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Short communication

Spatial heterogeneity stabilizes livestock productivity in a changing climate

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ABSTRACT

Sustaining livestock agriculture is important for global food security. Livestock productivity, however, can fluctuate due to many environmental factors, including climate variability. Current predictions of continued warming, decreased precipitation, and increased climate variability worldwide raise serious questions for scientists and producers alike. Foremost is understanding how to mitigate livestock production losses attributed to climate extremes and variability. We investigated the influence of spatial heterogeneity on livestock production over six years in tallgrass prairie of the southern Great Plains, USA. We manipulated heterogeneity by allowing fire and grazing to interact spatially and temporally at broad scales across pastures ranging from 430 to 900 ha. We found that the influence of precipitation on livestock productivity was contingent upon heterogeneity. When heterogeneity was absent, livestock productivity decreased with reduced rainfall. In contrast, when heterogeneity was present, there was no relationship with rainfall and livestock productivity, resulting in heterogeneity stabilizing livestock productivity through time. With predicted increases in climate variability and uncertainty, managing for heterogeneity may assist livestock producers in adapting to climate change and in mitigating livestock productivity loss caused by climatic variability.

1. Introduction

Grasslands and rangelands occupy more of the Earth's surface than other major ecosystems (White et al., 2000). Of the many goods and services provided by these ecosystems, grazing by domestic livestock (primarily varying breeds of cattle, goat, and sheep) for agricultural production is the most widespread. The Great Plains of North America is no exception and includes grasslands and rangelands that support many livestock operations. Development of agriculture within this region through the 19th and 20th centuries resulted in a successful economic enterprise—cattle produced throughout the Great Plains constitute a significant portion of US meat production and farm income. The 2011 estimate of cattle and their gross income for the nation was 92 million individuals and $63 billion, respectively, with about half coming from states within the Great Plains (NASS, 2012).

Livestock productivity can fluctuate greatly due to many environmental factors, including precipitation and temperature. Current projections of continued warming threaten agriculture and livestock productivity globally (IPCC, 2013). The Great Plains region is in particular danger as temperature increases are significant and precipitation is predicted to mostly decrease (Karl et al., 2009). Severe droughts of the past century reduced livestock productivity across the Great Plains (Lockeretz, 1978). More recently, the droughts of 2011 resulted in billions of dollars lost in agricultural income. In the state of Texas alone, agricultural losses were estimated to exceed $5.2 billion in 2011, with half attributed to losses in livestock production (AgriLife Today, 2011). Events such as these raise serious questions about the effect of climate variability and climate change on livestock productivity. Knowing how to mitigate livestock productivity losses resulting from climate change and climate extremes is critical.

The level to which climate change will be damaging to livestock producers – and therefore food security – will ultimately depend upon the producer's ability to adapt to changing conditions (McCarthy et al., 2001). Livestock management practices that create and allow for both variability and adaptation are likely to be

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successful in mitigating adverse effects of climate change. Rangeland management, however, developed under a utilitarian paradigm focused on livestock use and has historically focused on creating and managing for homogeneity (Holechek et al., 2004). While such management practices have undoubtedly minimized extreme grazing effects and disturbances, they have also limited heterogeneity, biodiversity, and the overall conservation of pattern and process (Fuhlendorf et al., 2012). In addition to being essential in creating biodiversity, landscape heterogeneity also provides additional forage resources to livestock, allowing them to choose and select among forages to better meet dietary needs (Provenza et al., 2003).

In the Great Plains (as well as in numerous fire-prone grasslands around the world) the fire-grazing interaction is an ecological process that drives ecosystem structure and function (Fuhlendorf et al., 2009). This interaction occurs as grazing animals preferentially select burned patches. When fire occurs in spatially discrete patches across a landscape, grazing animals – including domestic livestock – will select recently burned patches over other areas with greater time since fire (Allred et al., 2011). As new patches are burned and fire moves around the landscape, grazing activity and concentration of animals will follow. This interaction between fire and grazing will shape the landscape and create heterogeneity at multiple scales (Archibald et al., 2005; Fuhlendorf and Engle, 2004). Integrating the fire-grazing interaction into livestock management advances the conservation of ecosystem pattern and process by promoting biodiversity and heterogeneity while retaining profitability (Limb et al., 2011). The fire-grazing interaction also has the ability to moderate inter-annual livestock productivity by providing landscape heterogeneity and increased forage resources.

In this paper we studied the influence of spatial heterogeneity created by the fire-grazing interaction on livestock production over six years in the southern Great Plains, USA. Our specific objectives were twofold: (1) examine the influence of pasture level heterogeneity and fire return interval on livestock weight gain and (2) examine trends of weight gain relative to growing season precipitation as a function of spatial heterogeneity. We manipulated heterogeneity by using the fire-grazing interaction at broad landscape scales across multiple large pastures. We show that spatial heterogeneity stabilizes livestock production, preventing weight gain reductions in dry years. Important to agricultural profitability and food security, incorporating heterogeneity into livestock management practices can reduce productivity loss caused by climatic extremes.

2. Methods

We examined the role of heterogeneity in livestock production at The Nature Conservancy Tallgrass Prairie Preserve, located in northeastern Oklahoma, USA. The preserve is a 16,000 ha natural area managed primarily for biodiversity (Hamilton, 2007). Livestock production is a secondary product as land is leased to producers for grazing. The plant community is primarily tallgrass prairie, with small patches of cross timbers forest. Dominant grasses include *Andropogon gerardii* Vitman, *Schizachyrium scoparium* (Michx.) Nash, *Panicum virgatum* L., and *Sorghastrum nutans* (L.) Nash. Cross timbers vegetation is dominated by woody species *Quercus stellata* Wang. and *Q. marilandica* Münchh. Grazing by domestic livestock occurs within seven pastures ranging from 430 to 900 ha. Pastures are stocked equally at a moderate level (2.4 AUM/ha) with yearling stocker steers. Cattle are present only during the growing season, April–September.

We used the fire-grazing interaction to create spatial heterogeneity. The attraction and preference of animals to recently burned areas creates forage heterogeneity and results in areas ranging from recently burned and heavily grazed (i.e., increased forage quality but reduced forage availability) to unburned and ungrazed (i.e., decreased forage quality but increased forage availability) within a pasture. We manipulated the number and relative size of burn patches within a pasture to establish a gradient of heterogeneity across all seven pastures. A pasture with one patch only represents homogeneity, as the entire pasture is burned and animals graze uniformly across the pasture (Fuhlendorf et al., 2006). As patch number increases and the relative size of a patch decreases, grazing animals will concentrate more heavily on such a patch, increasing the level of heterogeneity within the pasture (Allred et al., 2011). The number of patches within a pasture ranged from one (representing homogeneity) to eight (representing increased heterogeneity). Patches within pastures varied in the season of burn and fire return interval (Fig. 1). Pastures with two to four patches were burned in the spring (March–April), while pastures with four to eight patches were burned in the spring and summer (July–August). Application of fires began in 2008 and continued through 2013; only one patch was burned per pasture, season, and year. All pastures are in similar condition, with similar potential productivity, topo-edaphic features, and no land use legacy effects.

Livestock productivity for each pasture was evaluated by weight gain. Animals in each pasture were weighed en masse each year at their arrival in April and again at their departure in September. We calculated an average individual weight gain for each pasture by dividing total weight by total number of animals. We used ANOVA to examine differences in gain among number of patches and fire return interval (objective one). Due to the lack of replicates at these broad spatial scales (400–900 ha), time was substituted for spatial replication ($n = 6$ years for each pasture). We used linear regression ($\alpha = 0.10$) to examine livestock gain relative to growing season precipitation (objective two). We first examined correlations between weight gain and precipitation for each pasture individually. We then examined correlations between weight gain and precipitation based on two treatments: homogeneous (one pasture with one patch), and heterogeneous average (a mean of six pastures with two to eight patches). We performed all analysis in R (R Development Core Team, 2013).

3. Results

When examined by itself, livestock gain did not differ among the number of patches or fire return interval at the pasture level (objective one; Fig. 2). Whether a pasture was burned entirely (i.e., one patch) or had eight patches burned over four years, annual weight gain was similar when averaged over six years. Year to year variation was present, however, and was dependent upon growing season precipitation. In the six year period examined, growing season precipitation nearly doubled from the driest year to the wettest year. When pastures were examined individually, the correlation of livestock gain with growing season precipitation was only present in the pasture with one patch–the pasture where spatial heterogeneity was minimized (Fig. 3A). Examining pastures by treatment (homogenous and heterogeneous) revealed an interactive effect with precipitation ($y = 0.08 precipitation - 64.73 trt + 0.10 precipitation \times trt + 93.07$; $precipitation \times trt$; $p = 0.08$). Livestock weight gain increased with growing precipitation in the homogenous treatment ($y = 0.19 precipitation + 28.34$; $p = 0.01$, $R^2 = 0.80$) but had no relationship with growing season precipitation in the heterogeneous treatment (Fig. 3B; $p = 0.16$).

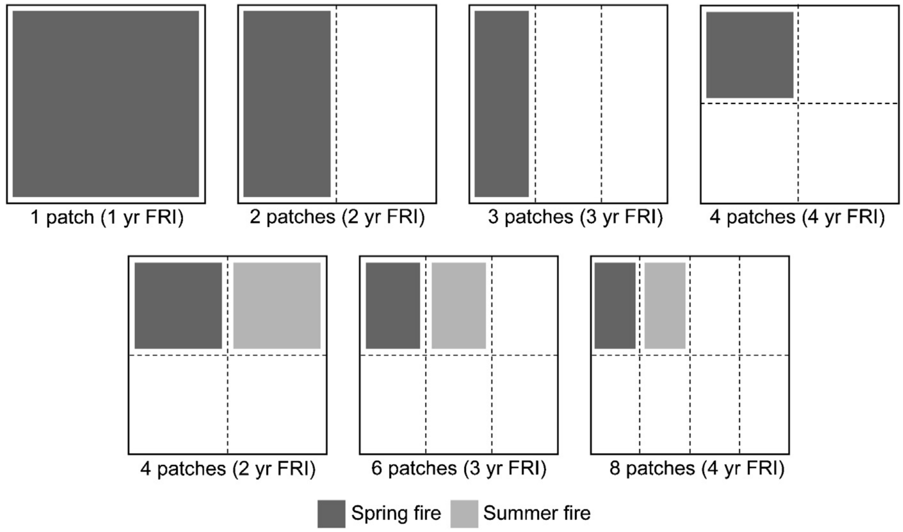

Fig. 1. Graphical illustration of the seven pastures studied at The Nature Conservancy Tallgrass Prairie Preserve, Oklahoma, USA. Pastures range in size from 430 to 900 ha. Illustration depicts the number of patches within each pasture, the fire return interval in years (FRI), and the season of burn (shading; spring: March–April; summer: July–August) of each patch. Application of fire began in 2008 and continued through 2013; only one patch was burned per season and year (i.e., dark shaded patch in the two-patch pasture was burned in spring 2008, 2010, and 2012; dark shaded patch in the eight-patch pasture was burned spring 2008 and 2012; light shaded patch in the eight-patch pasture was burned in summer 2008 and 2012). Only the perimeter of each pasture is fenced and animals have access to all patches within a pasture. The burning of spatially distinct patches within a pasture establishes the fire-grazing interaction and creates spatial heterogeneity. Increasing the number of patches (and decreasing relative size) creates greater heterogeneity within a pasture as animals selectively graze smaller areas.

4. Discussion

With increased drought and climatic variability predicted in the Great Plains due to climate change, spatial heterogeneity will provide a buffer against livestock productivity loss. We show that spatial heterogeneity within a pasture results in greater stability in annual cattle gains. Weight gains in pastures with two or more patches created by the fire-grazing interaction were not dependent upon precipitation. We also demonstrate that the fire-grazing interaction and heterogeneity management can be used as drought mitigation for livestock production. Equally important, heterogeneity management can be considered as a viable strategy to minimize the predicted negative effects of climate change, namely the increase in precipitation variability and uncertainty. The increasing of spatial variability within a pasture can subsequently stabilize temporal variability, potentially mediating disastrous economic losses from future climatic extremes.

Within pasture heterogeneity in this study was created using the fire-grazing interaction, an ecological process present in fire-prone grasslands around the world (Fuhlendorf et al., 2009). The application of spatially discrete or patchy fire influences grazing animal selection and results in heterogeneity of forage resources. This heterogeneity can mitigate drought and other climatic extremes by maximizing forage quality in recently burned areas while maintaining high forage quantity in other areas within a pasture (Allred et al., 2011). Using the fire-grazing interaction as a livestock management tool within fire-prone ecosystems will not only create forage heterogeneity to stabilize weight gains through time, but will also

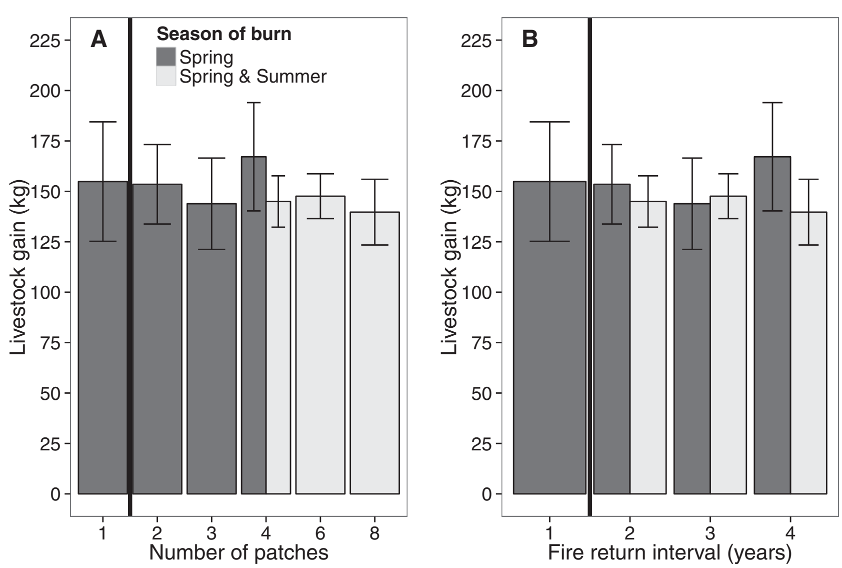

Fig. 2. Mean livestock gain (kg/head) in relation to (A) number of fire patches within a pasture and (B) fire return interval. Vertical line separates the homogeneous treatment from the heterogeneous treatments. There is no difference in weight gain among number of patches or fire return interval ($p > 0.10$). Bars represent a six-year average (2008–2013); error bars are one SE.

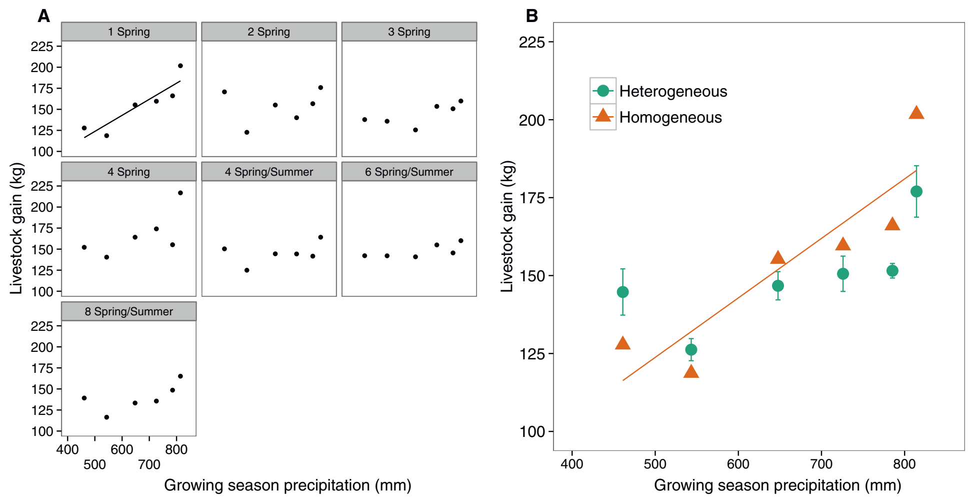

Fig. 3. Livestock gain (kg/head) in relation to growing season precipitation. (A) Individual relationships within studied pastures as illustrated in Fig. 1. The number represents the number of patches and the text represents the seasonality of fire. Livestock gain in pastures with more than one patch (indicating greater heterogeneity) did not correlate with growing season precipitation ($p > 0.10$). (B) Comparison of livestock gain for the homogenous (one patch; $n = 1$) and an average of heterogeneous treatments (two or more patches; $n = 6$). While the homogenous treatment had a significant relationship with growing season precipitation ($y = 0.19$*precipitation* $+ 28.34$; $p = 0.01$, $R^2 = 0.80$), the averaged heterogeneous treatment did not ($p = 0.16$). Error bars are one SE.

increase overall biodiversity (Skowno and Bond, 2003; Fuhlendorf et al., 2006). Such use of the fire-grazing interaction is an application of conserving ecosystem pattern and process while maintaining livestock management goals and objectives (Fuhlendorf et al., 2012).

Spatial variability is the precursor to biodiversity and should be a foundation for both management and conservation (Wiens, 1997). The conservation of ecological processes and biodiversity needs to be integrated into rangeland management for the sustainability of the full suite of ecosystem services valued by society. The use of the fire-grazing interaction in managing livestock and rangelands accomplishes this by increasing biodiversity at multiple levels (Churchwell et al., 2008; Doxon et al., 2011; Fuhlendorf et al., 2006). Furthermore, the shifting mosaic created by fire and grazing has direct livestock handling benefits, such as manipulating grazing in order to overcome constraints such as topography or distance to water (Vermeire et al., 2004) or reducing horn flies and ticks – two of the most economically damaging ecto-parasites (Scasta et al., 2012; Polito et al., 2013).

Precipitation and stocking rate are the leading factors that drive livestock production in tallgrass prairies and other grasslands throughout the Great Plains (McCollum et al., 1999; Holechek et al., 2004; Reeves et al., 2014). Other factors, including management schemes, grazing systems, etc. are secondary but are commonly used to increase livestock performance or to achieve a desired ecosystem objective. The use of the fire-grazing interaction is unique in that it is similar to the portfolio effect – providing stability in weight gains through diversity of forage resources. Such stability, however, is not completely exempt from precipitation, as extreme decreases in rainfall will likely affect livestock productivity. Likewise, the stocking rate of livestock production systems will affect the fire-grazing interaction and influence the subsequent heterogeneity and diversity of forage resources (McGranahan et al., 2012).

5. Conclusion

Our results show that spatial heterogeneity created by the fire-grazing interaction decouples the relationship of livestock production and precipitation in the Great Plains. The fire-grazing interaction creates spatial variation in both forage availability and quality (Allred et al., 2011), mediating the negative effects of reduced vegetation on weight gain during abnormally dry years. While the use of the fire-grazing interaction has largely been developed on the basis of restoring developmental drivers of spatial heterogeneity and biodiversity in fire-prone ecosystems, our results demonstrate that it has beneficial effects for sustainable livestock production. Managing for heterogeneity will aid producers in adapting to climatic variability while integrating agricultural production and biodiversity conservation goals simultaneously.

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