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Constraints to restoring fire and grazing ecological processes to optimize grassland vegetation structural diversity

John Derek Scasta[a,*], Courtney Duchardt[a,b], David M. Engle[c], James R. Miller[b], Diane M. Debinski[d], Ryan N. Harr[e]

[a] Department of Ecosystem Science and Management, University of Wyoming, Laramie, WY, USA
[b] Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL, USA
[c] Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK, USA
[d] Department of Ecology and Evolutionary Biology Department, Iowa State University, Ames, IA, USA
[e] Iowa Department of Natural Resources, Des Moines, IA, USA

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ABSTRACT

Extirpation of the ecosystem engineer (bison) and its interaction with fire, coupled with the utilitarian concept of moderate grazing, have contributed to homogenization of grassland habitat in North America. Although cattle may serve as a proxy for bison, combining fire with cattle grazing has been uncommon and to date managers have not always successfully applied cattle and controlled burns as tools to manipulate grassland vegetation heterogeneity and increase habitat diversity. Using an information-theoretic approach, we assessed factors constraining the fire-grazing interaction ecological process to engineer habitat structure of grasslands via patch-burn grazing. We assessed how grazing, fire, and biotic and abiotic features in tallgrass prairie influenced establishment and maintenance of low vegetative structure in burned patches, the positive feedback driving the fire-grazing interaction, and subsequent structural heterogeneity across a pasture. Four pastures were divided into three patches with a different patch burned annually in March/April from 2007 to 2013. Cattle were stocked from light to heavy (1.1–4.4 AUM/ha) from May to October (~150 days) with access to the entire pasture. We hypothesized that the exotic C3 grass tall fescue (*Schedonorus arundinaceus*), lag-time between burning date and the date cattle were put into experimental pastures, and burn date would be the constraining factors. However, the most informative model included stocking rate, date of burn completion, and precipitation. The lightest cattle stocking rate did not establish low vegetative structure in the burn patch, which resulted in the lowest heterogeneity among patches. The heaviest cattle stocking rate established but did not maintain low vegetative structure in the burn patch. The intermediate cattle stocking rate maintained the lowest vegetative structure in the burn patch and the greatest heterogeneity among patches, i.e., the best efficacy of patch-burn grazing to engineer habitat structural heterogeneity. The relationships of stocking rate to burn patch vegetative structure and to landscape heterogeneity were both quadratic and were both optimized at intermediate stocking rate.

1. Introduction

In North American grasslands, extirpation of the facilitating ecosystem engineer (bison) and its interaction with frequent fire, coupled with the utilitarian concept of moderate grazing, have contributed to homogenization of grassland habitat. Because the utilitarian concept of moderate grazing seeks to eliminate the extreme ends of the grazing utilization gradient and evenly distribute utilization across the landscape, homogeneous vegetation structure is the result (Fuhlendorf et al., 2012). This homogenization has been linked with severe declines in grassland bird populations, as the structural habitat requirements of these species are often diverse (Brennan and Kuvlesky Jr., 2005; Fuhlendorf et al., 2006; Machicote et al., 2004). Examples of bird species in decline due to habitat homogenization include Henslow's sparrows (*Ammodramus henslowii*) that need high vegetation structure, mountain plovers (*Charadrius montanus*) that need low vegetation structure, and lesser prairie chickens (*Tympanuchus pallidicinctus*)

* Corresponding author at: Department of Ecosystem Science and Management, University of Wyoming, Agriculture C 2004, Laramie, WY 82071, USA.
E-mail address: jscasta@uwyo.edu (J.D. Scasta).

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Table 1
Description of patch burning through space and time (nb = not burned; #/##-##% = date and completeness of prescribed burn; * = burn that escaped out of the intended burn patch and burned remainder of pasture) with experimental pastures in the Grand River Grasslands of Iowa, USA, 2007–2013.

Pasture	Year						
Patch	2007	2008	2009	2010	2011	2012	2013
Kellerton North							
Patch 1	3/19–60%	nb	nb	4/10–40%	nb	nb	3/19–95%
Patch 2	nb	3/29–83%	nb	nb	3/18–95%	nb	nb
Patch 3	nb	nb	3/6–55%	nb	nb	3/12–95%	nb
Pyland North							
Patch 1	3/28–70%	nb	nb	4/9–80%	nb	nb	4/3–95%
Patch 2	nb	3/12–85%	nb	nb	3/16–93%	nb	nb
Patch 3	nb	nb	4/22–70%	nb	nb	3/9–100%	nb
Pyland South							
Patch 1	3/28–85%	nb	*3/17–85%	4/9–78%	nb	nb	4/3–100%
Patch 2	nb	3/12–95%	*3/17–85%	nb	3/16–100%	nb	nb
Patch 3	nb	nb	3/17–85%	nb	nb	3/9–100%	nb
Ringgold South							
Patch 1	3/29–33%	n	nb	4/10–40%	nb	nb	4/4–99%
Patch 2	nb	3/29–73%	nb	nb	3/18–90%	nb	nb
Patch 3	nb	nb	3/17–85%	nb	nb	3/15–95%	nb

that require both high and low vegetation structure (Derner et al., 2009; Hovick et al., 2015).

Altering cattle grazing distribution by moving feeding locations, redistributing water, or burning spatially discrete fires has been proposed as a proxy for bison and wildfire as grassland habitat engineers (Derner et al., 2009). However, conventional cattle grazing, in and of itself, is not a replication of how bison and fires engineered habitat and managers need specifications for how to mechanistically alter the cattle-forage interaction to achieve habitat engineering objectives. Conventional cattle grazing is different than historic bison grazing because bison selection and distribution patterns were driven by frequent and low-intensity fires, but the restoration of the fire regime could similarly alter cattle herbivory (Allred et al., 2011a,b). While we know that altering feeding locations or water distribution to focus cattle in a specific area are effective tools for manipulating grazing behavior, these practices cannot replicate the effects that strategically applied fires and the response of bison have on vegetation structure (Machicote et al., 2004; Towne et al., 2005). Only prescribed fire maintains herbaceous plant composition by reducing woody plant encroachment in grasslands while also accomplishing grazing manipulation (Anderson, 2006). Furthermore, the ecological engineering principle of 'imitation' is conventionally applied by spatially and temporally variable fires and the response of grazing animals – imitating the developmental processes regulating grasslands and modifying grassland habitat prior to European settlement of North America (Fuhlendorf et al., 2009; Jones et al., 1996; Jørgensen and Nielsen, 1996; Kangas, 2004; Levin, 1992; Lü et al., 2011; Turner, 1989).

The historic interaction between fire and grazing has been mimicked contemporarily by the management practice of patch-burn grazing or burning discrete patches within pastures and allowing cattle to select where they graze. This application of patch-burn grazing was conceived as a restoration framework of recoupling grazing and fire interactions as an ecological process that maintained grassland flora and fauna in North America (Fuhlendorf and Engle, 2001; Fuhlendorf and Engle, 2004). Although patch-burn grazing experiments have been effective in establishing habitat structural heterogeneity in some experiments, they have not always altered vegetation structure in a predictable way, and specifications are lacking to guide effective applications of this ecological engineering concept (Derner et al., 2009; McGranahan et al., 2012b). The utility and transferability of successful projects also are limited because the majority of studies have been conducted on conservation land consisting of large contiguous pastures of undisturbed warm-season grasses (Fuhlendorf and Engle, 2004; Leis et al., 2013; Vermeire et al., 2004).

In reality, most grazed grasslands are highly fragmented, have a long history of overgrazing, and a high component of invasive species such as cool-season grasses (Brennan and Kuvlesky Jr., 2005; McGranahan et al., 2012b; Quan et al., 2015). From a social perspective, continuing agricultural production on these working lands also complicates restoration of grassland habitat. Ranchers rely on income from cattle, so stocking rates must often be maintained at a certain minimum level. However, how stocking rate affects patch-burn grazing is still not well understood, so we are faced with a knowledge gap that severely limits effective application (Fuhlendorf and Engle, 2004; Helzer and Steuter, 2005). Application of patch-burn grazing often has lacked the quantitative rigor and precision that is characteristic of engineering approaches to solving problems (Kangas, 2004), and this lack of control is especially relevant where applications have failed to meet predetermined objectives of establishing a mosaic of habitat structure (McGranahan et al., 2012b).

Developing and refining patch-burn grazing management specifications to effectively employ cattle as ecosystem engineers will benefit agriculture, conservation, and restoration ecology (Derner et al., 2009; Fuhlendorf and Engle, 2004; McGranahan et al., 2012b). This is especially crucial in systems where the utility of patch-burning is still not established – namely, smaller grassland patches located within a matrix with a high proportion of wooded or agricultural lands and is an issue identified as a severe knowledge gap (Miller et al., 2012). Because efficacy of patch-burn grazing has produced mixed results in these types of systems (McGranahan et al., 2012b) and to refine patch-burn grazing project specifications, we examined factors potentially constraining the efficacy of patch-burn grazing on sites within such a matrix. Using an information-theoretic approach, we modeled potential constraints to the primary positive feedback, which is here considered to be the focal grazing in the burn patch that establishes and maintains low vegetative structure (Allred et al., 2011a; Archibald et al., 2005). We also assessed how the establishment of the primary positive feedback influences structural heterogeneity of vegetation within a pasture and the ability to successfully conduct prescribed fire operations. This relationship between heterogeneity and successful burning is a function of the negative feedback, or establishment of unburned areas not as likely to be grazed due to accumulated dormant plant material deterring grazing and increasing burn potential following Fuhlendorf and Engle (2004). Our objectives for this study were to: (1) determine constraints limiting establish-