Kentucky bluegrass invaded rangeland: Ecosystem implications and adaptive management approaches

By Caley K. Gasch, David Toledo, Katherine Kral-O'Brien, Carol Baldwin, Cayla Bendel, Walter Fick, Leslie Gerhard, Jason Harmon, John Hendrickson, Torre Hovick, Micayla Lakey, Devan McGranahan, Sayjro Kossi Nouwakpo, and Kevin Sedivec

On the Ground

- Summary of multidisciplinary research on Kentucky bluegrass expansion throughout the Great Plains based on symposium held at 2019 SRM Annual Meeting.
- Fire, grazing, and their combination are promising tools for managing Kentucky bluegrass to maintain diverse and productive grasslands.
- Kentucky bluegrass growth and dominance results in accumulation of surface residues, which alter soil hydrology.
- Gradients of Kentucky bluegrass abundance in grasslands are associated with shifts in butterfly pollinator communities.
- Community organization, education, and establishment of burn associations support prescribed fire on the ground, but challenges in adopting fire as a management tool remain.

Keywords: Great plains, Hydrology, Forage quality, Pollinators, Prescribed burn associations, Transtheoretical framework

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Introduction

In the Great Plains of the United States, as well as in many other regions of the globe, native and non-native invasive plant species are dominating native grassland ecosystems and homogenizing the plant community. One such species, Kentucky bluegrass (*Poa pratensis* L.) makes up 14.5% of foliar canopy cover on nonfederal rangelands nationally.[1] Kentucky bluegrass cover has increased in states within the Great Plains, with foliar canopy cover increasing to 86% in North Dakota, 63% in South Dakota, 40% in Kansas, 38% in Nebraska, and 32% in Montana based on data collected at individual locations and then aggregated for the time period between 2011 and 2015.[1]

Grassland degradation and reductions in plant species diversity due to Kentucky bluegrass invasion and dominance have far-ranging consequences for both human and ecological systems.[2] Native grasslands provide important ecosystem services such as nutrient cycling, forage and habitat for wildlife and livestock, pollinator habitat, carbon capture, and regulation of hydrologic cycles.[3] Homogenization of plant communities following Kentucky bluegrass dominance may threaten or alter these ecosystem services.[2] Grassland degradation due to invasive plants also affects humans who rely on healthy grasslands as part of their livelihoods. For example, Kentucky bluegrass may produce forage in the spring, fall, and winter, but does not reliably provide high-quality forage during drier, warmer periods.[4] Shifts in plant communities from highly diverse to dominance by a single cool-season grass may limit forage availability during warmer and drier seasons, as well as reduce long-term ecosystem resilience.[5,6] For these reasons, Kentucky bluegrass invasion and dominance in the Great Plains is an ecological problem and livestock production risk.

Despite the recognition that the invasion of Kentucky bluegrass throughout the Great Plains is ecologically and economically concerning, control of this species has not been a management priority for most producers.[7] This may be because Kentucky bluegrass offers some forage value and options for effective landscape-level management that face logistical and social barriers.[8] As a result, the range and density of the species has continued to increase,[1] with unknown consequences on long-term rangeland sustainability. However, here we summarize evidence that grassland management strategies can achieve Kentucky bluegrass suppression, which can help maintain the provisioning services that diverse native plant communities provide.

We have investigated multiple aspects of Kentucky bluegrass ecology and management (Fig. 1) including 1) using adaptive management approaches that include natural disturbances (i.e., fire and livestock grazing) for restoring and maintaining diverse grasslands; 2) impacts of Kentucky bluegrass on ecosystem services (i.e., soil water regulation and pollinator services); and 3) effectively overcoming social barriers to treatment options aimed at restoring these grasslands. To facilitate the integration of current multidisciplinary knowledge on Kentucky bluegrass in the Great Plains, a symposium at the 2019 SRM Annual Meeting in Minneapolis, Minnesota was held. We presented summaries of research progress on these topics and identified future directions for managing Kentucky bluegrass and conserving native grasslands and their ecosystem services.

Topic 1: The Potential for Adaptive Management Strategies to Control Kentucky Bluegrass

Prescribed fire, grazing, and their interactions were historically important tools for maintaining forage quality and plant species diversity across the Great Plains. As adaptive management strategies are considered for controlling Kentucky bluegrass at the regional and landscape scale, we can use these management tools to combat widespread plant species diversity loss. Here, we present a short summary of how prescribed fire has successfully controlled Kentucky bluegrass in the Great Plains. We also present a recent evaluation of grazing and patch-burn grazing for managing plant communities in the northern Great Plains.

Prescribed Fire

The Great Plains has a long history of humans using fire to enhance forage production. American Indian tribes burned grasslands in the spring to attract game animals to fresh green forage.[9] During the 1860s and 1870s drovers moved cattle into Kansas[10,11]; shortly thereafter, Texas cattlemen burned pastures in the Flint Hills to promote early grass growth and rapid weight gains for their transient cattle herds.[11] Over 100 years ago, burning pastures in the spring was a common practice on Kansas farms,[12] and prescribed burning continues today as a frequent practice in the Kansas Flint Hills.[13]

Prescribed burning has been studied intensively in the tallgrass prairie of Kansas and offers promise as a management tool to control Kentucky bluegrass. During a 2-year period (1918–1921), the Kansas Agricultural Experiment Station compared the impacts of spring burning on soil temperature, forage yield, and plant composition in the absence of grazing.[12] Burning conducted between March 13 and April 7 was compared with unburned and ungrazed conditions. The principal grasses on the site included big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Nash] E.P. Bicknell), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), and Kentucky bluegrass. Total grass cover increased during the 4-year study on the burned and unburned areas. However, the percent cover of Kentucky bluegrass in unburned areas increased from 0% to 34% in unburned areas, which was a greater rate of increase than in the burned areas (4% in 1918 to 11% in 1921).

Timing and seasonality of prescribed fire are factors in targeting Kentucky bluegrass in the tallgrass prairie. Aldous[14] initiated a study in 1926 in Kansas comparing timing of burning on vegetation response. Burning occurred annually during winter (December 1), early spring (March 20), mid-spring (April 10), and late spring (May 1). Aldous[14] also had unburned sites. Over the first 5 years, early, mid-, and late-spring burning decreased Kentucky bluegrass from 80–94%, and Kentucky bluegrass increased by 176% on unburned plots.[14] After 54 years, Kentucky bluegrass comprised <1% of the composition on the burned plots and covered 13.5% of unburned plots.[15]

Additional research conducted in Kansas supports these findings and suggests burning and grazing decreases the presence of Kentucky bluegrass and increases the presence of tallgrass prairie species native to Kansas.[16–20] Left unburned, dramatic increases in Kentucky bluegrass occur on both grazed[21] and ungrazed[14,15] Kansas rangelands. Additionally, high stocking rates can reduce fuel loads, leading to reduced fire intensity and subsequent persistence and increases of Kentucky bluegrass.[21,22] Collectively, this research suggests that burning and grazing alone or in combination can reduce Kentucky bluegrass and/or increase native plant species cover in the Great Plains. Furthermore, this research from Kansas highlights that burning should be a primary tool for controlling Kentucky bluegrass, regardless of season, and especially if pastures are left ungrazed.

Research on utilizing prescribed fire to reduce the cover of Kentucky bluegrass is much less studied in the mixed-grass prairie of the northern Great Plains compared with the tallgrass prairie in the southern Great Plains. Unlike the southern Great Plains where prescribed fire is used to improve forage quality and livestock utilization,[14] public perceptions of fire and fire use are generally not as acceptable in the northern Great Plains, and therefore fire is not broadly used.[8,23] Even so, past studies in the northern Great Plains have found prescribed fire can reduce the cover of Kentucky bluegrass.[24–26] For example, Kral et al.[26] found that burning in May, September, or November resulted in reduced Kentucky bluegrass cover and increased plant species diversity. After September prescribed fires, reduced Kentucky bluegrass cover persisted for at least 3 years, while cover increased to pre-fire levels after 1 year following May burning. Thus, prescribed fire can only temporarily reduce Kentucky bluegrass cover,[2,26] and without landowner support, implementing fire at the landscape scale is difficult in the northern Great Plains.

Grazing

With adoption of prescribed fire low in the northern Great Plains, appropriate livestock grazing could be a potential management tool to control the invasion of Kentucky bluegrass. Targeted grazing (i.e., the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals[27]) could be a management tool to reduce Kentucky bluegrass because native cool-season grasses (e.g., *Hesperostipa*

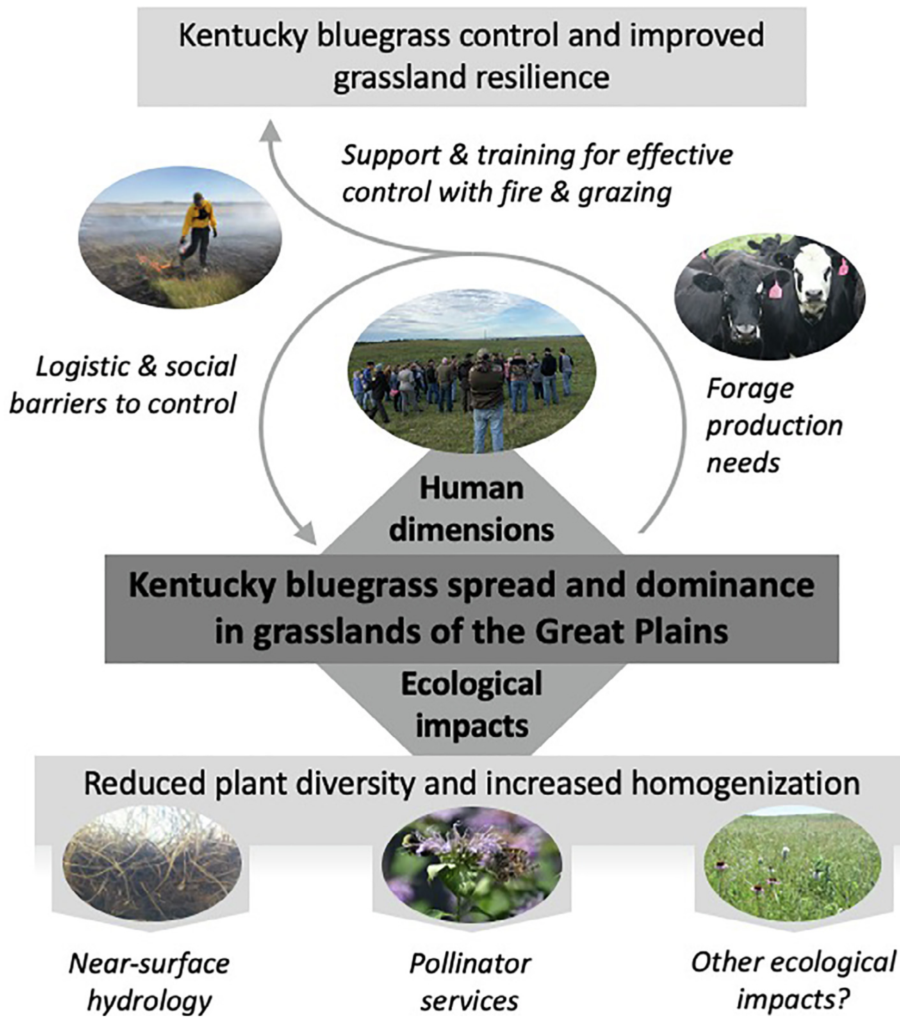

Figure 1. Depiction of recent research on Kentucky bluegrass (*Poa pratensis* L.) in the Great Plains, including both ecological impacts of its spread and dominance, as well as human dimensions related to grassland management. Kentucky bluegrass can provide inconsistent forage throughout the growing season. Logistical and social barriers prevent adoption of prescribed fire as a management tool to encourage plant community diversity; however, the lack of management encourages the continued expansion of Kentucky bluegrass. Education and training of livestock producers can overcome the barriers of using prescribed burns and can promote grazing practices that suppress Kentucky bluegrass to retain native plant diversity and provide continuity in forage production. Ecological impacts include reduced native plant diversity, which alters near-surface hydrology and pollinator services. There are likely additional and/or cascading effects associated with this shift in plant communities that are yet to be identified.

comata [Trin. & Rupr.] Barkworth and *Nassella viridula* [Trin.] Barkworth) in the northern Great Plains require more growing degree days to produce leaf emergence than introduced species.[28,29] This delay in emergence may provide a window of opportunity for applying a targeted grazing strategy.

Unpublished data from the Northern Great Plain Research Laboratory collected between 1984 and 2014 indicated that Kentucky bluegrass invasion was slower for a heavily grazed pasture than for a moderately grazed pasture (Fig. 2). A targeted grazing study at the same location demonstrated that early grazing could increase native grass abundance but the effect on cool-season perennial grasses was less clear.[30] Generally, native grasses increased under early targeted grazing strategies, but the results were mixed for specific invasive cool-season perennials (e.g., Kentucky bluegrass or smooth brome [*Bromus inermis* Leyss.]). Even so, the use of targeted grazing may help in managing cool-season invaders in areas where producers or land managers are unable or unwilling to utilize alternative control strategies such as prescribed fire.

Patch-burn Grazing

Given the research results from Kansas showing the benefits of prescribed fire for controlling the spread of Kentucky bluegrass, the constraints and resistance to fire adoption in the northern Great Plains, and the limited ability of targeted grazing to provide control, patch-burn grazing may be an alternative strategy. This strategy could simultaneously alleviate social concerns about prescribed fire, meet livestock production needs, and encourage native grassland conservation.

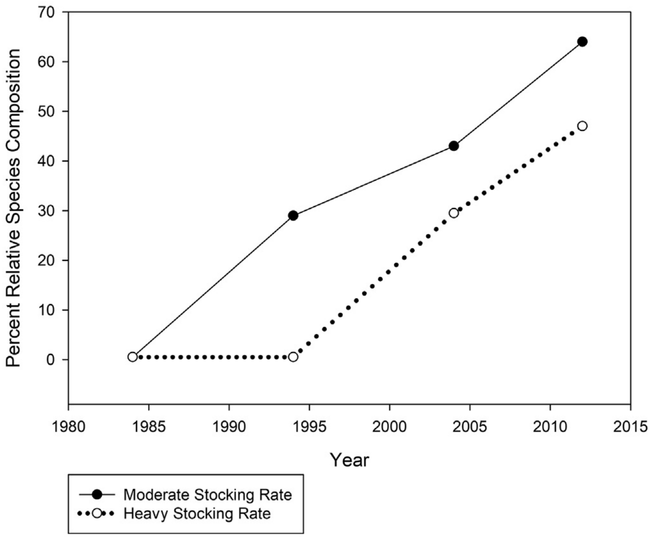

Figure 2. Kentucky bluegrass as a percent of the relative species composition determined by basal hits in 1984, 1994, 2004, and 2012 under moderate and heavy stocking rates in Mandan, North Dakota. Unpublished data from the USDA-ARS Northern Great Plains Research Laboratory.

Disturbance-driven heterogeneity is an important characteristic of rangelands that evolved with fire and grazing and is essential for maintaining forage diversity in rangelands.[31] By combining fire and grazing interactions, patch-burn grazing creates contrast in forage quality and quantity between burned and unburned patches within a pasture compared with traditional season-long grazing.[32] This heterogeneity enhances the value of rangelands for both livestock and wildlife and attracts grazers to the most recently burned patches.[32] In addition, patch burning does not require entire pastures be burned, thereby reducing the extent of blackened rangelands, nor cross-fencing to manipulate livestock movements. Patch-burn grazing in Kentucky bluegrass-invaded rangelands restricts its spread,[33] but questions exist about how patch-burn grazing in these invaded systems will impact forage resources.

Kentucky bluegrass provides forage for livestock, but widespread invasions create homogenous forage resources across the landscape. Since Kentucky bluegrass goes dormant during drought,[4] the extent of an invasion becomes uniformly susceptible to a loss of forage resources. Lakey[34] sought to increase forage heterogeneity (and therefore the probability of forage continuity) in the northern Great Plains by applying a rotational patch-burn grazing treatment to pastures with season-long grazing. Lakey's[34] project monitored forage quality, forage biomass, and grazer occupancy over 2 years of a 4-year patch burn rotation at North Dakota State University Central Grasslands Research Extension Center (CGREC), in the mixed-grass prairie region of North Dakota. This research is ongoing, but preliminary results show that forage biomass was lower in recently burned patches than in all other patches.[34] However, biomass in these burned patches increased over the growing season, and biomass in other patches was stable. As expected, forage quality (represented by crude protein percentages) was higher in recently burned patches. Average fecal pat counts were high in burned patches and low in unburned patches, however, this result was minimized by the end of the growing season, likely due to decreasing forage quality over the season. Cattle on the patch-burn grazing pastures showed consistent average daily gains in both years of the study. Lakey[34] expected continued grazer attraction to the most recently burned patches, consistent increases in cattle performance on patch-burn grazing pastures, and a change in forage quality and quantity as the burn patches shifted.

The patch-burn grazing approach to encourage increased heterogeneity and forage quality across the landscape is compatible with efforts seeking to combat Kentucky bluegrass dominance and homogenization. Patch-burn grazing may be a vital strategy moving forward because 1) it utilizes disturbances proven to reduce the extent and spread of Kentucky bluegrass (e.g., fire and heavy grazing) at a smaller scale (which may be more appealing to landowners); and 2) it increases forage quality and quantity to increase landowner's investment beyond increasing rangeland heterogeneity and diversity.

Both historical and recent studies throughout the Great Plains reinforce the idea that prescribed fire, targeted grazing, and their combination are viable management tools to control Kentucky bluegrass. Prescribed fire consistently reduces Kentucky bluegrass on both short and long timescales in Kansas but is not a widely accepted management tool by producers in the northern Great Plains. Targeted grazing, although less effective at controlling Kentucky bluegrass, and patch-burn grazing offer alternative strategies that can facilitate both livestock production and enhanced native plant diversity. Future directions could focus on understanding risk, liability, and constraints associated with prescribed fire application, especially in the northern Great Plains, and identifying solutions to overcome these barriers. Additionally, we can learn more about the conditions under which prescribed fire and grazing can effectively control Kentucky bluegrass, such as fire intensity and behavior across Kentucky bluegrass abundance gradients, seasonality and sequence of treatments, and strategies that maximize positive response by the native plant communities.

Topic 2: Kentucky Bluegrass Impacts on Ecosystem Services

In 2014, Toledo et al.[2] recognized how Kentucky bluegrass may threaten the ecosystem services provided by grasslands. Many of these ecosystem services are subjects of current and ongoing research, but more research is needed. Here, we provide summaries of recent research on how Kentucky bluegrass interacts with two specific services: the soil's ability to capture and store shallow water, and butterfly community response across gradients of Kentucky bluegrass invasion in the northern Great Plains.

Soil Hydrology

Rangelands dominated by Kentucky bluegrass often develop a dense litter layer, thatch layer, and root mat near the soil surface.[35] These layers have the potential to increase overland flow rate and reduce infiltration rates of water.[36–38] Litter is the uppermost layer of detached organic debris on the soil surface,[39–41] and thatch is a tight layer of living and dead plant material that accumulates between the plant canopy and the soil surface of perennial grasses, which results from an imbalance between production and decomposition of organic material.[41] Root mats are the dense layer of fibrous roots between the plant base and mineral soil, which can be very pronounced in established Kentucky bluegrass stands.[42]

Thatch accumulation in older turfgrass stands resulted in more severe soil water repellency compared with a younger turfgrass stand with less thatch accumulation.[43] McCarty et al.[43] observed that reducing soil organic matter on turfgrass reduced repellency and improved infiltration, suggesting these practices are potential management options for controlling the spread of Kentucky bluegrass. In rangeland ecosystems, grazing and prescribed fire have been proposed as management strategies to reduce litter and thatch accumulation.[44–48] Some studies have demonstrated an increase in soil water repellency after fire,[49–51] whereas others have shown no change,[52,53] or even a decrease in soil water repellency.[54,55] Grazing has been shown to limit thatch accumulation in grasslands,[44,47,48] but it is unclear if thatch reduction with grazing results in hydrologic benefits (reduced runoff and improved infiltration).

Nouwakpo et al.[42] studied hydrologic function on Kentucky bluegrass-invaded areas in the northern Great Plains to determine the ability of Kentucky bluegrass litter, thatch, and root mats to intercept and redistribute water resources in rangeland settings. They found that prescribed fire increased litter water repellency, but this did not adversely affect hydrologic response. Additionally, initial soil water content was more influential on infiltration than any grazing treatment. Specifically, when soil was dry (<20% volumetric water content), water drop penetration time increased on litter (20 seconds) and thatch (3 seconds) relative to bare ground, and this delay increased linearly as Kentucky bluegrass cover increased. Additionally, earlier runoff accompanied slower infiltration. When initial soil volumetric water content was >20%, runoff was delayed at a rate inversely proportional to the Kentucky bluegrass cover. These results indicated that dry soils, litter, and thatch are initially more resistant to water infiltration than when wet, but once strata are wet, infiltration increased, and this effect was exacerbated as Kentucky bluegrass cover increased.

Gerhard[56] also aimed to quantify the impacts of Kentucky bluegrass dominance and thatch development on water runoff and infiltration. Sites located across the North Dakota State University's CGREC were excluded from fire and grazing for >30 years; these sites hosted dense Kentucky bluegrass stands (39% mean cover) and thick thatch and litter accumulation. Adjacent sites in pastures managed with season-long moderate grazing and a prescribed spring fire regime were used for comparison. The managed sites had lower Kentucky bluegrass cover (mean 12–19%), little thatch accumulation, and a greater expression of native plant species richness.[56]

Gerhard[56] simulated rainfall events using the Cornell Sprinkler Infiltrometer,[57] which provided infiltration and runoff rates for a small footprint (0.046 m^2 [0.5 $feet^2$]). Hydrologic parameters were highly variable within and across treatments; however, mean infiltration rates were generally higher and runoff rates were lower in the unmanaged sites compared with the sites with a history of grazing and fire. Thus, more water entered the soil and percolated to deeper depths in sites with a greater proportion of Kentucky bluegrass and thatch. These observations were coupled with buried soil moisture sensor records. The sensors confirmed that volumetric water content was 8% to 13% higher in the unmanaged sites in shallow soil (5 cm depth [2 inches]) throughout the growing season, compared with sites managed with fire and grazing. These results could be explained by the dense and shallow rooting structure characteristic of Kentucky bluegrass that potentially promotes soil porosity, water flow, and conductivity in the shallow portions of the soil profile.

Both Nouwakpo et al.[42] and Gerhard[56] indicated that Kentucky bluegrass dominance, as well as litter and thatch development, have the potential to alter soil infiltration and water storage capacities. Specific changes in hydrology likely depend on multiple factors including the extent of Kentucky bluegrass dominance, climate, percent litter and thatch cover and the water content of these strata leading up to a rainfall event, fuel loading and fire severity during a prescribed burn, and soil structural characteristics. Future research should address hillslope- and watershed-scale hydrologic impacts of Kentucky bluegrass dominance and its management, as well as increasing our understanding of Kentucky bluegrass residues and fire effects on soil hydrophobicity.

Pollinator Services

The general relationship between Kentucky bluegrass and plant species diversity is well understood as Kentucky bluegrass increases, plant species diversity decreases.[26] However, we have not quantified relationships between Kentucky bluegrass and higher trophic levels that rely on a more diverse plant community.[2] While we could predict that higher trophic levels associated with native plant communities would also decline in response to Kentucky bluegrass invasion, the generalized relationships between pollinators and invasive plant species are lacking.[58]

Kral-O'Brien et al.[59] determined correlations between butterflies, one of many potential rangeland pollinators, and the plant community across a gradient of Kentucky bluegrass abundance over 3 years in the northern Great Plains. They expected the butterfly community to change in response to the plant community (and associated pollinator resources) because butterflies are dependent on vegetation, are mobile, and have short generation times (1 month to 1 year). During their butterfly and plant community surveys, they categorized butterfly species as either obligate (i.e., those relying on grasslands to complete their life cycles) or facultative (i.e., occur in grasslands, but not an obligate species). Butterfly species richness declined as Kentucky bluegrass cover increased, but total butterfly species abundance did not decline. Only the abundance of obligate grassland butterfly species declined with increasing Kentucky bluegrass cover. Sites with Kentucky bluegrass cover >20% saw an average 24% decrease in obligate butterfly abundance. Moreover, butterfly communities at sites with less Kentucky bluegrass cover had diverse facultative and more obligate grassland species. In contrast, butterfly communities at sites with more Kentucky bluegrass cover were dominated by several facultative (i.e., generalist) species and fewer obligate species.

Butterfly observations were presumed to be related to differences in plant communities—both directly and indirectly correlated with Kentucky bluegrass and management history. Indeed, sites with higher Kentucky bluegrass cover had reduced plant diversity, driven by a reduction in native forb species. Generally, the sites with lower Kentucky bluegrass cover were managed with fire, grazing, or a combination. Although fire is not traditionally used for butterfly conservation, spatially discrete fires have been beneficial to butterfly conservation in other regions[60] and may be necessary to reduce Kentucky bluegrass cover and improve resource availability for butterflies and other grassland dependent species.

Kentucky bluegrass invasion and dominance may be associated with effects on higher trophic levels in grassland communities.[59] Butterflies represent a subset of pollinators, and a much smaller subset of animals that directly interact with plant communities. The reduction in forb richness and plant species richness overall with higher Kentucky bluegrass cover indicates that additional pollinator species, such as bees, would struggle to find diverse resources for pollen, nectar, and nesting. Certainly, future research directions should focus on potential cascading impacts of Kentucky bluegrass dominance on other grassland-dependent animals. Additional areas to pursue may include the role of land management strategies in enhancing wildlife habitat and resources in landscapes with widespread Kentucky bluegrass occurrence.

Topic 3: Social Dynamics and Reducing Kentucky Bluegrass with Adaptive Management Strategies

We have summarized here that past and current research in the Great Plains indicate that reintroduction of fire may be one of the best ways to combat Kentucky bluegrass invasion in the northern Great Plains, but perceptions of risk and other constraints currently limit its use. One of these constraints may be the perception of fire. Bendel et al.[8] mailed a self-administered questionnaire to landowners in North Dakota to identify differences in ranchers', nonranchers', and beekeepers' attitudes and perceptions toward prescribed fire to better understand major factors that limit the use of fire in rangeland management. A total of 96 landowners responded (out of 460 surveys sent). Of those who identified themselves as ranchers (22 respondents), the majority of respondents disagreed that prescribed fire was a beneficial tool (38% agree, 43% disagree, 19% neutral) and were split on whether they would apply it on their land (38% agree, 38% disagree, 24% neutral). Only 9% of ranchers who responded had ever applied prescribed fire on their land (2 respondents). Nonranch landowners' (74 respondents) perception to fire was relatively more receptive than ranchers, and respondents found prescribed fire to be a beneficial tool for restoring rangelands (55% agree, 26% disagree, 19% neutral). Likewise, nonranchers agree with the use of prescribed fire (64% agree, 31% disagree, 5% neutral) with 25% of respondents having performed a prescribed fire on their land (11 respondents). Survey responses also indicated that there are several factors that potentially constrain fire application. Knowledge and experience were a weak constraint with time and financial resources identified as larger constraints. Perception of both labor and equipment as a constraint to prescribed fire application varied between rancher (65%) and nonrancher (33%) landowners.

To place the responses into context, Bendel et al.[8] applied their survey findings to the transtheoretical model of behavior change[61] to compare ranchers' and nonranchers' behavior and identify solutions fitted to their respective perspectives (Fig. 3). Transtheoretical models help to decipher motivations and determine where behavioral changes are possible.[62] For example, most rancher respondents disagreed fire was a beneficial tool and had limited experience in implementing a burn, whereas a fairly large percentage were neutral. Thus, they may be in the precontemplation or contemplation stages (Fig. 3). At these stages, ecological impacts (e.g., Kentucky bluegrass or woody plant invasions) may be noticeable on the landscape but are not severe enough to change behavior. Once in the contemplation stage, ranchers are more responsive to information and resources about changing their behavior. Therefore, some of these ranchers might be receptive to fire demonstrations or workshops that emphasize benefits of fire to forage quality and livestock production. Conversely, nonrancher respondents mostly agreed that fire was a beneficial tool and would use it as a management tool on their land. Yet only 25% had conducted a prescribed burn. Although they stated less concern with labor and equipment needs than ranchers, labor and equipment was a significant predictor of prescribed fire application in the model. These landowners are more likely in the preparation (or even action) stages of the transtheoretical model (Fig. 3). In the action stage, even though an individual has adopted a new behavior they still need support to continue that behavior, as it has not yet become permanent. Strategies aimed at reducing negative attitudes toward prescribed fire to all landowners would be a beneficial step for influencing societal acceptance of fire in the northern Great Plains. Therefore, education and outreach can

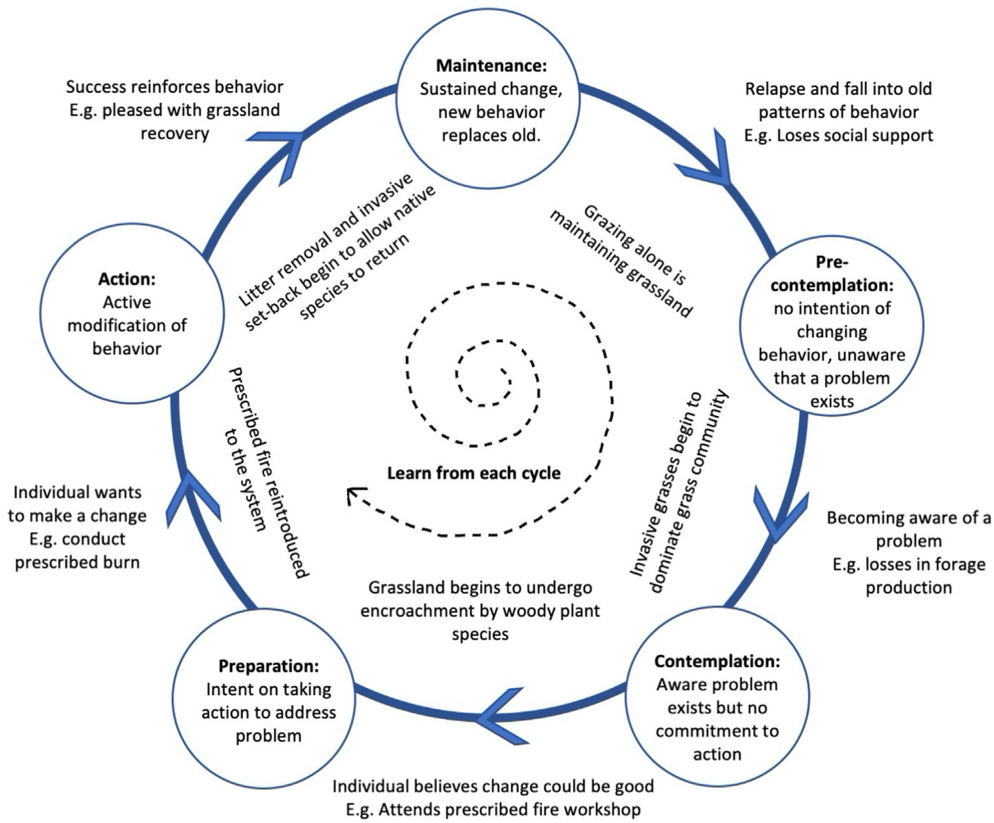

Figure 3. Transtheoretical model of behavior change as applied to prescribed fire behavior in North Dakota. This model was developed from survey responses to identify motivations behind landowner decisions and opportunities for behavioral change to using fire as a management tool. Adapted from Bendel et al.[8] and Prochaska and DiClemente.[6].

be better targeted to adequately address barriers and limitations based on landowners' background, norms, beliefs, stages of change, processes of change, self-efficacy, and decisional balance.

While these constraints exist in the northern Great Plains and are apparent across the landscape (as reflected in the limited use of prescribed fire), areas in the southern Great Plains (Kansas, Oklahoma, and Texas) have made progress in supporting fire as a management tool.[63] In these areas, landowners and ranchers have created self-assembled prescribed burn associations, which provide a forum for sharing knowledge and resources. By cooperating, landowners in burn associations successfully address some of the main challenges to conducting prescribed burns: sharing equipment and labor, learning techniques from more skilled prescribed burners, and gaining experience from burning in a variety of topographical and weather situations improving the safety of conducting prescribed burns while reducing liability concerns that a fire might escape. Prescribed burn associations also foster good community relations, the capacity to burn more acres in a year, and provide personal satisfaction in helping others.[7]

However, prescribed burning is being underutilized, as attested by trends in community change and through personal communication with ranchers, extension agents, agency personnel, and a regional survey.[8] Despite best efforts, and as described for North Dakota in Bendel et al.,[8] many producers still lack resources, including training, equipment, and experience. In addition, regulations can impede prescribed burning by requiring extensive training or resource requirements—an excessively lengthy, slow, costly, or labyrinthine permission process—and very narrow allowable weather parameters.[64] These regulations can also be used by managers, agencies, and legislators to intentionally discourage prescribed burning if they are uncomfortable with or unknowledgeable about its use.

Finally, it is the fear of a fire escaping control that keeps much-needed prescribed burning from occurring. Research indicates actual risk is less than perceived risk,[65] but mental images of a prescribed burn turning into a raging wildfire are persistent. While damage to rangelands, if any, from an escaped prescribed burn can be remedied, infrastructure can be destroyed and smoke on roadways can cause fatal accidents. Certainly, escaped fires, managed by insufficiently trained or careless burners, only reinforce the perception that prescribed burning is a costly, risky operation. Research can answer many questions, but "ultimately, many of the [prescribed fire] questions we're dealing with are not scientific. They are about resolving conflicts between values, ethics, and what kinds of institutions should be in place."[66]

Insights and Future Directions

Both historical and recent research has addressed ecological and livestock production concerns related to expansion of Kentucky bluegrass across the Great Plains. Over 100 years of research in Kansas shows that fire and grazing can effectively reduce and/or control Kentucky bluegrass. Kentucky bluegrass research in the northern Great Plains also points toward fire, grazing regimes, and a combination of both as appropriate tools for reducing and controlling Kentucky bluegrass, improving forage quality, and promoting landscape heterogeneity. Using these management tools in the northern Great Plains rangelands has implications for important ecosystem services that these rangelands provide. Specifically, leaving lands idle and without management can lead to Kentucky bluegrass proliferation, which has negative consequences for ecosystem services (likely including those yet to be investigated). Additionally, management treatments and their timing, frequency, and extent may also impact these services, and decision-making processes would benefit from identifying risks and consequences associated with different management approaches.

However, large-scale shifts in management approaches require a change in how these ecosystems have traditionally been managed. Prescribed fire is an effective tool for managing Kentucky bluegrass, yet Bendel et al.[8] pointed towards several constraints on the application of prescribed fire but also pointed out that targeted education, outreach and extension efforts, as well as the promotion and adoption of prescribed burn associations could help overcome many of these barriers. Even so, burn associations continue to face challenges in supporting widespread use of prescribed fire as a management tool.

Research related to Kentucky blue grass has increased in the last 3 to 4 years and as the SRM symposium and our follow-up summary indicate, our understanding of the dynamics of Kentucky bluegrass invasion into ecosystems in the northern Great Plains has advanced and we are closer to identifying feasible management strategies that can reduce and control Kentucky bluegrass. However, knowledge gaps exist regarding management of this novel ecosystem under changing climatic conditions. Unless there are major shifts in climate patterns, Kentucky bluegrass eradication is not feasible, nor is it necessarily a goal of producers. Yet, evidence indicates that we are dealing with a novel ecosystem, and we need to manage this ecosystem in novel ways that ensure the greatest possible diversity and resilience. This will require that we overcome challenges regarding large-scale adoption of management practices (such as prescribed fire).

Moving forward from the topics that we have explored here, we need research that addresses both the ecological and human dimensions aspects of Kentucky bluegrass invaded areas, including:

1. Identifying management systems that use fire and grazing to effectively control Kentucky bluegrass across its extent. Specifically, understanding fire intensity and behavior across Kentucky bluegrass abundance gradients, identifying optimum seasonality and sequence of treatments to control Kentucky bluegrass, and promoting strategies that maximize positive response by the native plant communities.
2. Scaling and modeling of how Kentucky bluegrass growth and thatch impact hydrology at the hillslope and watershed scales.
3. Understanding how Kentucky bluegrass growth and residues affect surface and soil properties, and if they promote soil hydrophobicity (either with or without fire) or other physical and chemical changes.
4. Investigating potential impacts of Kentucky bluegrass dominance and its management on grassland-dependent animals across multiple trophic levels.
5. Understanding sources of risk, liability, and constraints associated with adoption and application of prescribed fire, especially in the northern Great Plains, and identifying solutions to overcome these barriers.

Through multidisciplinary research, evaluating management practices on the ground, and exploring options for overcoming resistance to prescribed fire, we can optimize the management and conservation of the northern Great Plains landscape despite any challenges that Kentucky bluegrass has introduced.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors are in: Department of Soil Science, School of Natural Resource Sciences, North Dakota State University, Fargo, ND, USA; USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND, USA; Department of Entomology, School of Natural Resource Sciences, North Dakota State University, Fargo, ND, USA; Agriculture, Natural Resources and Community Vitality, Kansas State University, Manhattan, KS, USA; Pheasants Forever, Bismarck, ND, USA; Department of Agronomy, Kansas State University, Manhattan, KS, USA; Department of Entomology, School of Natural Resource Sciences, North Dakota State University, Fargo, ND, USA; USDA-ARS Northwest Irrigation and Soils Research Laboratory, Kimberly, ID, USA; Range Science Program, School of Natural Resource Sciences, North Dakota State University, Fargo, ND, USA