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Stocking Rates and Vegetation Structure, Heterogeneity, and Community in a Northern Mixed-Grass Prairie☆

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ABSTRACT

Currently, livestock management in the North American Great Plains aims for even use of forage, which creates a homogenous landscape. Reintroducing heterogeneity, defined here as the variation in vegetation structure and composition, to native North American rangelands is imperative to maintaining grassland biodiversity, and using a variety of cattle stocking rates on the landscape could accomplish this. We assessed effects of stocking rates on northern mixed-grass prairie vegetation structure, structural heterogeneity, and plant species diversity. The study took place in Grasslands National Park in Saskatchewan, Canada, using nine pastures (~300 ha) that were grazed at a range of stocking rates from very low to very high for this region. Three of these pastures were ungrazed controls. We used generalized linear mixed models to describe effects of stocking rate on vegetation over 4 years, following the reintroduction of livestock grazing to this landscape after 15 years without grazing. We used a Mantel test to determine whether plant communities changed with varying stocking rates and over time. Effects of grazing on many response variables were cumulative and changed over time. Species richness in uplands increased with stocking rate and time, but richness decreased with stocking rate in lowlands. Heterogeneity generally increased with stocking rate and time in upland but not lowland habitats. While natural annual variability influenced many variables, the cumulative effects of grazing were still apparent. A variety of stocking rates could be used to maximize structural heterogeneity and provide a diversity of habitat structure at the landscape scale.

Introduction

North American grasslands evolved under the influence of disturbances such as fire and grazing, and one or both forms of disturbance are needed to maintain structural and compositional heterogeneity, and therefore biodiversity, in these ecosystems (Collins and Barber, 1986; Fuhlendorf and Engle, 2001; Fuhlendorf et al., 2012; Knapp et al., 1999; Hart, 2001). Widespread fire suppression is practiced across the North American Great Plains to protect human assets, and thus the only practical ecological disturbance that can be used to promote ecological heterogeneity at a large spatial scale is grazing by livestock. However, typical cattle grazing practices, by encouraging uniform distributions of grazing animals in space or time to maximize the use of forage (Teague and Dowhower, 2003), have led to a decrease in heterogeneity (Fuhlendorf and Engle, 2001; Fuhlendorf et al., 2012). Alternatively, by introducing "conservation grazing," cattle grazing management could be transformed into a tool that can restore heterogeneity to prairie communities (Fuhlendorf et al., 2012).

Different stocking rates (number of cattle per unit area and time) can have divergent ecological effects. Many studies suggest moderate stocking rates are most sustainable (e.g. Biondini et al., 1998) because they result in predictable cattle weight gains and do not lead to deterioration of rangeland. This approach is known colloquially as "managing for the middle" (Fuhlendorf et al., 2012) or "take half, leave half." However, using a single stocking rate throughout each ecoregion does not provide all types of habitat preferred or needed by species that evolved with more diverse grazing intensities (Fuhlendorf et al., 2012). Further, while foraging selectivity and thus structural patchiness may be maximized at intermediate stocking rates under some management regimens (Fuhlendorf and Smeins, 1999), this may not occur in small pastures or those with well-distributed water sources (Fuhlendorf et al., 2012). Although other studies have compared effects of various stocking rates on vegetation (e.g., Gillen et al., 2000; Hart, 2001; Manley et al., 1997; Vermeire et al., 2008), few have evaluated their potential effects, within and among pastures, and over time, with the objective of restoring heterogeneity at landscape scales by using grazing as a conservation tool.

Here, we define heterogeneity as the variation in vegetation structure and composition at one or more scales (Fuhlendorf and Engle,

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2001). While one contributor to grassland heterogeneity is the distribution and extent of livestock foraging patches, at a smaller spatial scale, heterogeneity is influenced by plant species diversity. Plant species richness is hypothesized to vary with stocking rate depending on the productivity and evolutionary grazing history of a rangeland (Milchunas et al., 1988). The northern mixed-grass prairie of Canada and the United States occurs at the climatic interface between semiarid and subhumid sites used by Milchunas et al. (1988) to derive this general theory, and thus its predictions for this region are not clear. However, diversity may be maximized at intermediate durations or intensities of grazing disturbance, at which point overlap between grazing tolerant and intolerant species is presumably maximized (Cingolani et al., 2005; Milchunas et al., 1988). There have been few studies conducted in the mixed-grass prairie where this semiarid versus subhumid model has been tested, and the results are mixed (e.g., Bai et al., 2001; Biondini et al., 1998; Willms et al., 2002).

The primary objective of this study was to assess how grazing can be used as a conservation tool by evaluating effects of introducing livestock at a range of stocking rates to a previously ungrazed northern mixed-grass prairie, on 1) vegetation structure, 2) structural heterogeneity, and 3) plant species diversity over the first 4 years after reintroducing livestock grazing. If the effects of livestock on vegetation structure change at different stocking rates because selectivity is inhibited at high stocking rates, but low stocking rates have few highly grazed patches, then we predicted that 1) vegetation structure would vary among stocking rates and 2) habitat heterogeneity within a single pasture would be maximized at moderate stocking rates and the landscape scale using multiple stocking rates. If most plant communities in mixed-grass prairies that evolved with grazing are adapted to this stressor, then we predicted that grazing at all stocking rates should increase plant diversity compared with the ungrazed control plots, as seen in previous studies (Bai et al., 2001; Hart, 2001; Manley et al., 1997), but that plant diversity would peak at moderate stocking rates because of the patchy distribution of both grazing-tolerant and grazing-intolerant plant communities (Cingolani et al., 2005; Milchunas et al., 1988). We also predicted that vegetation in lowland and upland habitats may respond differently to grazing, as communities within these habitats experience different biophysical pressures in addition to grazing.

Methods

Study Site

Grasslands National Park (GNP) in southern Saskatchewan, Canada, initiated an adaptive management, large-scale grazing experiment within the Biodiversity and Grazing Management Area (BAGMA) to assess the effects of different stocking rates on a suite of biodiversity and ecological integrity indicators in mixed-grass prairie. This experiment was unique in that the individual pasture units were very large, at approximately 300 ha each, relative to many other manipulative grazing experiments (e.g., Hart et al., 1988; Biondini et al., 1998; Fuhlendorf and Smeins, 1999). In addition, relative to each other, pastures had a similar distribution and arrangement of water, as well as upland and lowland habitats. Within BAGMA, we introduced naïve yearling steers each year, at a range of stocking rates, to a landscape that had been ungrazed for at least 15 years. Before reintroducing livestock to this landscape, we surveyed the habitat over 2 years to allow us to control for pre-existing ecological variation (for further detail see Koper et al., 2008).

The study site comprises approximately 26.5 km^2 of northern mixed-grass prairie (Coupland, 1950) in the East Block of GNP in southern Saskatchewan, Canada, at approximately lat 49°01′00″N, long 106°49′00″W (Koper et al., 2008). This area had only intermittent and light livestock grazing from the 1930s until Parks Canada purchased the land in 1990–1991, after which livestock grazing ceased. The site is not fragmented by cultivation, and there were few trails or cross-fences present. Mean annual precipitation is approximately 352 mm, with the majority of the precipitation falling in the form of rain during the spring and summer months (Environment Canada, 2013a). In the grazing season (May–August), mean annual precipitation is 212 mm, with June usually being the wettest month. Mean annual temperature is 4.1°C, with reported extreme temperatures of −49°C and +41°C (Environment Canada, 2013a).

The experimental area is characteristic of northern mixed-grass prairie and includes upland habitat and lowland habitat adjacent to riparian zones. Upland areas were dominated by grasses such as blue grama grass (C_4 grass; *Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), speargrass (C_3 grass; *Hesperostipa comata* [Trin & Rupr.] Barkworth), northern and western wheatgrasses (both C_3 grasses; *Elymus lanceolatus* [Scribn. & J.G. Sm.] Á. Löve and *Pascopyrum smithii* [Rydb.] Á. Löve), and June grass (C_3 grass; *Koeleria macrantha* [Ledeb.] Schult). Pasture sage (*Artemisia frigida* Willd.), scarlet mallow (*Sphaeralcea coccinea* [Nutt.] Rydb.), and moss phlox (*Phlox hoodii* Richardson) were the dominant forbs, and little clubmoss (*Selaginella densa* Rybd.) was also found throughout the upland areas. Lowland areas were distinguished by an additional shrub component of western snowberry (*Symphoricarpos occidentalis* Hook.), wild prickly rose (*Rosa acicularis* Lindl.) and silver sagebrush (*Artemisia cana* Pursh). Predominant forbs in the lowlands included Canada goldenrod (*Solidago canadensis* L.) and wild licorice (*Glycyrrhiza lepidota* Pursh).

The study followed a Beyond-BACI design (Koper et al., 2008; Underwood, 1994) and consisted of nine pastures, each approximately 300 ha in area (pastures 1–9, Fig. 1). Two years of baseline data were collected in the summers of 2006 and 2007 on the ungrazed prairie before cattle were reintroduced to the park from 2008–2011. Six of the pastures were grazed at a range of stocking rates, two with the intention of removing approximately 70% biomass (Pastures 4, 8; Fig. 1), and four were grazed aiming for approximately 57% (Pasture 3), 45% (Pasture 7), 32% (Pasture 6), and 20% (Pasture 2) biomass removal, respectively. The remaining three pastures (Pastures 1, 5, 9) were ungrazed and considered controls (Koper et al., 2008). These stocking rates were selected as they were at, below, and above the average stocking rates for the region (Koper et al., 2008). The control pastures were evenly distributed throughout the project to capture the natural variation of the landscape, ensure dispersion, and minimize the construction of unnecessary fences. Stocking rates were initially randomly assigned to each pasture; however, to accommodate a different research project studying the effects of grazing on water quality, two of the randomly assigned treatments were switched so that higher-grazed treatments were located downstream of the lighter-grazed pastures on the two streams running through the study site, while still ensuring dispersion across the study site overall. Variance among pastures could be estimated without replication of specific stocking rates, as we treated stocking rate as a continuous rather than a categorical variable and thus could estimate variance around the regression line rather than within individual treatment levels. Elsewhere we demonstrated that this is the more statistically powerful approach to addressing effects of stocking rates compared with treating stocking rate as a categorical variable (Koper et al., 2008).

The 4-year average of the stocking rates were 0.83 and 0.77, 0.69, 0.56, 0.38, and 0.24 animal unit months per hectare (AUMs · ha^{-1}; Fig. 1). These stocking rates range between very low to very high for our region; the average stocking rate in four adjacent community pastures was 0.40 AUM · ha^{-1} (SD = 0.09 AUM · ha^{-1}), which is typical for the area. Long-term average forage production estimates for equivalent range ecosites were used to set these stocking rates to achieve biomass removal targets (Koper et al., 2008), but attempts at field verification of the utilization rates from year to year were unsuccessful because of the large size and natural variability within each pasture.

Vegetation Sampling

While the experimental unit was the pasture scale for some analyses, we further subdivided each pasture into plots. Each pasture