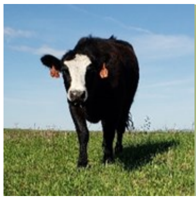

Alternative Grazing Management Strategies Combat Invasive Kentucky Bluegrass Dominance

Megan Dornbusch, Ryan Limb and Kevin Sedivec
North Dakota State University School of Natural Resource Sciences, Fargo, N.D.

Maintaining native biodiversity is essential to ensure the long-term sustainability of livestock production in the Great Plains. This is especially important in the northern Great Plains where Kentucky bluegrass (Poa pratensis, hereafter bluegrass), a cool-season invasive species, is actively displacing native prairie species with consequences for several ecosystem services.

Reducing or controlling the abundance of bluegrass is necessary to manage the deleterious effects of its invasion, but no evidence is available to recommend effective grazing management. Therefore, we examined the effects of traditional and alternative grazing management practices on bluegrass-invaded pastures.

We found that traditional season-long (SL) grazing increased the influence of bluegrass on plant community composition after four years of treatment. Two alternative management strategies, early-intensive (EI) and patch-burn (PB) grazing, on the other hand, reduced its influence without negative effects on the two most dominant native cool-season grasses or forage production.

These results suggest that livestock producers in the northern Great Plains may need to transition away from traditional grazing management to alternative strategies to combat bluegrass invasion. Moreover, our results add to the growing body of evidence supporting the use of rangeland management practices, such as patch-burn grazing, that mimic historic disturbances to promote native biodiversity.

Introduction

Kentucky bluegrass (*Poa pratensis* L.; hereafter bluegrass) invasion is actively reducing the abundance of native plant species and developing novel ecosystems throughout the northern Great Plains (Toledo et al., 2014). Its origin in the U.S. is not clear (Carrier et al., 1916), but bluegrass was not a part of the region's historic plant community (Barker et al., 1986).

Bluegrass is a cool-season perennial grass that begins growth in early spring and develops a dense root and thatch layer that restricts the establishment and growth of other species. Changes in vegetation structure and community composition from bluegrass invasion have developed novel ecosystems throughout the northern Great Plains that may be irreversible (Toledo et al., 2014).

The development of novel bluegrass-invaded grasslands in the northern Great Plains has gone unnoticed, likely because bluegrass can provide adequate forage for livestock production, especially during early spring and wet years (Toledo et al., 2014).

An area of a season-long (SL) grazed pasture on CGREC property that has been taken over by Kentucky bluegrass.

However, bluegrass goes dormant with heat and water stress experienced during the summer and drought conditions (Hockensmith et al., 1997), as it does in a front lawn.

Therefore, as bluegrass increases in a pasture, the forage supply becomes increasingly susceptible to climate change and drought. A diverse prairie community, on the other hand, provides adequate forage across a wider range of conditions.

Grasslands managed for livestock production utilize strategic livestock grazing strategies that traditionally promote uniform distribution and forage utilization (Fuhlendorf and Engle, 2001, 2004) such as season-long (SL) or rotational grazing (Bailey et al., 1998). Uniform disturbances simplify plant community composition because they do not allow the development of areas with varying levels of disturbance intensity or frequency (Fuhlendorf and Engle, 2004).

Bluegrass increases under SL grazing regardless of grazing intensity in the absence of fire (Murphy and Grant, 2005; Limb et al., 2018), which implies that its invasion expands under uniform disturbance regimes. Combatting bluegrass invasion will require a change in grazing management practices in the northern Great Plains.

Empirical evidence is lacking at this time to suggest effective grazing management strategies for bluegrass control in the cool-season mixed-grass prairie ecoregion. Early-intensive (EI) grazing, combined with annual burning, can stabilize or decrease bluegrass populations in warm-season prairie (Smith and Owensby, 1978) and may reduce its productivity (Bryan et al., 2000) but has not been tested for bluegrass control in cool-season mixed-grass prairie.

The northern Great Plains is a fire-adapted system, and evidence suggests that fire alone has the potential to control bluegrass dominance in the tallgrass (Anderson et al., 1970) and mixed-grass prairie. However, reductions are highly dependent on precipitation and soil type (Engle and Bultsma, 1984) and are short term in mixed-grass prairie (Bahm et al., 2011; Kral et al., 2018).

Therefore, grazing bluegrass after burning with patch-burn (PB) grazing management could extend bluegrass reductions in the mixed-grass prairie, but this option remains uninvestigated. Analyzing the effects of EI and PB grazing management strategies on bluegrass-invaded pastures of the northern mixed-grass prairie is relevant to determine if they can control bluegrass dominance where traditional SL grazing does not.

In our study, we hypothesized that traditional (SL) and alternative grazing management strategies (EI and PB) would generate differences in plant community metrics (richness, evenness and diversity), composition, bluegrass cover, cover of the two most dominant native cool-season grasses and production. Because native Great Plains plants evolved with fire and grazing (Samson et al.. 2004), we also hypothesized that alternative management would increase or maintain the cover of native cool-season grasses without reducing above-ground biomass production.

Procedures

We initiated a completely randomized design experiment in 2014 on nine approximately 40-acre bluegrass-invaded pastures with three grazing treatments each replicated three times (n = 3). Each grazing treatment involved stocking yearling mixed-breed heifers moderately at the same number of animal unit months (1.85 AUM/hectare). The experiment continued through the 2017 growing season for a total of four years of treatment.

Grazing treatments emulated practices typical of, or alternative to, those used in the northern Great Plains. Traditional grazing management involves stocking pastures for the duration of the growing season. Thus, we stocked pastures annually in early May for 12 weeks to establish a season-long (SL) grazing treatment.

Our alternative grazing management treatments consisted of early -intensive (EI) and patch-burn (PB) grazing. EI grazing involved stocking pastures at triple stock density for the first third of the growing season (four weeks, early May to early June). PB grazing combined the SL grazing strategy with a prescribed-fire regime in which we burned a different fourth (10 acres) of each PB-grazed pasture annually after a hard frost. The first fire occurred in October 2014. At the end of the study (2017), each fourth of the PB pastures had a different time-since-fire.

We standardized sampling intensity among pastures by arbitrarily dividing each pasture into four equal patches based on the PB treatment. Data from 2014 revealed that plant community metrics and composition were not different among treatments at the study's initiation (p > 0.05, data not shown). Thus, experimental plant community and forage production monitoring occurred in 2015, 2016 and 2017 to monitor for changes among treatments.

Plant Community Monitoring

To compare plant community composition among grazing treatments, we performed vegetation surveys every two meters along one 40-meter transect in each patch of every pasture (20 surveys per transect; 80 per pasture) during peak production (late July to early August). Each survey involved identifying all plant species within a 0.5- by 0.5-meter quadrat and visually estimating each species' canopy cover with a Daubenmire cover class system (Daubenmire, 1959). Plant nomenclature, status and distribution followed the U.S. Department of Agriculture's National Plant Database (USDA-NRCS 2018).

Forage Production Monitoring

We monitored forage production annually by collecting biomass samples also during peak production from three randomly placed 2- by 2-meter (m) caged grazing exclosures in each patch of every pasture (12 cages per pasture). We collected samples by clipping all standing biomass to the soil surface from one random 0.5- by 0.5-m quadrat placed within each exclosure. All samples were oven dried to constant weight.

Statistical Analyses

We determined mean species richness, evenness, Simpson's diversity and forage production (pounds per acre [lb/ac]) for each pasture and compared treatments using ANOVA and post hoc Tukey's B means separation in SPSS (Version 25; IBM Corp. 2017). We evaluated 2015 and 2016 means as trends and only tested for differences among treatment means in 2017 to allow the full implementation of the PB treatment when time-since-fire differed for each of the four patches.


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We analyzed differences in plant community composition among grazing treatments within and across study years using permutation-based nonparametric multivariate analysis of variance (perMANOVA) and non-metric multidimensional scaling (NMS) procedures in PC-ORD 6.0. We also compared 2017 ordination scores and mean canopy cover of bluegrass and native cool-season grasses, green needlegrass and western wheatgrass to investigate differences among treatments.

Results

Plant Community Monitoring

We recorded 123 plant species across the study's 12 pastures throughout three years of monitoring (2015, 2016 and 2017). Grazing treatments did not differ in species richness, evenness or diversity at the end of the study (Figure 1). However, the perMANOVA analysis indicated differences across years, treatments and the year by treatment interaction.

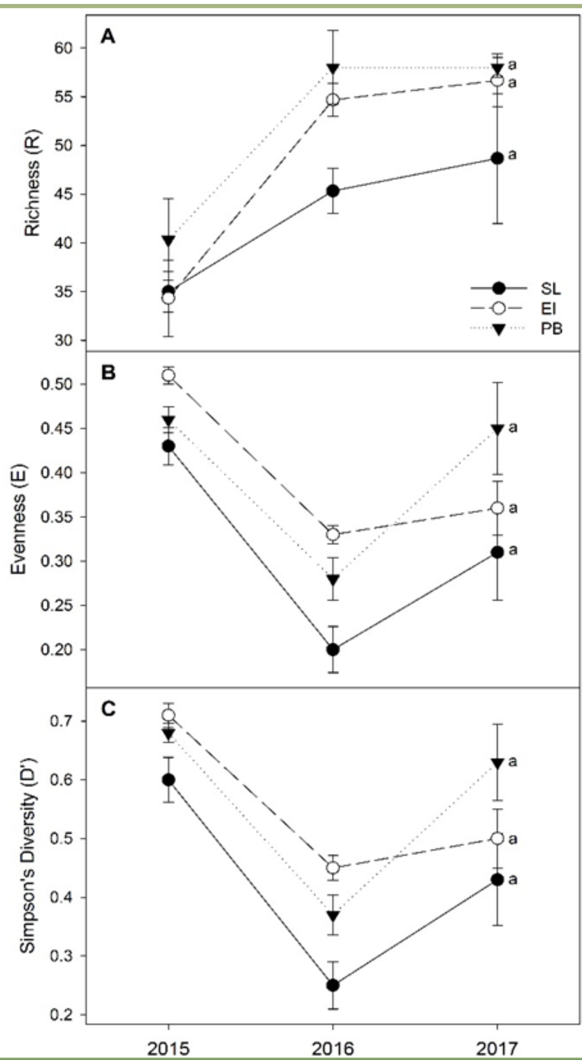

Figure 1. Richness (A), evenness (B) and Simpson's diversity (C) averages for pastures treated with season-long (SL), early-intensive (EI) and patch-burn (PB) grazing from 2015 through 2017. Note different scaling among graphs.

The NMS analysis of all plant species, across all years and treatments, indicated year had the strongest influence on plant community composition, with grazing management strategy having a secondary effect. Moreover, the NMS ordination revealed that plant community composition was similar among all treatments in 2015 and 2016 but not 2017 when alternative communities separated from traditional (Figure 2a, next page).

The perMANOVA analysis of 2017 plant species data alone confirmed a treatment effect on plant community composition at the end of the study ($p = 0.01$). Therefore, plant community composition shifted through time according to year and treatment (Figure 2b).

We found bluegrass within every individual quadrat each year. Our NMS analysis revealed that year primarily influenced bluegrass. while grazing strategy exerted a secondary effect. The NMS analysis of 2017 revealed that bluegrass was strongly correlated with traditional management (-0.909), while green needlegrass (0.785) and western wheatgrass (0.727) were strongly correlated with alternative management strategies upon the full implementation of the PB treatment.

Therefore, the trajectory of changes in plant community composition shifted toward bluegrass dominance with SL grazing and shifted away with alternative EI and PB grazing strategies (Figure 2b). Likewise, bluegrass canopy cover differed among traditional and alternative grazing treatments in 2017 ($p = 0.003$).

Mean bluegrass cover with alternative EI and PB grazing management was approximately 18 and 21 percent lower than the traditional SL grazing treatment mean (48 percent), respectively (Figure 3a). Across years, trends reveal that bluegrass cover was highest for each individual treatment in 2016 when precipitation was above average (Figure 3a). Interestingly, bluegrass cover in 2017 was similar to 2015 levels in PB and EI grazed pastures but was approximately 160 percent greater than 2015 levels in SL-grazed pastures.

In contrast, grazing treatments did not differentially influence the canopy cover of the two most dominant native cool-season grasses or forage production at the study's end. Canopy cover of green needlegrass (Figure 3b) and western wheatgrass (Figure 3c) did not differ among treatments in 2017.

Above-ground biomass production followed the same trend (Figure 4). Production was highest with above-average (2016) and lowest with below-average (2017) annual precipitation (Figure 4).

Discussion

Kentucky bluegrass invasion is actively developing novel ecosystems in northern Great Plains grasslands with consequences for several ecosystem services (Toledo et al., 2014). Little evidence is available to recommend best management practices for bluegrass-invaded rangelands, so we compared vegetation

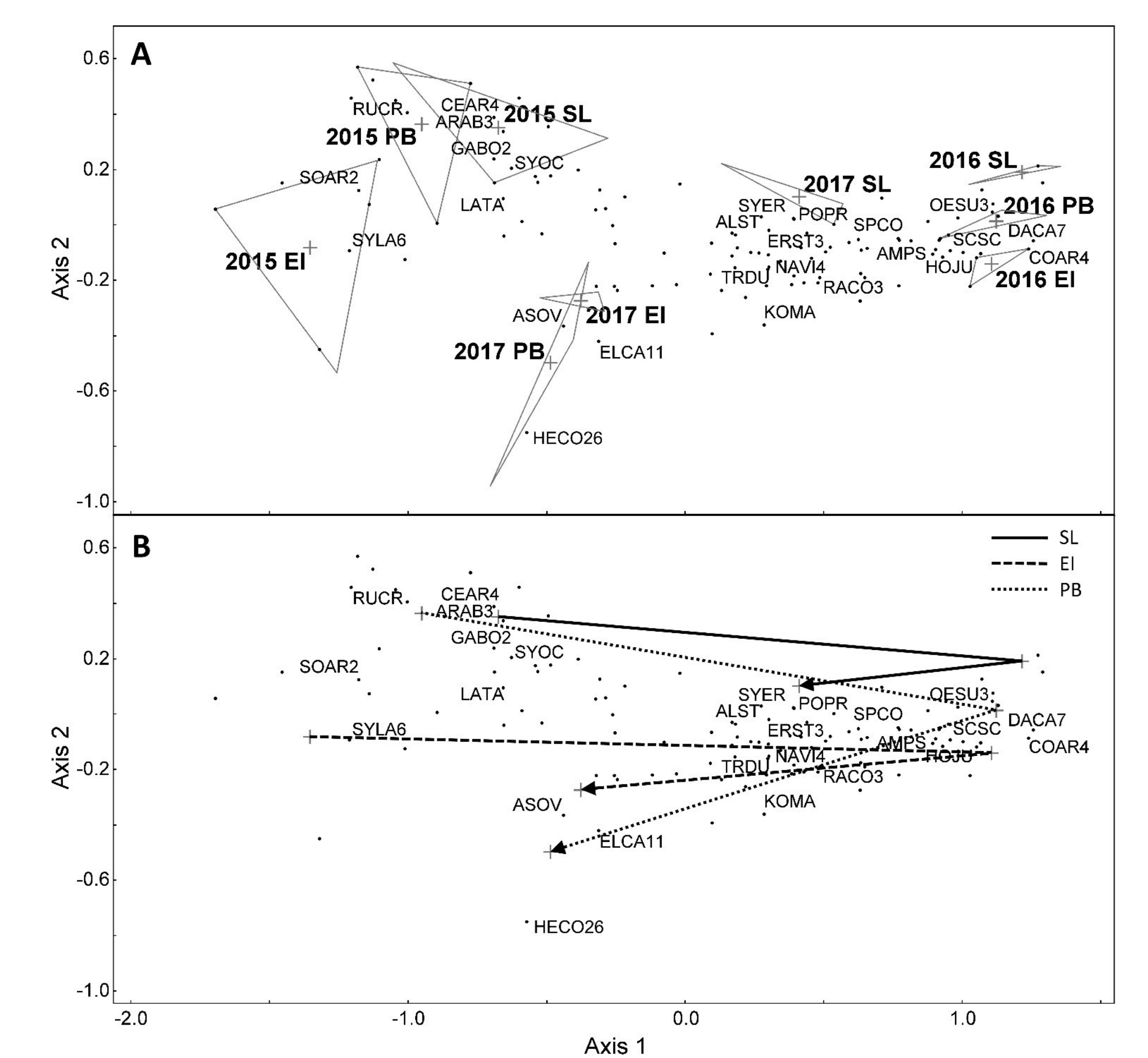

Figure 2. NMS ordination of plant community composition with all species found across all years for pastures treated with season-long (SL), early intensive (EI) and patch-burn (PB) grazing. *Triangles* represent average plant composition for each treatment by year (A) and *vectors* represent the trajectory of changes in plant composition through time for each treatment (B). *Points* represent individual plant species.

Symbol	Scientific name	Common name
ALST	*Allium stellatum*	wild prairie onion
AMPS	*Ambrosia psilostachya*	western ragweed
ARAB3	*Artemisia absinthium*	wormwood
ASOV	*Asclepias ovalifolia*	oval-leaf milkweed
CEAR4	*Cerastium arvense*	field chickweed
COAR4	*Convolvulus arvensis*	field bindweed
DACA7	*Dalea candida*	white prairie clover
ELCA11	*Elymus caninus*	bearded wheatgrass
ERST3	*Erigeron strigosus*	daisy fleabane
GABO2	*Galium boreale*	northern bedstraw
HECO26	*Hesperostipa comata*	needle and thread
HOJU	*Hordeum jubatum*	foxtail barley
KOMA	*Koeleria macrantha*	prairie Junegrass

Symbol	Scientific name	Common name
LATA	*Lactuca tatarica*	blue lettuce
NAVI4	*Nassella viridula*	green needlegrass
OESU3	*Oenothera suffrutescens*	scarlet gaura
POPR	*Poa pratensis*	Kentucky bluegrass
RACO3	*Ratibida columnifera*	upright prairie coneflower
RUCR	*Rumex crispus*	curly dock
SCSC	*Schizachyrium scoparium*	little bluestem
SOAR2	*Sonchus arvensis*	field sowthistle
SPCO	*Sphaeralcea coccinea*	scarlet globemallow
SYER	*Symphyotrichum ericoides*	white heath aster
SYLA6	*Symphyotrichum lanceolatum*	white panicle aster
SYOC	*Symphoricarpos occidentalis*	western snowberry
TRDU	*Tragopogon dubius*	yellow goat's beard

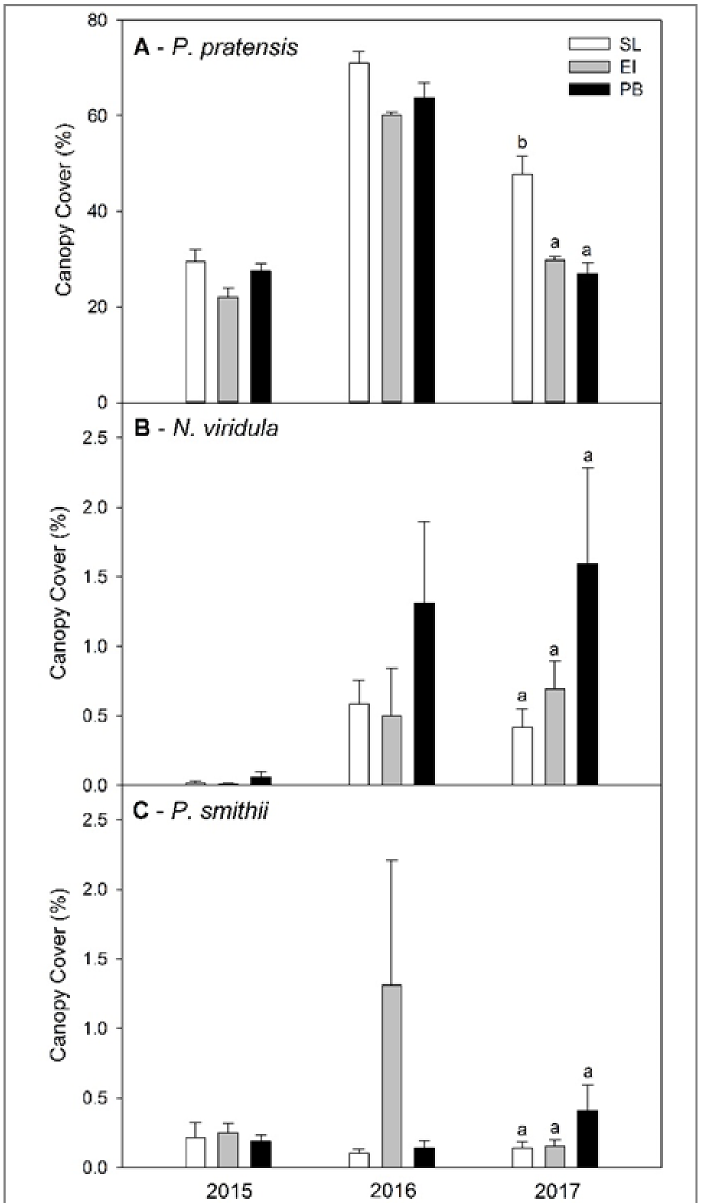

Figure 3. Mean canopy cover of invasive Kentucky bluegrass (*Poa pratensis*) (A), green needlegrass (*Nassella viridula*) (B) and western wheatgrass (*Pascopyrum smithii*) (C) of pastures treated with season-long (SL), early-intensive (EI) and patch-burn (PB) grazing.

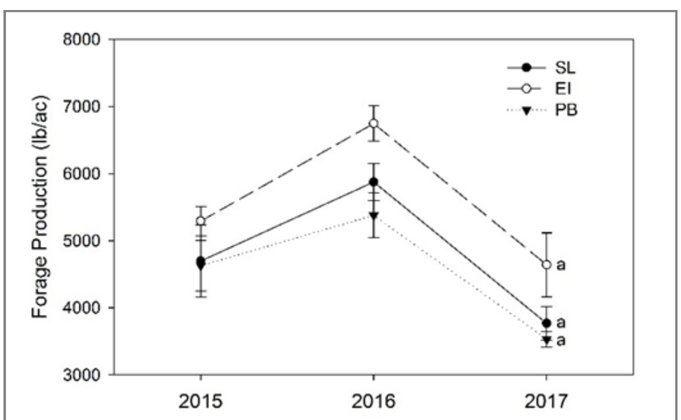

Figure 4. Mean forage production (measured as annual above-ground biomass production) of pastures treated with season-long (SL), early-intensive (EI) and patch-burn (PB) grazing.

responses to traditional (SL grazing) and alternative grazing management strategies (EI and PB grazing) in the northern Great Plains.

With regard to controlling bluegrass invasion, we found that traditional management increased the influence of bluegrass on community composition through time, while alternative management did the opposite and increased the influence of other species, including oval-leaf milkweed (*Asclepias ovalifolia*), bearded wheatgrass (*Elymus caninus*) and needle and thread (*Hesperostipa comata*).

Interestingly, we did not observe differences among grazing strategies in richness, evenness or diversity indices at the end of the study (Figure 1), but we did see changes in community composition (Figure 2). Growing-season precipitation drives grassland composition and production (Biondini et al., 1998). Accordingly, shifts in plant community composition were influenced primarily by year-to-year variation, with treatment having a secondary effect.

Community composition changed the most for PB, followed by EI grazing, and least for SL grazing through time (Figure 2b). SL grazing increased the influence of bluegrass on community composition, whereas EI and PB decreased it. Our study agrees with others that SL grazing increases bluegrass abundance (Figure 3a) (Murphy and Grant, 2005; Limb et al., 2018), which likely amplified its influence on plant community composition in our study.

EI grazing reduces the early productivity of bluegrass (Bryan et al., 2000), and increased grazing intensity reduces dead biomass accumulation (Biondini et al., 1998). Thus, EI grazing may have stunted the early growth of bluegrass and limited its ability to establish a thickened thatch layer before the emergence of native species.

Burning also releases native plants from the inhibitory effects of bluegrass by removing accumulated thatch (Kral et al., 2018), and regrowth increases grazing pressure in recently burned patches (Fuhlendorf and Engle, 2004). Thus, we propose that increased grazing intensity following prescribed burning may have limited thatch accumulation post-fire and continued to release more later-emerging species from its inhibiting effects. Therefore, grazing after burning may decrease the influence of bluegrass on composition throughout more of the growing season and following seasons than burning alone.

Four years of treatment did not elicit differences among grazing treatments in the cover of green needlegrass or western wheatgrass at the end of the study (Figure 3b,c). Native mixed-grass prairie species evolved with variations in climate, fire and grazing (Fuhlendorf and Engle, 2001), so no effect or an increasing effect was expected. Although not significant, observed differences in their cover in 2017 warrants further investigation into the potential for both species to increase during extended periods of time with PB grazing management.

Year-to-year variation strongly influenced bluegrass cover, with treatment exerting a secondary influence through time (Figure 3a). Above-average precipitation in 2016 likely elicited an increase in bluegrass cover in all treatments by intensifying its rhizome production more than native species (Dong et al., 2014). Notably, bluegrass cover returned to first-year levels under EI and PB grazing the following year, while it remained high under SL grazing (Figure 3a).

Grazing during drought can reduce the growth potential and vigor of bluegrass (Dong et al., 2014). Below-average precipitation in 2017 may have provided a competitive advantage for native plants that were released from bluegrass inhibition with burning (Kral et al., 2018) and EI grazing (Biondini et al., 1998).

We also found that patch burning did not differentially influence average above-ground biomass production in grazing exclosures at the end of our study (Figure 4). Therefore, patch burning mixed-grass prairie invaded by bluegrass neither reduced nor increased average annual forage availability for livestock after four years of treatment.

Management Implications

Our study suggests that transitioning away from traditional SL grazing management to alternative strategies may be necessary to combat bluegrass invasion in the northern Great Plains. Alternatives PB and EI grazing, however, may affect livestock production differently, although they had similar effects on plant community metrics in our study. Studies have revealed that EI grazing management results in decreased livestock weight gains (Grings et al., 2002), while PB grazing weight gains are unchanged or improved (Limb et al., 2011), as compared with weight gains associated with SL grazing in mixed-grass prairie.

The fact that average above-ground biomass production was not affected by patch burning in our study also attests to the resilient nature of the mixed-grass prairie to fire. Patch burning can increase the consistency in above-ground biomass production across years (McGranahan et al., 2016), which will become increasingly important for producers as climate change continues to alter precipitation patterns (Alexander et al., 2006).

Additional research is necessary to confirm these findings through extended timespans and identify management specifics in bluegrass-invaded mixed-grass rangelands. Nevertheless, our results join a growing body of evidence that suggests PB grazing is a viable management strategy that can meet economic and biological objectives simultaneously in fire-dependent grassland ecosystems such as those invaded by bluegrass in the northern Great Plains (DeKeyser et al., 2013).

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