1.05 (0.64)	0.06	3.66
Intercept	2.6085	0.2698	--	--	--
LSH	-0.0000	0.0001	70.26 (28.3)	35.22	175.55
NSR	0.0021	0.0071	0.79 (0.7)	0.00	3.66
PARA:no	0.0335	0.0672	--	--	--
PARA:yes	0.0000	0.0000	--	--	--
PDSI	0.0182	0.0399	-3.18 (0.36)	-3.91	-2.70
SDEN	-0.0154	0.0294	0.24 (0.93)	0.00	12.02
SP: Blue-winged Teal	0.0008	0.0024	--	--	--
SP:Common Nighthawk	0.0014	0.0032	--	--	--
SP:Gadwall	-0.0131	24.8013	--	--	--
SP:Grasshopper	0.0001	0.0012	--	--	--
SP:Horned Lark	-0.0006	0.0020	--	--	--
SP:Lark Bunting	-0.0006	0.0019	--	--	--
SP:Lark Sparrow	0.0002	0.0013	--	--	--
SP:Long-billed Curlew	-0.0005	0.0021	--	--	--
SP:Mallard	0.0007	0.0023	--	--	--
SP:Mourning Dove	-0.0003	0.0014	--	--	--
SP:Sharp-tailed Grouse	0.0008	0.0022	--	--	--
SP:Upland Sandpiper	0.0002	0.0012	--	--	--
SP:Vesper Sparrow	0.0007	0.0021	--	--	--
SP:Western	-0.00001	0.00106	--	--	--
SP:Willet	0.00000	0.00000	--	--	--
SSH	0.00492	0.01785	0.97 (0.25)	0.57	1.48
SYST:long	-0.00067	0.00344	--	--	--
SYST:medium	-0.00094	0.00382	--	--	--
SYST:short	0.00000	0.00000	--	--	--
YEAR:2003	-0.00694	0.01710	--	--	--
YEAR:2004	0.00000	0.00000	--	--	--

Table 9. Comparison of models in the secondary *a posteriori* assessment of variation in daily nest survival rates of 271 grassland bird nests on private rangelands in the Nebraska Sandhills, 2002-2004. Models correspond to hypotheses listed in text; *k* represents the number of parameters estimated by each model. Models are listed as ranked by AICc values; AIC weight (w_i) is the weight of evidence in favor of the given model from the model set considered. Models have decreasing empirical support as ΔAICc values become larger

Model	k	AICc[a]	ΔAICc	w_i
Drought (PDSI)	2	843.67	0.00	0.783
Null	1	849.29	5.63	0.047
Stocking density	2	850.08	6.42	0.032
Year	3	850.15	6.48	0.031
Parasitism status	2	850.53	6.86	0.025
Stocking density*year	4	850.91	7.24	0.021
Parasitism status*stocking	3	851.03	7.36	0.020
System	3	852.75	9.09	0.008
Species	16	852.89	9.22	0.008

[a] Effective sample size for computing AICc: 2363.

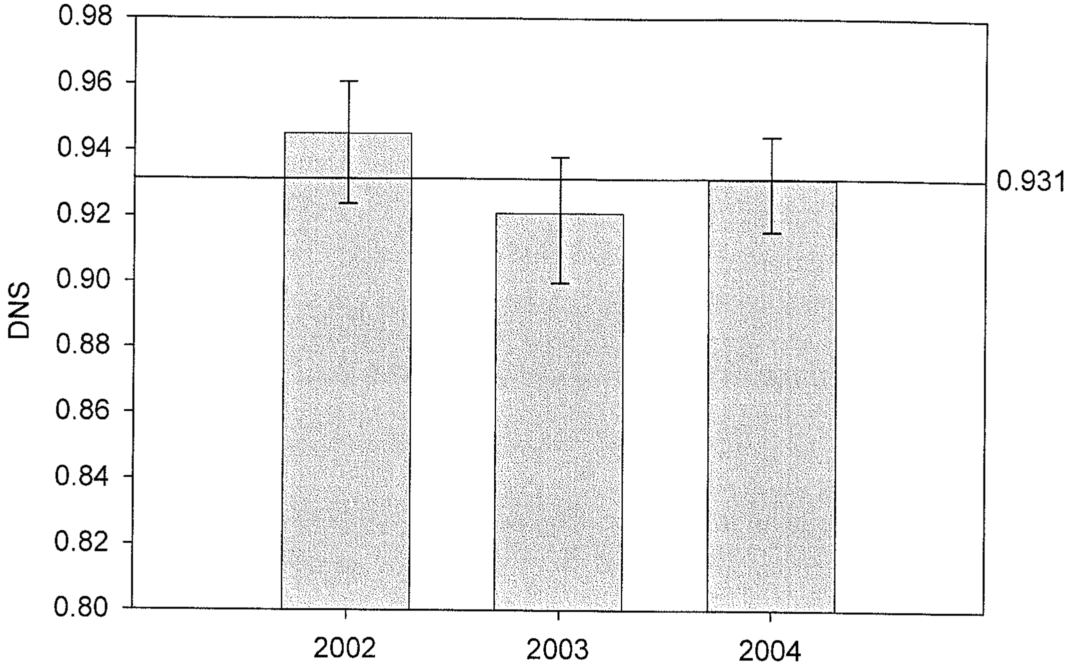

Figure 1. Daily nest survival (DNS) rates of ground nesting birds during 2002-2004 on private rangelands on the Nebraska Sandhills. Horizontal line is overall DNS.

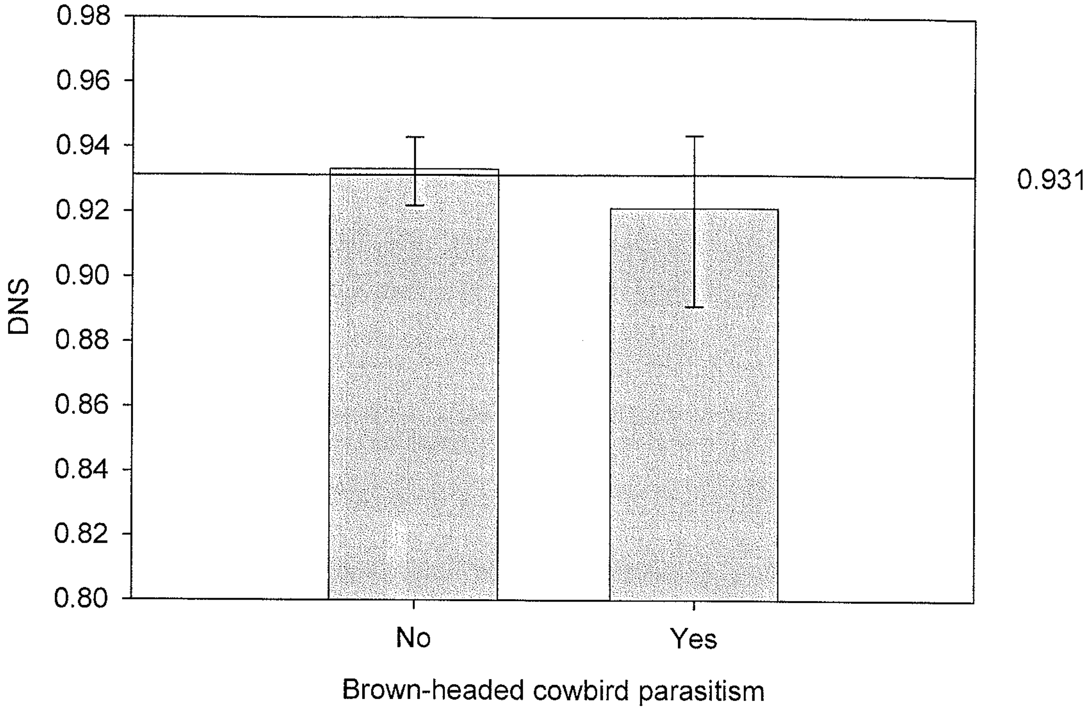

Figure 2. Daily nest survival rates (DNS) of parasitized and unparasitized nests on private rangelands in the Nebraska Sandhills 2002-2004. Horizontal line is overall DNS.

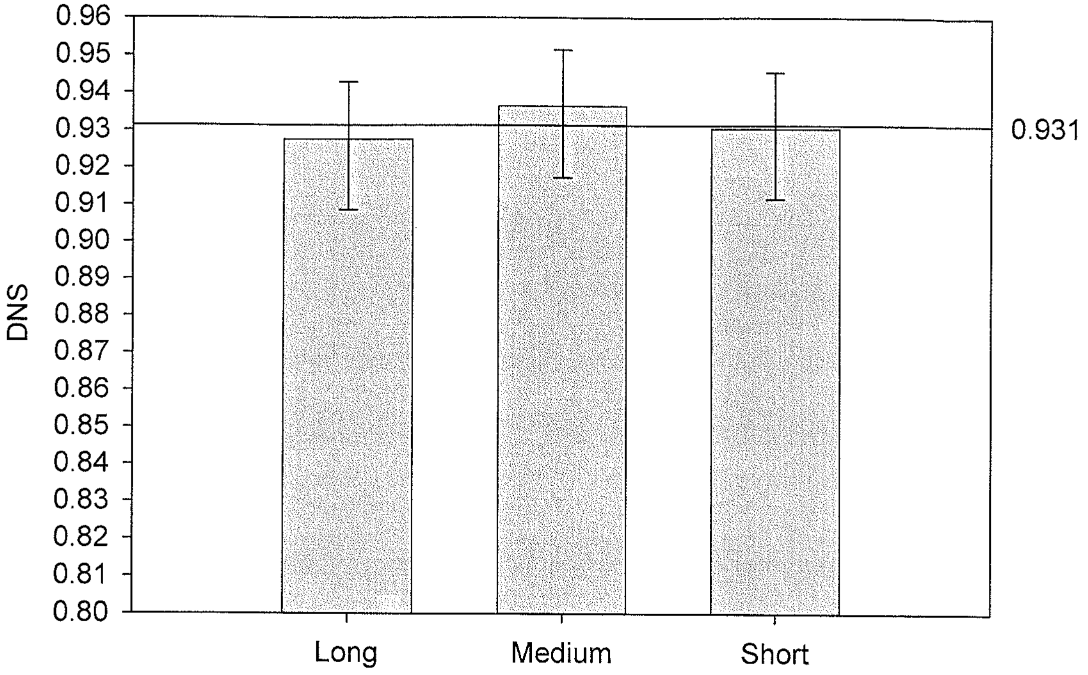

Figure 3. Daily nest survival rates (DNS) of species nesting on private lands managed by one of three grazing systems (long, medium, and short rotations) in the Nebraska Sandhills 2002-2004. Horizontal line is overall DNS

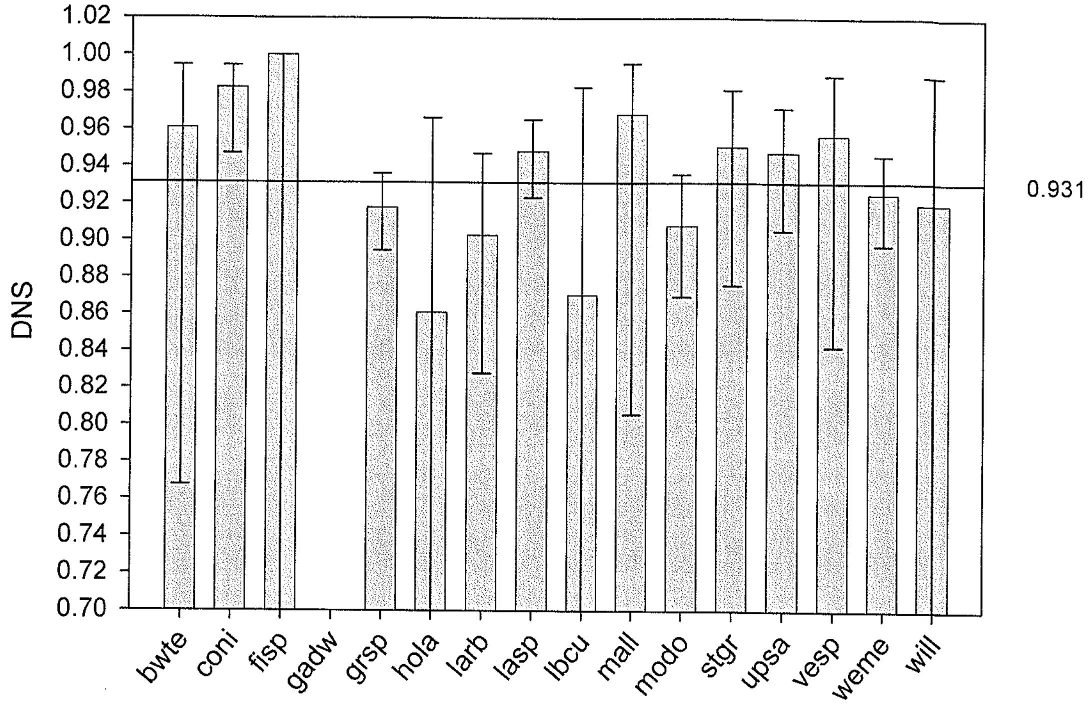

Figure 4. Daily nest survival rates (DNS) of species nesting on private lands managed by three grazing systems in the Nebraska Sandhills 2002-2004; bwte: blue-winged teal, coni: common nighthawk, fisp: field sparrow, gadw: gadwall, grsp: grasshopper sparrow, hola: horned lark, larb: lark bunting, lasp: lark sparrow, lbcu: long-billed curlew, mall: mallard, modo: mourning dove, stgr: sharp-tailed grouse, upsa: upland sandpiper, vesp: vesper sparrow, weme: western meadowlark, will: willet.

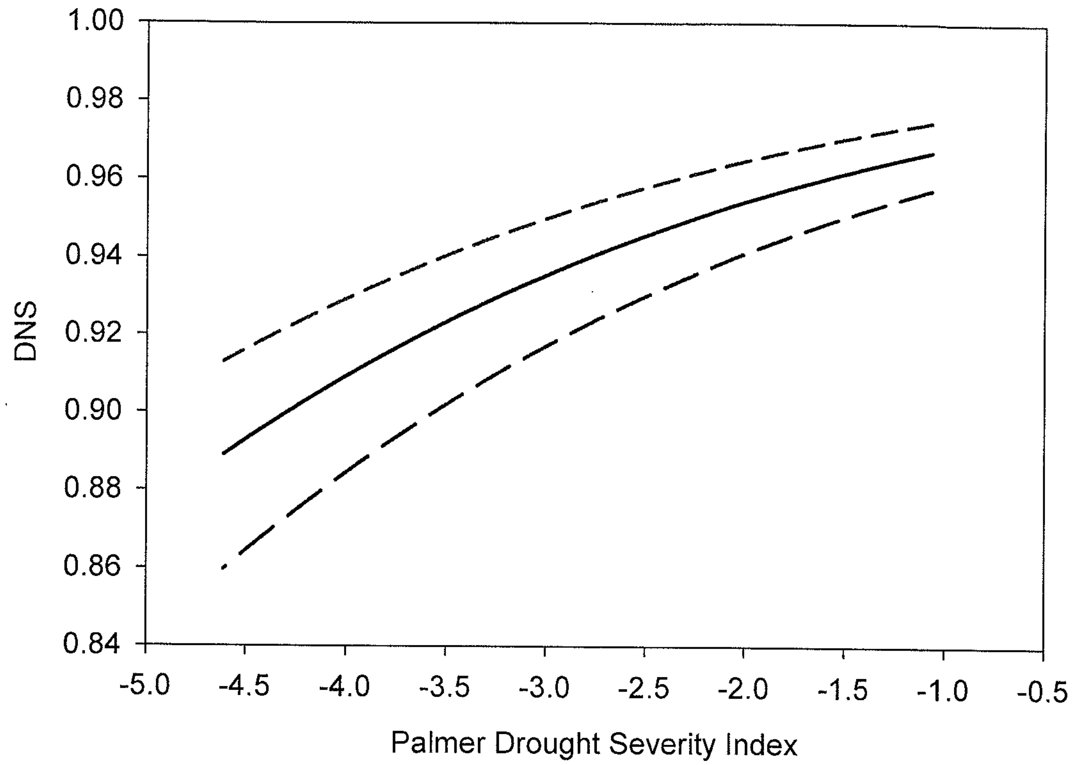

Figure 5. Model predicted daily nest survival (DNS) rates using Palmer drought severity index (PDSI; a measure of precipitation, temperature and soil moisture used to indicate drought) for grassland birds nesting on private rangeland managed by one of three grazing systems (long, medium, or short) in the Nebraska Sandhills, 2002-2004. Solid black line is predicted DNS; dashed grey lines are upper and lower 95% confidence intervals

APPENDIX I

Figure 1. Location of our study area in eastern Cherry and northern Thomas counties in Nebraska, USA

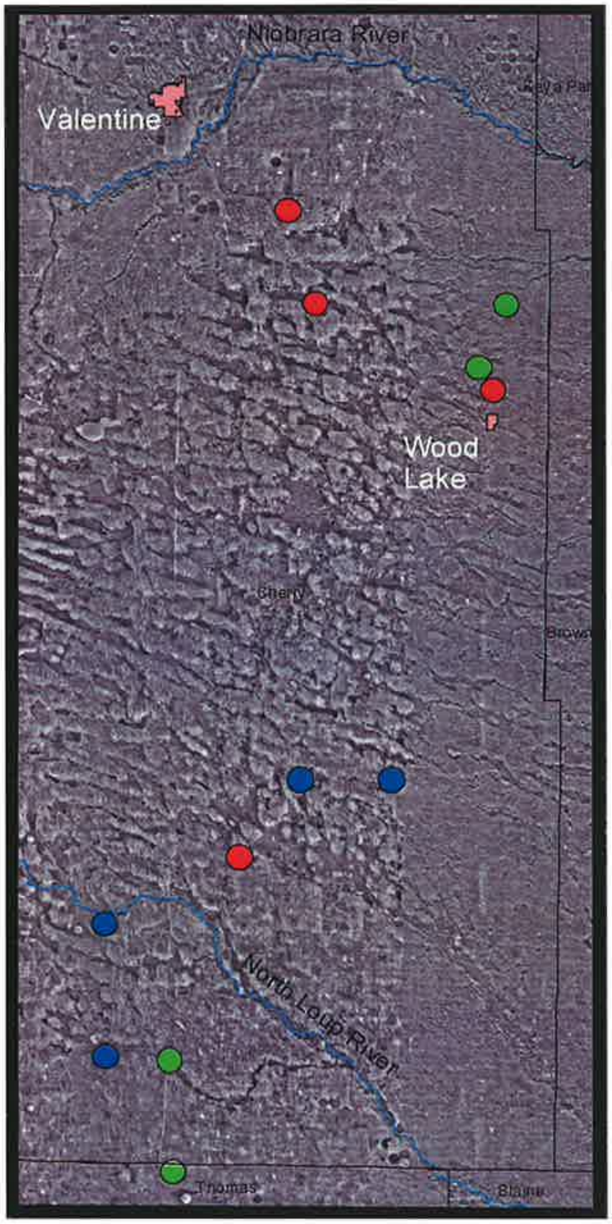

Figure 2. Location of study sites, by grazing treatment in eastern Cherry and northern Thomas Counties, Nebraska, 2002-2004; red: long duration, green: medium duration, blue: short duration.

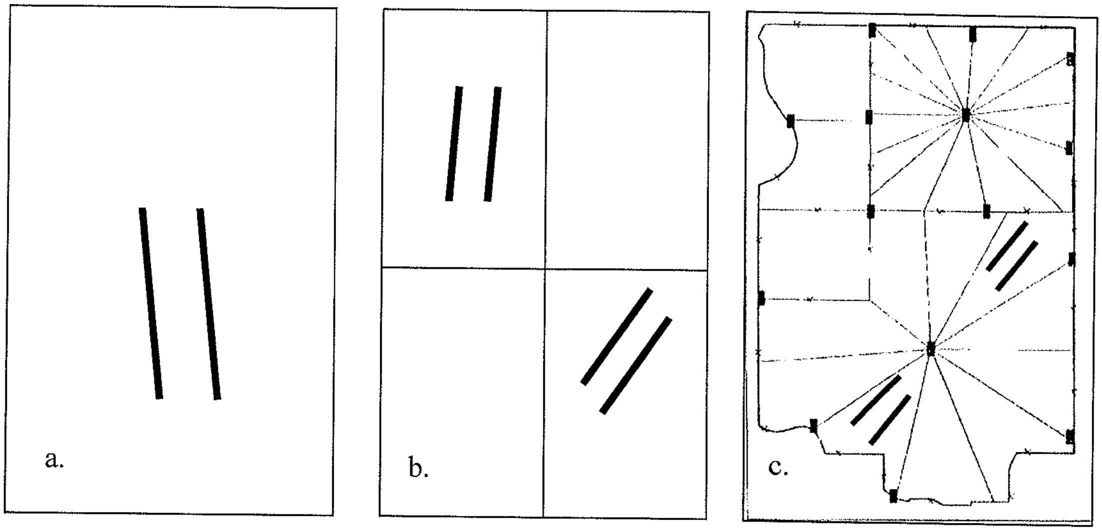

Figure 3. Hypothetical illustration of transect layout, length and spacing of transects used to sample grassland structure and bird species richness, density, and productivity on long (a), medium (b), and short (c) duration grazing systems used on private rangelands in the Nebraska Sandhills, 2002-2004. Transect length = 1,500 m on long duration systems and 750 m on medium and short duration systems. Distance between all transects is 250 m. Pasture shapes and transect are not to scale; Figure 3c is after Fuhlendorf, S. D. and D. M. Engle (2001). Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. Actual pasture shapes and sizes vary from those shown here.

APPENDIX II

Table 1. Description of grazing system treatments (long, medium, and short duration rotations) during the growing season (1 May to 30 September) on private rangelands in the Nebraska Sandhills, 2002-2004.

	Growing Season Grazing							
	2002		2003		2004		study	
Variable	$\bar{x}$	SD, n	$\bar{x}$	SD, n	$\bar{x}$	SD, n	$\bar{x}$	SD, n
Herd Size								
long	170	(51, 4)	144	(57, 4)	161	(42, 4)	158	(47, 12)
medium	262	(81, 6)	167	(95, 11)	188	(107, 11)	196	(101, 28)
short	531	(129, 8)	842	(202, 10)	555	(386, 11)	626	(295, 29)
Pasture Size (estimated ha)								
long	623	(248, 3)	549	(252, 4)	559	(308, 3)	574	(239, 10)
medium	240	(146, 5)	182	(137, 8)	182	(137, 8)	196	(134, 21)
short	90	(34, 3)	79	(35, 8)	79	(35, 8)	82	(33, 19)
Duration (days)								
long	71	(25, 4)	97	(21, 4)	65	(25, 4)	78	(26, 12)
medium	22	(16, 6)	26	(30, 11)	20	(18, 11)	23	(23, 28)
short	3	(2, 8)	3	(2, 10)	4	(2, 11)	3	(2, 29)
Stocking Rate (AUM/ha)[a]								
long	1.27	(0.83, 3)	1.40	(0.66, 4)	1.64	(1.75, 3)	1.4	(0.96, 11)
medium	1.92	(0.57, 3)	1.13	(0.63, 4)	1.05	(0.65, 4)	1.32	(0.68, 11)
short	2.87	(1.82, 3)	0.67	(0.23, 4)	1.06	(0.36, 4)	1.42	(1.27, 11)
Stocking Density (# animals/ha)								
long	0.5	(0.16, 4)	0.6	(0.23, 4)	0.7	(0.45, 3)	0.6	(0.26, 11)
medium	2.6	(1.79, 6)	2.4	(1.87, 11)	2.5	(2.57, 11)	2.5	(2.10, 28)
short	9.1	(5.45, 8)	15.5	(6.88, 9)	9.6	(5.4, 11)	11.0	(6.30, 29)

[a] pasture average for two paddocks studied in each medium and short duration system

Table 2. Description of grazing system treatments (medium and short duration rotations) during the dormant season (1 October to 30 April) on private rangelands in the Nebraska Sandhills, 2003-2004.

	Dormant Season Grazing					
	2003		2004		study	
Variable	$\bar{x}$	SD, n	$\bar{x}$	SD, n	$\bar{x}$	SD, n
Herd Size						
medium	210	(102, 6)	271	(135, 5)	238	(116, 11)
short	612	(258, 6)	424	(184, 6)	518	(235, 12)
Pasture Size (estimated ha)						
medium	175	(114, 5)	237	(150, 5)	206	(130, 10)
short	88	(40, 5)	85	(50, 4)	87	(42, 9)
Duration (days)						
medium	53	(47, 6)	33	(13, 5)	44	(35, 11)
short	5	(2, 6)	4	(2, 6)	4	(2, 12)
Stocking Rate (AUM/ha)[a]						
medium	3.30	(1.82, 4)	1.76	(0.54, 4)	1.74	(1.72,8)
short	0.86	(0.62, 4)	1.15	(0.07, 2)	0.72	(0.61,8)
Stocking Density (# animals/ha)						
medium	1	(1, 6)	2	(2, 5)	2	(1, 11)
short	7	(3, 6)	6	(1, 6)	7	(2, 12)

[a] average for two paddocks studied in each medium and short duration pasture replicate.

APPENDIX III

Table 1. Detection function level, selected model, and fit for grassland bird species densities on private rangeland in the Nebraska Sandhills, 2002.

Species	Level	g(x)=	key=	adjust=	GOF=
Brown-headed cowbird	Long	strata	uniform	cosine	0.8625
	Medium	strata	uniform	cosine	0.2785
	Short	strata	uniform	cosine	0.9191
Field sparrow	Sandhills	global	hazard rate	cosine	0.9663
Grasshopper sparrow	L2	sample	uniform	simple polynomial	0.6006
	L3	sample	half normal	cosine	0.3782
	L4	sample	uniform	simple polynomial	0.2711
	M1	sample	hazard rate	cosine	0.6650
	M3	sample	hazard rate	cosine	0.2163
	M4	sample	uniform	cosine	0.5651
	S1	sample	half normal	cosine	0.7488
	S3	sample	half normal	hermite polynomial	0.8997
	S4	sample	half normal	hermite polynomial	0.9135
Lark bunting	Sandhills	global	uniform	cosine	0.7373
Lark sparrow	Long	strata	hazard rate	cosine	0.9973
	Medium	strata	half normal	cosine	0.9252
	Short	strata	half normal	hermite polynomial	0.6528
Mourning Dove	Long	strata	uniform	simple polynomial	0.6558
	Medium	strata	hazard rate	cosine	0.8586
	Short	strata	half normal	hermite polynomial	0.6781
Upland sandpiper	Long	strata	uniform	simple polynomial	0.9873
	Medium	strata	uniform	cosine	0.6606
	Short	strata	half normal	cosine	0.8025
Western meadowlark	L2	sample	half normal	cosine	0.3660

L3	sample	uniform	simple polynomial	0.6700
L4	sample	hazard rate	cosine	0.3580
M1	sample	half normal	cosine	0.9864
M3	sample	uniform	simple polynomial	0.4378
M4	sample	hazard rate	cosine	0.8643
S1	sample	uniform	cosine	0.7568
S3	sample	uniform	cosine	0.6113
S4	sample	uniform	simple polynomial	0.2221

Table 2. Detection function level, selected model, and fit for grassland bird species densities on private rangeland in the Nebraska Sandhills, 2003.

Species	Level	g(x)=	key=	adjust =	GOF=
Brown-headed cowbird	Long	strata	half normal	cosine	0.999
	Medium	strata	uniform	cosine	0.634
	Short	strata	uniform	cosine	0.817
Common nighthawk	Sandhills	global	hazard rate	cosine	0.711
Field sparrow	Sandhills	global/av	half normal	cosine	0.578
Grasshopper sparrow	L1	sample	hazard rate	cosine	0.110
	L2	sample	hazard rate	cosine	0.851
	L3	sample	uniform	cosine	0.280
	L4	sample	uniform	polynomial	0.148
	M1	sample	half normal	cosine	0.690
	M2	sample	uniform	cosine	0.475
	M3	sample	uniform	polynomial	0.455
	M4	sample	hazard rate	cosine	0.059
	S1	sample	hazard rate	cosine	0.930
	S2	sample	hazard rate	cosine	0.497
	S3	sample	hazard rate	cosine	0.581
	S4	sample	uniform	polynomial	0.171
Horned lark	L1	sample	uniform	polynomial	0.707
	L2	sample	half normal	hermite polynomial	0.692
	L3	sample	uniform	simple polynomial	0.949
	L4	sample	uniform	cosine	0.875
	M1	sample	uniform	cosine	0.917
	M2	sample	half normal	cosine	0.359
	M3	sample	uniform	simple polynomial	0.969
	M4	sample	half normal	cosine	0.882
	S1	sample	uniform	simple polynomial	0.404
	S2	sample	uniform	simple polynomial	0.341
	S3	sample	hazard rate	cosine	0.222
	S4	sample	uniform	simple	0.999

Killdeer	Long	strata	uniform	polynomial cosine	0.648
	Medium	strata	uniform	simple polynomial	0.580
	Short	strata	uniform	simple polynomial	0.861
Lark sparrow	L1	sample	uniform	cosine	0.935
	L2	sample	hazard rate	cosine	0.880
	L3	sample	uniform	simple polynomial	0.965
	L4	sample	hazard rate	cosine	0.999
	M1	sample	uniform	simple polynomial	0.341
	M2	sample	uniform	simple polynomial	0.955
	M3	sample	hazard rate	cosine	0.271
	M4	sample	half normal	cosine	0.777
	S1	sample	uniform	simple polynomial	0.605
	S2	sample	half normal	cosine	0.613
	S3	sample	hazard rate	cosine	0.961
	S4	sample	half normal	cosine	0.999
Mourning dove	Sandhills	global	hazard rate	cosine	0.807
Red-winged black bird	Long	strata	uniform	simple polynomial	0.988
	Medium	strata	uniform	simple polynomial	0.086
	Short	strata	uniform	simple polynomial	0.987
Sharp-tailed grouse	L1	sample	uniform	polynomial	0.630
	L2	sample	uniform	polynomial	0.610
	L3	sample	uniform	polynomial	0.413
	L4	sample	uniform	polynomial	0.618
	M1	sample	uniform	polynomial	0.821
	M2	sample	half normal	cosine	0.821
	M3	sample	uniform	polynomial	0.369
	M4	sample	uniform	polynomial	0.984
	S1	sample	half normal	cosine	0.662
	S2	sample	uniform	polynomial	0.827
	S3	sample	uniform	polynomial	0.519
	S4	sample	uniform	polynomial	0.740
Upland	L1	sample	half normal	cosine	0.458

sandpiper					
	L2	sample	uniform	polynomial	0.727
	L3	sample	uniform	cosine	0.601
	L4	sample	hazard rate	cosine	0.978
	M1	sample	hazard rate	cosine	0.472
	M2	sample	half normal	hermite polynomial	0.587
	M3	sample	half normal	cosine	0.242
	M4	sample	uniform	polynomial	0.874
	S1	sample	hazard rate	cosine	0.932
	S2	sample	hazard rate	cosine	0.994
	S3	sample	half normal	cosine	0.493
	S4	sample	half normal	hermite polynomial	0.909
Vesper sparrow	Long	strata	half normal	hermite polynomial	0.618
	Medium	strata	uniform	simple polynomial	0.411
	Short	strata	uniform	cosine	0.814
Western meadowlark	L1	sample	hazard rate	cosine	0.743
	L2	sample	half normal	cosine	0.459
	L3	sample	uniform	polynomial	0.548
	L4	sample	uniform	polynomial	0.310
	M1	sample	half normal	cosine	0.950
	M2	sample	half normal	cosine	0.813
	M3	sample	half normal	cosine	0.469
	M4	sample	uniform	polynomial	0.789
	S1	sample	hazard rate	cosine	0.826
	S2	sample	hazard rate	cosine	0.532
	S3	sample	uniform	polynomial	0.981
	S4	sample	hazard rate	cosine	0.993

Table 3. Detection function level, selected model, and fit for grassland bird species densities on private rangeland in the Nebraska Sandhills, 2004.

Species	Level	g(x)=	key=	adjust=	GOF=
Brown-headed cowbird	L1	sample	uniform	cosine	0.6662
	L2	sample	hazard rate	cosine	0.5877
	L3	sample	uniform	polynomial	0.0962
	L4	sample	half normal	cosine	0.5650
	M1	sample	half normal	cosine	0.6618
	M2	sample	uniform	polynomial	0.8814
	M3	sample	uniform	simple polynomial	0.8022
	M4	sample	half normal	cosine	0.9487
	S1	sample	half normal	cosine	0.9954
	S2	sample	uniform	cosine	0.7121
	S3	sample	uniform	simple polynomial	0.8239
	S4	sample	uniform	cosine	0.8717
	Sandhills	strata	uniform		0.9101
Common Nighthawk	Long	strata	uniform	cosine	0.6970
	Medium	strata	uniform	polynomial	0.4493
	Short	strata	uniform	polynomial	0.6950
Grasshopper sparrow	Long	strata	hazard rate	cosine	0.0524
	Medium	strata	hazard rate	cosine	0.3194
	Short	strata	hazard rate	cosine	0.2615
Horned lark	Sandhills	global	half normal	hermite	0.7772
Lark bunting	Sandhills	global	uniform	simple polynomial	0.9489
Lark sparrow	Sandhills	global	uniform	cosine	0.9341
Mourning dove	Sandhills	global/av	half normal	cosine	0.0872
Red-winged black bird	Long	strata	uniform	polynomial	0.5765

	Medium	strata	uniform	cosine	0.3674
	Short	strata	uniform	polynomial	0.8736
Sharp-tailed grouse	L1	sample	uniform	polynomial	0.9317
	L2	sample	uniform	cosine	0.7248
	L3	sample	half normal	cosine	0.2028
	L4	sample	uniform	polynomial	0.7733
	M1	sample	uniform	polynomial	0.9885
	M2	sample	uniform	polynomial	0.9757
	M3	sample	uniform	cosine	0.7581
	M4	sample	uniform	polynomial	0.9275
	S1	sample	uniform	polynomial	0.7878
	S2	sample	uniform	cosine	0.7209
	S3	sample	uniform	cosine	0.9811
	S4	sample	uniform	polynomial	0.9483
Upland sandpiper	Sandhills	global	half normal	cosine	0.9947
Vesper sparrow	Long	strata	half normal	cosine	0.9236
	Medium	strata	hazard rate	cosine	0.9568
	Short	strata	half normal	hermite	0.9997
Western meadowlark	Long	strata	half normal	hermite	0.4992
	Medium	strata	uniform	polynomial	0.2040
	Short	strata	half normal	hermite	0.9297

Table 4. Components of the coefficient of variation (CV), measured in proportion of total sampling error for species found on private rangelands in the Nebraska Sandhills, 2002-2004. Proportions for CV components add to 100% for each combination of year and species

	CV component (% sampling error)			
Species / year	Detection Probability	Encounter rate	Cluster size	Sample size
Brown-headed Cowbird				
2002	5.29	69.33	25.38	9
2003	9.75	61.32	28.93	12
2004	31.93	48.63	19.43	12
pooled	15.7	59.8	24.6	
Common Nighthawk				
2002	--	--	--	--
2003	40.78	51.35	7.88	12
2004	26.77	65.71	7.52	12
pooled	33.8	58.5	7.7	
Field Sparrow				
2002	41.80	57.80	0.40	3
2003	29.83	69.20	0.97	3
2004	--	--	--	--
pooled	35.8	63.5	0.7	
Grasshopper Sparrow				
2002	51.17	48.58	0.26	9
2003	43.97	55.64	0.38	12
2004	22.29	77.13	0.57	12
pooled	39.1	60.4	0.4	
Horned Lark				
2002	--	--	--	--
2003	29.68	65.35	4.98	12
2004	4.10	85.90	9.99	12
pooled	16.9	75.6	7.5	
Killdeer				
2002	--	--	--	--
2003	6.53	84.82	8.66	9
2004	--	--	--	--
pooled	6.5	84.8	8.7	
Lark Bunting				

2002	9.66	89.74	0.58	5
2003	--	--	--	--
2004	6.42	81.82	11.76	5
pooled	8.0	85.8	6.2	
Lark Sparrow				
2002	20.64	74.31	5.03	9
2003	51.58	43.28	5.14	12
2004	10.51	81.49	7.99	12
pooled	27.6	66.4	6.1	
Mourning Dove				
2002	13.59	76.94	9.47	9
2003	33.19	58.37	8.46	12
2004	4.86	85.93	9.23	12
pooled	17.2	73.7	9.1	
Red-winged Blackbird				
2002	--	--	--	--
2003	7.28	79.85	12.88	10
2004	12.73	73.87	13.40	7
pooled	10.0	76.9	13.1	
Sharp-tailed Grouse				
2002	--	--	--	--
2003	41.32	44.36	14.32	12
2004	22.95	69.74	7.31	12
pooled	32.1	57.1	10.8	
Upland Sandpiper				
2002	13.58	81.41	5.03	8
2003	40.24	56.01	3.75	12
2004	9.20	85.78	5.00	12
pooled	21.0	74.4	4.6	
Vesper Sparrow				
2002	--	--	--	--
2003	11.07	88.82	0.12	9
2004	16.34	80.54	3.11	9
pooled	13.7	84.7	1.6	
Western Meadowlark				
2002	28.00	71.24	0.97	9
2003	47.01	51.13	1.87	12
2004	30.12	67.82	2.06	12
pooled	35.0	63.4	1.6	
Study Average	22.3	70.4	7.3	