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Inconsistent outcomes of heterogeneity-based management underscore importance of matching evaluation to conservation objectives

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ABSTRACT

Conservation policy often incentivizes managers of human-impacted areas to create landscape heterogeneity to maximize biodiversity. In rangeland, patchy disturbance regimes create landscape heterogeneity (patch contrast), but outcomes of heterogeneity-based management are rarely tested for a universal response. We analyzed four habitat variables – vegetation structure, plant functional group composition, litter cover, and bare ground – from five experimental rangelands in Oklahoma and Iowa, USA. We tested for response consistency to heterogeneity-based management across and within locations. We calculated effect sizes for each variable to compare patch contrast on pastures managed for heterogeneity (patch burn-grazing) and pastures managed for homogeneity (grazing with homogeneous fire regimes). Effects varied considerably across and within locations. Effects of heterogeneity-based management were positive for all variables at only three of five experimental rangeland locations. No location showed a consistent pattern of positive effect across all four variables, although one location showed no effect for any variable. At another location, we found a positive effect of heterogeneity-based management on litter cover and bare ground, but no effect on vegetation structure and plant functional group composition. We discuss effect variability and how the fire–grazing interaction applies to rangeland management and conservation. Although it is accepted practice to use heterogeneity-based management to increase rangeland habitat diversity, managers should also confirm that evaluation metrics match desired conservation outcomes.

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1. Introduction

Heterogeneity and patchiness are central themes in environmental management (Ostfeld, 1997; Wiens, 1997) and have been suggested as specific goals of conservation policy (Benton et al., 2003; Fischer et al., 2008, 2006). Policy emphasis stems from growing evidence that heterogeneity enhances biodiversity, especially in human-impacted landscapes (Franklin and Lindenmayer, 2009; Ricketts et al., 2001; Tews et al., 2004). At the same time, it is important that heterogeneity-based conservation programs are cost-effective and ecologically sound (Drechsler et al., 2007; Ohl et al., 2008; Toombs and Roberts, 2009).

Essential to the assessment of conservation programs are appropriate monitoring and understanding of the ecological drivers of landscape heterogeneity (Eyre et al., 2011; Wallington et al., 2005). Heterogeneity results from variation in the extent, frequency, and intensity of abiotic and biotic processes, including disturbance (Fraterrigo and Rusak, 2008; Pickett and White, 1985). Throughout the evolutionary history of many rangeland ecosystems, fire and grazing have been influential disturbances affecting heterogeneity (Allred et al., 2011). In managed rangeland, prescribed fire is applied in discrete patches to replicate the spatially- and temporally-shifting mosaic of pre-European landscapes (Fuhlendorf and Engle, 2004; Fuhlendorf et al., 2009). Known as patch burn-grazing (McGranahan et al., 2012a), such heterogeneity-based management creates a landscape mosaic to support greater biodiversity than conventional, homogeneity-based management (Coppedge et al., 2008; Doxon et al., 2011; Engle et al., 2008; Fuhlendorf et al., 2006). As such, managers are often encouraged to promote landscape heterogeneity to conserve rangeland fauna (Toombs et al., 2010).

Relatively little research has tested the universality of the theory that heterogeneity-based management creates meaningful rangeland diversity, and even less has presented

experimental results in a manner accessible to environmental managers and policy-makers. We use a meta-analytical approach with data from five rangeland locations in the North American Great Plains to determine whether heterogeneity-based management (patch burn-grazing) increases spatial heterogeneity in four variables (vegetation structure, plant functional group composition, litter cover, and bare ground) when compared to conventional, homogeneity-based management (grazing without spatially discrete fire). Each variable is important to rangeland fauna, including birds, small mammals, and invertebrates (Table 1). We calculate an effect size for each variable at each location to compare the level of patch contrast – “the degree of difference between patches” (Kotliar and Wiens, 1990) – created by heterogeneity-based management versus homogeneity-based management. Although we do not expect all study locations to universally respond to heterogeneity-based management (McGranahan et al., 2012a), we predict that habitat variables should respond consistently within each location. We discuss these results with respect to conservation goal-setting and the evaluation of management outcomes.

2. Methods

2.1. Data

We used an existing dataset of five rangeland experiments in Oklahoma and Iowa, USA (McGranahan et al., 2012a). Experimental locations include: Cooper Wildlife Management Area, Woodward County, Oklahoma; Klemme Range Research Station, Washita County, Oklahoma; Oklahoma State University Range Research Station, Paine County, Oklahoma; Tallgrass Prairie Preserve, Osage County, Oklahoma; and the Grand River Grasslands, Ringgold County, Iowa. The experimental locations spanned a broad geographic range (ca. 650 km) and represented different grassland types, tract sizes,

Table 1 – Examples of habitat functions for rangeland wildlife associated with four vegetation variables analyzed in this study.

Habitat variable	Observed wildlife response	References
Plant functional group composition	Conservation plantings comprised of grasses, legumes, and forbs increase habitat value for ring-necked pheasant nesting and brood-rearing	Matthews et al. (2012)
	Diversity of conservation plantings support diverse bird communities	Patterson and Best (1996)
Vegetation structure	Sward height affects prey density, predation risk among insectivorous grassland birds	Atkinson et al. (2004)
	Bird nest site selections based on vegetation structure, variable among species	Fondell and Ball (2004)
	Grasshopper species richness increased with heterogeneous vegetation structure	Joern (2005)
Bare ground	Ground-foraging birds depend on access to bare patches for food	Tagmann-Ioset et al. (2012) and Atkinson et al. (2004)
	Ca. 30% bare ground minimum habitat requirement for Mountain Plover Ant community composition affected by changes in bare ground	Knopf and Miller (1994) Graham et al. (2008)
Litter cover	Litter cover < 25% doubled success rate of Greater Prairie-chicken nests Altered litter cover associated with altered ant community composition Winter cover, greater soil moisture increase survival of grassland obligate butterflies	McKee et al. (1998) Bestelmeyer and Wiens (1996) Vogel et al. (2010)

Table 2 – Precipitation, vegetation, and stocking information for five experimental locations comparing heterogeneously applied fire management with homogeneous fire regimes. Refer to Methods and Supplementary data for experimental design, data collected, and years included. Locations listed geographically from west to east.

Study location	Cooper ^a	Klemme ^b	Stillwater ^c	TGPP ^d	GRG ^e
Annual precipitation (cm)					
Long-term mean	57	78	83	88	91
Study period range	41–77	51–82	61–99	59–109	97–147
Vegetation type	Artemisia shrubland-mixed prairie	Midgrass prairie	Tallgrass prairie	Tallgrass prairie	Tallgrass prairie
Stocking rate ^f					
Prior to study period	Moderate	Heavy	Moderate	Moderate-light	Severe
Study period (AUM/ha)	0.8	1.6	4.3	3.2	3.1
Grazing season	1 April–15 Sept.	15 Mar.–15 Sept.	1 Dec.–1 Sept.	15 Apr.–20 Jul.	1 May–1 Oct.
Pasture area (ha)	406–848	Ca. 50	45–65	400–900	15–31
Annual primary productivity ^g (kg/ha)	1500	2000	5600	6000	7000

Table modified with permission from McGranahan et al. (2012a).

^a Hal and Fern Cooper Wildlife Management Area (Gillen and Sims, 2004; Winter et al., 2012).

^b Marvin Klemme Experimental Research Range (Gillen et al., 2000; Limb et al., 2011).

^c Stillwater Research Range (Fuhlendorf and Engle, 2004; Gillen et al., 1987; Limb et al., 2011; OK Mesonet, 2011).

^d Tallgrass Prairie Preserve (Coppedge et al., 2008; Hamilton, 2007; OK Mesonet, 2011).

^e Grand River Grasslands (IEM, 2011; Pillsbury et al., 2011).

^f Stocking rate categories expressed in relation to local recommendations from the USDA Natural Resource Conservation Service.

^g Estimated annual primary productivity of native vegetation not recently disturbed by grazing or fertilization. Published data were used for Cooper (Gillen and Sims, 2004), Klemme (Gillen et al., 2000), Stillwater (Gillen et al., 1987), and the Grand River Grasslands (McGranahan et al., 2013). Unpublished data on end-of-season biomass one year after fire from at least one year within the study period included here were used to estimate annual primary productivity at the TGPP.

and management schemes (Table 2). Although established independently, the basic structure of each experiment was consistent: each experiment consisted of a replicated treatment in which fire was applied in spatially discrete patches, and a replicated control reflecting conventional management with homogeneous fire regimes. All pastures in all locations were stocked with cattle at moderate rates according to local USDA Natural Resource Conservation Service recommendations (Table 2). Cattle (*Bos taurus*) were allowed free access to water and grazing within each replicate pasture with no interior fences.

Data from all five locations consisted of vegetation structure (visual obstruction readings that combine measurements of vegetation height and density (Harrell and Fuhlendorf, 2002)) and canopy cover of plant functional groups, litter cover, and bare ground area following Daubenmire (1959) cover classes. At each location, data were collected with a nested hierarchical design in which pastures were divided into patches, and patches were divided into transects, along which sampling points were located (at the Tallgrass Prairie Preserve, sampling points were located within avian point count areas established within the same nested patch structure). For specific information about the experimental design and data collected at each location, see Supplementary information S1.

2.2. Analysis

To determine the effect of heterogeneity-based management, we calculated patch contrast for each variable within each treatment group at each location. We then calculated an effect size to compare the effect of heterogeneity-based

management to homogeneity-based management at each location. Our statistical methodology is described below.

2.2.1. Patch contrast

To calculate patch contrast for vegetation structure, litter cover, and bare ground area, we used a linear mixed-effect (LME) regression model to determine the proportion of variation attributable to differences among patches (see also Winter et al., 2012). We created LME regression models with the `lmer` function in the `nlme4` package for the R statistical environment (Bates and Maechler, 2010; R Development Core Team, 2011).

To calculate patch contrast in plant functional group composition, we used the unconstrained ordination Non-Metric Multidimensional Scaling (NMDS) to determine the range of variation in plant functional group composition for pastures managed with heterogeneity versus pastures managed for homogeneity. Ordination is effective in calculating the range of variation in composition, a measure of contrast in plant functional group composition (McGranahan et al., 2012a). Range of variation was measured using site scores along NMDS axis 1, the gradient of greatest variation in plant functional group composition. A separate ordination was performed for each location using the `metaMDS` function in the `vegan` package for the R statistical environment (Oksanen et al., 2011). To facilitate comparison of NMDS results across locations, variation in site scores was standardized to a common range with the `scale` function in R.

2.2.2. Effect size

To express the effect of heterogeneity-based management versus homogeneity-based management on patch contrast

among measured habitat variables with a single value, we calculated an effect size for each variable at each location. We calculated the meta-analytical statistic Cohen's d (Cohen, 1977), which divides the difference between the mean of pastures managed for heterogeneity and the mean of pastures managed for homogeneity by the square root of the pooled standard deviation for each location. We also calculated 95% confidence intervals for each effect size statistic using an iterative procedure in R (McGranahan et al., 2012a).

3. Results

Response to heterogeneity-based management was not consistent across locations or within locations. At Cooper, Stillwater, and the Tallgrass Prairie Preserve, pastures managed for heterogeneity consistently demonstrated greater patch contrast in all four variables – plant functional group diversity, vegetation structure, bare ground, and litter cover – compared to pastures managed for homogeneity (Fig. 1). However, effect sizes varied considerably across and within locations: for example, heterogeneity-based management had the greatest effect on bare ground at Cooper and the Tallgrass Prairie Preserve, but bare ground had the greatest response at Stillwater (Fig. 1). At Klemme, the pattern was also consistent but effect size was not different than zero for any of the four variables (Fig. 1).

In the Grand River Grasslands, the response to heterogeneity-based management was more complex. Effect sizes for heterogeneity-based management plant functional group composition and vegetation structure were not different than zero (Fig. 1). But heterogeneity-based management did have an effect on bare ground and litter cover, and these responses were similar to locations with consistent effects of heterogeneity-based management: In the Grand River Grasslands, bare

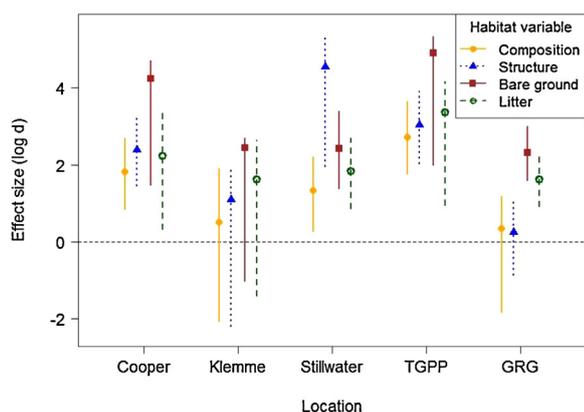


Fig. 1 – Effect size of four habitat variables at five rangeland locations in the North American Great Plains, comparing heterogeneity-based management (patch burn-grazing) to homogeneity-based management (grazing with homogeneous fire regimes). Effect sizes are plotted on a log scale. Study locations are ordered geographically from west to east and include four locations in Oklahoma – Cooper, Klemme, Stillwater, and the Tallgrass Prairie Preserve (TGPP) – and one in Iowa, the Grand River Grasslands (GRG).

ground had a similar response to Stillwater, and litter cover had a similar response to Cooper and Stillwater (Fig. 1).

4. Discussion

Our data indicate that the effect of heterogeneity-based rangeland management is neither consistent across locations nor among variables within a given location. While these results inform our understanding of the regulators of the fire–grazing interaction, they also offer important lessons in how habitat management objectives are set, implemented, and evaluated in the conservation of rangeland diversity.

4.1. Relative impacts of severe grazing and invasive species on the fire–grazing interaction

Under the fire–grazing interaction, herbivores preferentially follow the spatial pattern of fire on the landscape in response to high-quality forage in recently burned areas that is maintained by repeated grazing (Allred et al., 2011). However, severe grazing (the result of overstocking) and invasive species can weaken the influence of fire on the spatial pattern of grazing (McGranahan et al., 2012a) because they disrupt the continuity of the fuelbed and limit fire spread (McGranahan et al., 2013; Davies et al., 2010).

These results help parse the relative effect of overstocking and invasive species on the fire–grazing interaction. At Klemme, the impact of grazing just prior to the collection of our data was so severe as to create large gaps of bare ground that prevented fire spread (D. Engle and S. Fuhlendorf, pers. obs.) and limited the effect of heterogeneity-based management (Fig. 1). Recent data, however, indicate that recovery from severe grazing at Klemme has increased the effect of heterogeneity-based management following the restoration of the fire–grazing interaction (Limb et al., 2011).

While grazing in the Grand River Grasslands prior to the collection of our data was also severe (Table 2), nonetheless heterogeneity-based management created patch contrast in two habitat variables – bare ground and litter cover – to a similar degree as in three of the Oklahoma rangelands. From a habitat standpoint, fire spread in the Grand River Grasslands was sufficient to remove litter and create bare ground in burned patches. We suggest that patch contrast in plant functional group composition and vegetation structure was limited less by previous overstocking and more by tall fescue (*Schedonorus phoenix* (Scop.) Holub) invasion, which homogenizes the plant community (McGranahan et al., 2012b) and reduces vegetation height in the absence of taller native grass species.

4.2. Connecting habitat variables to responses of rangeland fauna

Managers of rangeland ecosystems are often encouraged to promote landscape heterogeneity under the assumption that habitat diversity begets species diversity (Derner et al., 2009; Toombs et al., 2010), and with due cause: heterogeneously managed rangeland can have more diverse, dynamic communities of birds, invertebrates, and small mammals than

Table 3 – Summarized literature review of wildlife responses to heterogeneity-based management (HBM) from four rangeland locations in Oklahoma and Iowa, USA. A fifth location used in this study, the Klemme Range Research Station in southwestern Oklahoma, is not included in this table because no relevant wildlife research was found in our literature review.

Location	Taxon (level)	Response	References
Cooper	Invertebrates (community)	Species abundances and community composition were distinct from pastures managed for homogeneity	Doxon et al. (2011)
Stillwater	Small mammals (community)	Several species responded to the extremes of habitat types created by HBM, indicating that increasing spatial heterogeneity enhances biodiversity and reducing temporal variability contributes to stable habitat availability	Fuhlendorf et al. (2010)
	Invertebrates (community)	Post-fire patches had greatest invertebrate biomass. HBM increased overall abundance of several invertebrate orders	Engle et al. (2008)
Tallgrass Prairie Preserve	Birds (species)	HBM increased Dickcissel nest success, decreased nest parasitism	Churchwell et al. (2008)
	Birds (community)	Bird species diversity and grassland-obligate richness greater under HBM. Some species of conservation concern absent from conventionally managed control pastures	Coppedge et al. (2008)
	Birds (species and community)	HBM increased spatial and temporal heterogeneity in vegetation and enhanced avian community diversity. Several species showed preference to patches of specific habitats available in HBM pastures but not conventionally managed pastures	Fuhlendorf et al. (2006)
Grand River Grasslands	Invertebrates (community)	Land-use history had stronger effect on butterfly, ant, and leaf beetle community composition than fire and grazing management	Debinski et al. (2011)
	Butterflies (community)	Butterflies responded more strongly to land-use legacies than fire and grazing management	Moranz et al. (2012)
	Birds (community)	Landscape context around and vegetation structure within HBM pastures differentiated bird communities from control pastures	Pillsbury et al. (2011)
	Birds (species)	Nest survival rates of Grasshopper Sparrows greatest in HBM pastures, while postfledgling survival did not vary among HBM and conventionally managed pastures	Hovick et al. (2012, 2011)

comparable rangeland managed homogeneously (Table 3). Not surprisingly, enhanced biodiversity under heterogeneity-based management is observed at the same three locations – Cooper, Stillwater, and the Tallgrass Prairie Preserve – where heterogeneity-based management consistently created patch contrast in the four variables tested here (Fig. 1).

Other studies that compare the effect of heterogeneity-versus homogeneity-based management on avian and invertebrate communities show mixed results (Table 3). For example, in the Grand River Grasslands, grassland bird communities were similar in pastures managed for heterogeneity as compared to pastures managed for homogeneity, although bird communities in pastures under heterogeneity-based management appeared to differentiate over time from pastures managed with homogeneous fire regimes (Pillsbury et al., 2011). Likewise, invertebrate community responses to heterogeneity-based management were weak, with differences in community composition driven primarily by pasture-level land use history (Debinski et al., 2011; Moranz et al., 2012).

Despite the lack of a consistent, community-level response as demonstrated at Cooper, Stillwater, and the Tallgrass Prairie Preserve, certain species in the Grand River Grasslands did show a response to heterogeneity-based management. As one example, Grasshopper Sparrow (*Ammodramus savannarum*)

nest survival was greater under heterogeneity-based management than homogeneity-based management (Hovick et al., 2012). This suggests that some species might respond to those habitat variables that did show a response to heterogeneity-based management in the Grand River Grasslands, namely litter cover and bare ground (Fig. 1). In fact, Hovick et al. (2012) specifically recommend decreasing vegetation cover to increase Grasshopper Sparrow survival and cite heterogeneity-based management as a tool. These recommended outcomes are measured here as patch contrast in bare ground, litter cover and vegetation structure, two of which were successful in the Grand River Grasslands.

4.3. Evaluation of rangeland management must match policy objectives

Painted broadly, effective conservation science and policy begins with stating clear goals and defining measurable objectives (Eyre et al., 2011; Tear et al., 2005). But specific goals and evaluation measures are often species- or ecosystem-dependent, and simply applying a given management practice is not a conservation endpoint. Our comparison of four measures of heterogeneity-based management across five rangeland locations indicates that a universal response from a practice should not be assumed. Two lessons follow:

(1) managers attempting to accomplish a breadth of conservation objectives with a single practice must evaluate specific outcomes, and (2) a lack of demonstrated success in one outcome does not necessarily mean that management has failed to advance the conservation needs of individual species.

These lessons prompt a reflection on a frequent approach in conservation science: the umbrella or focal species concept, in which managers focus on the needs of one or several specific species whose needs envelope the requirements of other species in the community (Lambeck, 1997; Roberge and Angelstam, 2004). In North America, grassland bird populations have declined precipitously following agricultural expansion (Samson and Knopf, 1994), and prairie grouse species such as the Greater Prairie Chicken (*Tympanuchus cupido pinnatus*) are considered umbrella species for the conservation of grassland ecosystems (e.g., Poiani et al., 2001) because their life histories require a breadth of habitat – i.e., a high degree of contrast in the landscape in each of the variables considered here. Alternatives to umbrella species include the keystone structure concept, in which managers seek to identify and promote spatial structure that provides resources necessary for other species (Tews et al., 2004). Such a bottom-up approach might be more inclusive of a wide variety of rangeland fauna and help managers identify common habitat needs, rather than assume that management for a single species supports the community.

To be sure, we do not intend to undermine the umbrella species concept; rather, we use our results to remind conservation scientists and policy-makers that the needs of one species of conservation concern might be met even if the needs of other species are not. While heterogeneity-based management has been shown to meet the needs of rangeland umbrella species like prairie grouse (Derner et al., 2009; Patten et al., 2007), individual species can benefit from specific habitat outcomes even if the entire community does not show a consistent response to management (Hovick et al., 2012; Moranz et al., 2012; Powell, 2008). Although desirable, it is not necessary for environmental management to meet the conservation needs of every species, nor are conservation projects necessarily unsuccessful if the needs of the entire community are not met. What is important is that managers set realistic conservation goals and match their evaluation to their objectives, i.e., measure the proper response variable(s) for the desired conservation outcome.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.envsci.2013.03.005>.

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