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David Toledo, Matt Sanderson, Kenneth Spaeth, John Hendrickson, and Jeff Printz*

Kentucky bluegrass, a nonnative species, has invaded rangelands in the United States and is currently present in most rangelands across the Northern Great Plains. Despite its accelerated expansion, the consequences of Kentucky bluegrass on the diversity of native plant species and on ecosystem services remain largely unknown. We synthesized the available data related to Kentucky bluegrass and how it affects native plant diversity and ecosystem services. We found that invasion may bring negative consequences to ecosystem services, such as pollination, habitat for wildlife species, and alteration of nutrient and hydrologic cycles, among others. To maintain the flow of ecosystem goods and services from these rangeland ecosystems, range science must adapt to the challenge of introduced, cool-season grass dominance in mixed-grass prairie. Based on our findings, we identify research needs that address ecosystem changes brought on by Kentucky bluegrass invasion and the corresponding effects these changes have on ecosystem services. We are dealing with novel ecosystems, and until we have better answers, adaptive management strategies that use the best available information need to be developed to adapt to the invasion of this pervasive invasive species.

Nomenclature: Kentucky bluegrass, *Poa pratensis* L.

Key words: Ecosystem services, National Resources Inventory, restoration effort, scale of invasion, spatial extent.

The geographic spread of invasive plant species in United States rangelands has been especially dramatic, and many native plant communities have shifted from native-dominated ecosystems to invasive species–dominated ecosystems (Devine 1998; DiTomaso 2000; Mack 1981). In the Great Plains region of the United States, Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leyss.) have invaded many areas, accounting for 10% of the total cover for all plant species and approximately 62% of the exotic species cover, with Kentucky bluegrass accounting for 39% of that cover, and smooth brome accounting for 23% (Cully et al. 2003). These results are confirmed by similar trends in National Resource Inventory rangeland data, which also include data from Northern Great Plains states (USDA 2014).

The prairies of the Northern Great Plains are typically dominated by cool season (C_3), perennial grasses, such as western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve] and green needlegrass [*Nassella viridula* (Trin.) Barkworth]; however, Kentucky bluegrass, a nonnative, grazing-tolerant, cool-season (C_3), perennial grass, has displaced many native plant communities. The consequences of this expansion on native plant species diversity and ecosystem services remain largely unknown, despite accelerated Kentucky bluegrass expansion (Murphy and Grant 2005; Travnicek et al. 2005). Potential reasons why this expansion has not received much attention include that Kentucky bluegrass can serve as nutritious forage during certain times of the year, it is a widely used turf grass, and it has been used as a soil stabilizer against erosion (Huff and Bara 1993).

Being a grazing-tolerant, C_3, perennial invader makes Kentucky bluegrass especially relevant in the predominantly

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Management Implications

Maintaining the flow of ecological goods and services instead of unrealistically managing for the past under changing cultural and climatic conditions (i.e., urbanization, climate change, and increased atmospheric nitrogen deposition) has become a reality. This has increased the need to implement adaptive management and new research approaches. Managing these novel ecosystems requires adjustment to timing and application of traditional management tools, such as grazing, fire, deferment, and rest, as well as bringing the collective knowledge and resources of government and educational and private sectors to bear. We need to be open to changing our traditional management practices and working on improving the flow of goods and services provided by natural areas.

C_3-dominated grasslands of the Northern Great Plains. Case studies in the Knife River Indian Villages National Historic Site (DeKeyser et al. 2009) and across five national wildlife refuges in North and South Dakota (Grant et al. 2009) have documented an increase in Kentucky bluegrass from trace amounts to greater than 90% of the vegetation during a 30-yr period. Additionally, analysis of National Resources Inventory rangeland data (USDA 2014) indicates Kentucky bluegrass is now present in most of the areas sampled across the Northern Great Plains, with some areas, such as North Dakota, having Kentucky bluegrass present on more than 50% of the acres sampled (Figure 1).

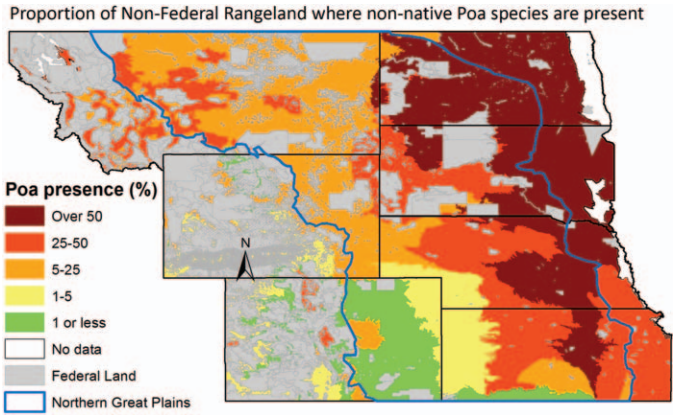

Figure 1. Kentucky bluegrass presence based on 2003 to 2006 National Resources Inventory rangeland canopy foliar cover data (USDA 2014). Percentages refer to the percentage of acres with *Poa* present within Major Land Use Resource Area polygons. For example, in North Dakota, Kentucky bluegrass is present in 82% of the acres of most polygons, and of these areas where it is present, there is at least 50% cover of Kentucky bluegrass in 33% of them (USDA 2014).

Invasive species are associated with a series of cascading effects on ecosystem function and integrity, lowering plant diversity (Pritekel et al. 2006; Vaness and Wilson 2007). The invasion and expansion of Kentucky bluegrass in the Northern Great Plains has contributed to a decrease in native prairie biotic integrity and plant diversity (Cully et al. 2003; DeKeyser et al. 2009; Miles and Knops 2009a) and has altered plant community structure and function (DeKeyser et al. 2013; Miles and Knops 2009a). Kentucky bluegrass has become dominant at landscape scales in many areas. Changes brought on by this invasion have the potential to contribute to the disappearance of many ecological interactions through trophic downgrading effects (Estes et al. 2011).

In this article, we synthesize available information related to Kentucky bluegrass and its effects on native plant diversity and ecosystem services in the Northern Great Plains of the United States. Our overall objective is to provide a better understanding of Kentucky bluegrass dynamics to serve in the development of adaptive management strategies. We do this by synthesizing available literature and identifying and prioritizing research and management needs for Kentucky bluegrass–invaded ecosystems.

Kentucky Bluegrass Effects on Native Plant Diversity

Invasive species have a severe and widespread effect on biodiversity (Pritekel et al. 2006; Randall 1996; Wilcove et al. 1998). About 35 to 46% of the plants and animals on the federal endangered species list have had their placement there attributed to habitat loss caused by invasive species (Wilcove et al. 1998). Kentucky bluegrass is no exception. In the tallgrass prairie of the United States, Kentucky bluegrass has a potential to displace little bluestem [*Schizachyrium scoparium* (Michx.) Nash], a native, perennial, C_4 grass species, following soil disturbance or nitrogen fertilization (Tilman 1987; Wedin 1995). Once Kentucky bluegrass becomes dominant, it can influence its environment and the available niches that other subdominant plants would then occupy (Emery and Gross 2007).

Plant communities dominated by Kentucky bluegrass have significantly less cover and diversity of native grasses and forb species (Dekeyser et al. 2009; Grant et al. 2009; Miles and Knops 2009b; Tatina 1994). For example, Dekeyser et al. (2009) reported that at the Knife River Indian Villages National Historic Site, near Stanton, ND, Kentucky bluegrass increased from 4 to 22%, whereas native forbs decreased from 34 to 14% at a sandy ecological site; while on a loamy ecological site, Kentucky bluegrass increased in cover from 13 to 34%, whereas native grasses and forbs decreased (66 to 4% and 24 to 12%, respectively) between 1984 and 2007. This change in dominance has the potential to affect not only plant cover and diversity but also the ecological function of higher trophic levels (Siemann et al. 1998), thus altering community function and ecosystem services at broader scales. A change in the plant community from a diverse, mixed-grass prairie to a Kentucky bluegrass–dominated

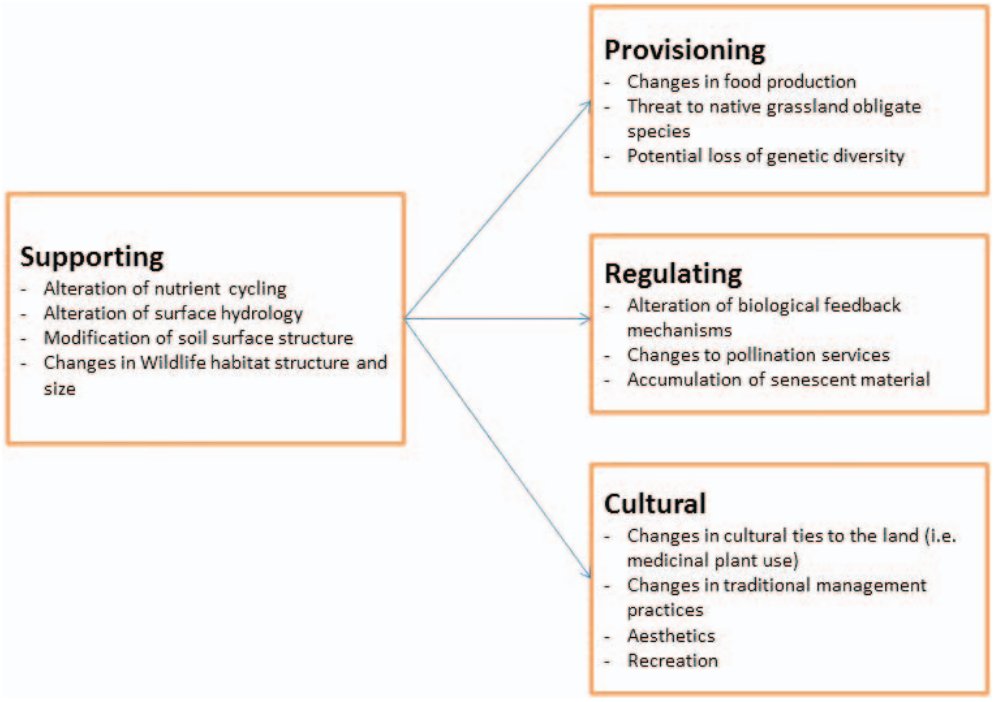

Figure 2. Major impacts of Kentucky bluegrass in the Northern Great Plains, classified by which of the four categories of ecosystem services they are affecting most. Based on Vila et al. (2009).

grassland would have effects on organisms at all levels of the food chain, from organisms that live below the soil surface to the macrofauna that live at the soil's surface. Even though there are several studies that mention the lower diversity in Kentucky bluegrass–dominated areas, none of those studies present data to explain the mechanisms for this community change. The trends presented in all of these studies, combined with changes in Kentucky bluegrass invasion reported in the 2014 National Resources Inventory rangeland data (USDA 2014), suggest this is an issue that warrants further attention and research. However, there is no research that directly links Kentucky bluegrass increase as the cause of decreased native species richness, and this change could be an effect of other factors, such as increased nitrogen levels (Tilman 1987). Kentucky bluegrass expansion might be occurring only in niches previously occupied by native plants that have been displaced by other factors, such as livestock grazing intensity (Sinkins et al. 2012).

Kentucky Bluegrass Effects on Ecosystem Services

Ecosystem services are broadly defined as nature's services that provide benefits to human well-being. In this section, we focus on how invasion by Kentucky bluegrass influences the four categories of ecosystem services, namely, supporting, provisioning, regulating, and cultural ecosystem services (MEA 2005; Figure 2).

Supporting Ecosystem Services. *Alteration of Nutrient Cycling.* The mixed-grass prairie of the Northern Great Plains developed under the influence of multiple disturbances, such as fire and grazing (e.g., Bowman et al. 2009; Coppedge 1998). In native, mixed-grass prairie sites, available nitrogen is sequestered in belowground organic matter, and intense prairie fires reduced available nitrogen through volatilization and transfer of organic N from labile to recalcitrant pools (Goergen and Chambers 2009). Additionally, most native grasses and forbs exhibit high carbon : low nitrogen ratios further delaying breakdown and reducing available nitrogen for plant growth.

The shift from a diverse native plant community dominated by plants with a high carbon : nitrogen ratio to a simplified plant community dominated by Kentucky bluegrass with a lower carbon : nitrogen ratio (Wedin and Pastor 1993) alters nutrient cycles, making nitrogen more available for plant growth (Hendrickson et al. 2001). The additional nitrogen results in greater overall production, but community structure is affected and plant species diversity is reduced because many native plants lose their natural competitive ability of coping with lower nitrogen levels (Wedin and Tilman 1990). Prairie systems are sensitive to changes in available nitrogen. Small changes in available nitrogen because of changes in community composition, atmospheric deposition, and fertilization can greatly alter these vulnerable prairie systems and may help explain the speed with which Kentucky bluegrass has come

to dominate large expanses of rangeland (Tilman 1987; Wedin and Tilman 1990).

Alteration of Surface Hydrology. Plant communities dominated by Kentucky bluegrass are very resilient to management treatments, such as prescribed fire and herbicide (Hendrickson and Lund 2010). Once Kentucky bluegrass invades a site, it can alter light and nutrient dynamics, reducing available niches for subdominant plant species. Additionally, its ability to regenerate by tillering gives it a competitive advantage over native vegetation (MacDougall and Turkington 2004, 2005; Miles and Knops 2009b; Wedin 1995).

Rangelands dominated by Kentucky bluegrass often develop a dense root and thatch layer near the soil surface, changing the surface hydrology of the invaded area (Pierson et al. 2002; Taylor and Blake 1982). Thatch is a tight layer of living and dead plant material that accumulates between the plant canopy and the soil surface of perennial grasses and is created because of an imbalance between production and decomposition of organic material (Murray and Juska 1977). Kentucky bluegrass alters the amount of thatch at the soil surface potentially increasing overland flow rate and reducing infiltration rate (Pierson et al. 2002; Taylor and Blake 1982). This effect on overland flow and infiltration rate might be short lived, however, and only evident within the first few minutes of any wetting period. Taylor and Blake (1982) reported that the time it took 2cm of water to infiltrate a sand column in a controlled infiltration experiment was much greater in areas with thatch than with no thatch (6.34 min vs. 0.36 min respectively), but once the thatch was wet, there was no delay in water infiltration. Despite the importance of hydrologic function on ecosystem health, there is an information gap on the ability of Kentucky bluegrass thatch and root mats to intercept and redistribute water resources of the different areas where it invades.

Modification of Soil Surface Structure. Soil structure is a dynamic soil property and can be an indicator to detect responses to different biotic and management actions (Tugel et al. 2005). Changes in soil structure have a potential to alter physical and biotic soil processes, which would further alter invaded ecosystems. The limited research data on agricultural soils suggest that changes associated with rooting depth and alteration of the microbiotic communities associated with soils could have an effect on soil structure (Angers and Caron 1998). Kentucky bluegrass has shallow roots and rhizomes that form a very shallow and dense root mat at the soil surface. The associated lack of root penetration affects the formation of soil aggregates and also affects the formation of macropores used for fluid transport (Angers and Caron 1998). Plant roots are key contributors to the development of soil structure, which is further stabilized by mycorrhizal fungi (Daynes et al. 2013).

High field-aggregate stability values for measurements performed in Kentucky bluegrass—dominated areas of the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) Northern Great Plains Research Laboratory near Mandan, ND, show that surface soil stability in these areas is very stable because of the dense root mat layers formed by this species. Field-aggregate stability measures (Herrick et al. 2001) at these sites were either a six (in a one-through-six scale, where six was the highest possible field-aggregate stability value), or observers were not able to collect samples because of the root mat protecting the soil surface. This root mat protects soils surface layers from wind and raindrop impact, but as with the effects of Kentucky bluegrass on hydrologic function, there is no published evidence, to our knowledge, of the net effects of this species on soil properties of rangeland ecosystems. Research is needed to determine whether there is a net positive or negative effect on soil surface properties that affect the erosion potential of these Kentucky bluegrass–invaded areas and on how variable these effects are in space and time.

Changes in Wildlife Habitat Structure and Size. Ecosystem changes due to invasive species often have direct effects on wildlife habitat structure (DiTomaso 2000). The loss of vegetative structure favors generalist species that can tolerate less heterogeneity in a plant community. A diverse plant community not only provides adequate food sources for a variety of primary consumers but also provides a variety of habitat needs for a variety of species. Kentucky bluegrass–dominated landscapes tend to be homogeneous and lack the botanical composition and physical structure needed to support many of the native wildlife (Dekyser et al. 2013; Ellis-Felege et al. 2013).

The effect of an invasive species depends on the scale at which the system is evaluated and the distribution of the invasion (Parker et al. 1999). As the size and the perimeter–area ratio of the area invaded increases, the impact will be more pronounced (Helzer and Jelinski 1999). Until recently, Kentucky bluegrass invasion patchiness provided some level of habitat heterogeneity. As the area invaded increases, the magnitude of the impacts will increase, forcing many native grassland-obligate species out of their historic ranges. Research on grasshopper sparrows (*Ammodramus savannarum*) shows that in areas with little Kentucky bluegrass cover, sparrows can benefit from increased grass cover, litter depth, and visual obstruction (Schneider 1998). However, as Kentucky bluegrass invasion expands and habitat heterogeneity is lost, negative effects on wildlife become more pronounced and severe (Kendeigh 1941).

Provisioning Ecosystem Services. *Changes in Food Production.* The inherent native plant productivity associated with rangeland in the Northern Great Plains is a major asset to the livestock industry. The diverse mixture of

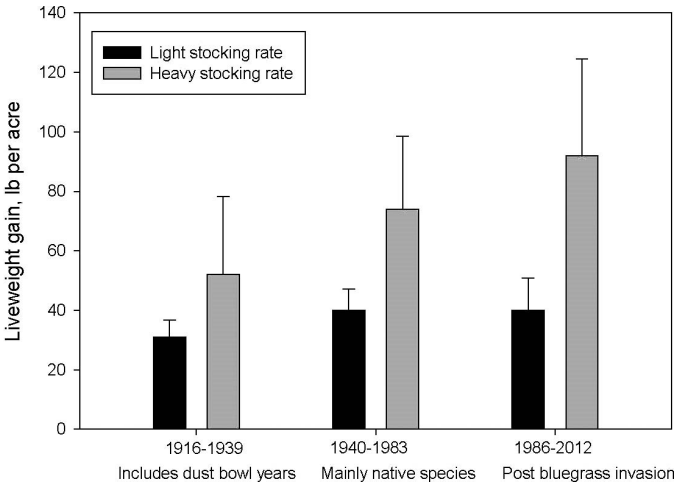

Figure 3. Historical pasture data from the U.S. Department of Agriculture, Northern Great Plains Research Laboratory, showing livestock liveweight gain in pounds per acre for three different periods, representing a gradient of Kentucky bluegrass invasion: in 1916 to 1939, vegetation was all native; during 1940 to 1983, bluegrass was reported, but the pastures were predominantly native grasses; during 1980, Kentucky bluegrass cover increased, and toward the end of that period, became dominant; and in 1986 to 2012, Kentucky bluegrass became the dominant plant in most pastures (compiled from unpublished USDA-ARS Northern Great Plains Research Laboratory data).

warm- and cool-season grasses, forbs, and shrubs provides grazing livestock access to actively growing, highly nutritious plants throughout the growing season. As invading, cool-season grasses reduce plant diversity, the active growth period for the plant community shortens and shifts from spring through summer to early spring and early summer. Even though Kentucky bluegrass can be nutritious forage during certain times of the year, during the summer months, it results in lower forage quality (Hockensmith et al. 1997; Waller and Schmidt 1983) because livestock no longer have other actively growing plants to select during this portion of the growing season. In long-term research at the USDA-ARS Northern Great Plains Research Laboratory, Kentucky bluegrass invasion of native rangeland has not reduced livestock production compared with preinvasion years (Figure 3). In this case, provisioning services have shifted but have not been disrupted, which points toward the difficulty of convincing ranchers to fight Kentucky bluegrass on their land.

Because Kentucky bluegrass is intolerant of heat and drought stress, it quickly becomes less productive and eventually goes dormant during the hot dry summers typical in the Northern Great Plains, reducing its utility as livestock feed (Hockensmith et al. 1997). When there are other forages accessible to livestock, the impact may be imperceptible. However, as the magnitude of the invasion increases and Kentucky bluegrass becomes dominant at a landscape scale, its effects on livestock production can become more pronounced. A cost–benefit analysis is needed to address the economic impacts of Kentucky bluegrass invasion on food production at multiple temporal and spatial scales. Such analysis would provide an insight that can have an effect on management and policy decisions.

Threat to Native Grassland Obligate Species. Many species of birds that depend on grassland or savanna habitats have shown substantial overall population declines in North America (Askins 1994). The most important factor associated with grassland bird population changes in eastern and central North America between 1980 and 1998 was loss of native rangeland (Hill et al. 2014; Murphy 2003). In many cases, agricultural intensification, including the introduction of exotic grasses and forbs in pastures and hay meadows (Askins 1994), has shifted diverse grasslands toward monocultures (Matson et al. 1997). As discussed previously, this loss in vegetative structure favors generalist species that can tolerate less habitat heterogeneity. Many grassland birds, however, do not require native vegetation for breeding habitat (NRCS 1999). Our literature search found only few research studies with direct evidence linking Kentucky bluegrass invasions to specific positive or negative effects on wildlife (Kendeigh 1941; Schneider 1998; Wilson and Belcher 1989). Different species have different habitat requirements, and results from such studies are likely to be varied and at times contradictory; however, we need more research on this topic, so rangelands can be better managed based on the presence of invasive plant species and what types of wildlife are present and desirable. Further understanding of the habitat requirements of wildlife species would provide information to better manage production-oriented landscapes (Askins 1994) and to better manage landscapes to provide multiple ecosystem services.

Potential Loss of Genetic Diversity. High genetic variation and gene flow within and among individuals or populations ensures long-term survival of species and ecosystems under changing environmental conditions (Van Dyck and Baguette 2005). The increase of Kentucky bluegrass–invaded areas has fragmented native grasslands, creating habitat discontinuities that affect the distribution of resources and environmental conditions. This habitat fragmentation has affected the connectivity among population fragments (Kindlmann and Burel 2008) and has potentially affected gene flow (Fischer and Lindenmayer 2007). Genetic variation is distributed over space and time and increased habitat fragmentation may reduce dispersal success of native grassland species resulting in an increased probability of regional extinction of native grassland–obligate species.

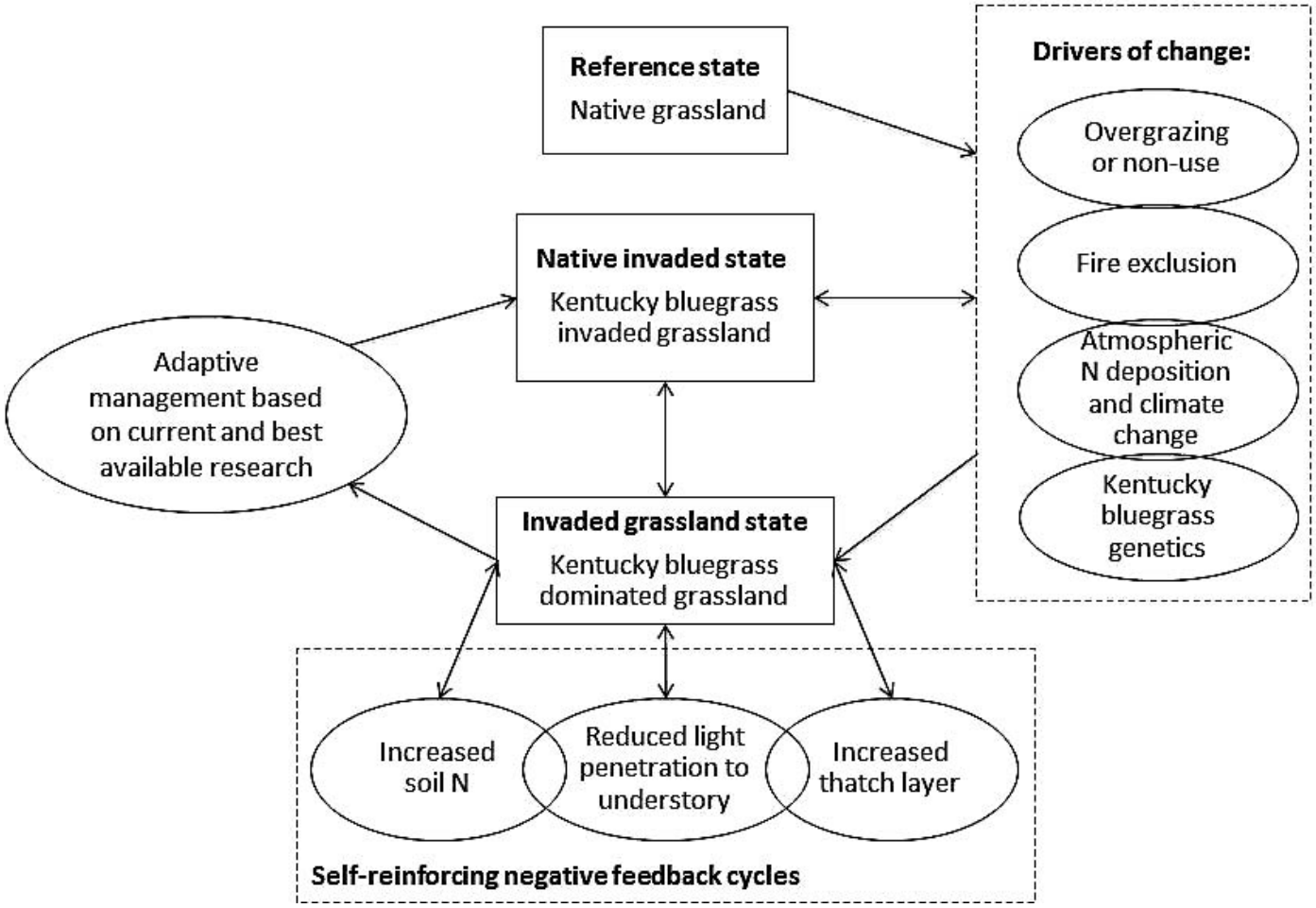

Figure 4. Based on our current state of knowledge, once native grasslands are invaded by Kentucky bluegrass, overgrazing, fire exclusion, atmospheric nitrogen deposition, climate change, or a combination of the above, can contribute to the dominance of this grass species. Once established, Kentucky bluegrass can alter nutrients, hydrology, and light penetration, creating self-reinforcing feedbacks, which serve to promote its dominance. Preliminary observations suggest that adaptive fire and grazing management approaches can reestablish the dominance of native grass species.

Kentucky bluegrass reproduces mainly by a form of gametophytic apomixis. Apomixis is a complex form of asexual reproduction through seed that increases its value for many turfgrass cultivars because of added stability and uniformity in crop cultivars (Huff and Bara 1993). However, the traits that make Kentucky bluegrass a successful turfgrass species are also the traits that make it a good competitor against many of the native species. Once Kentucky bluegrass successfully invades an area, it not only reduces the genetic diversity of other species through habitat fragmentation but also reduces within-species diversity and, therefore, resilience during future environmental stress events. From the perspective of conserving natural habitats and maintaining the flow of ecosystem services that native grassland ecosystems provide, it is thus essential to maintain the functional connectivity of plant and animal populations across landscapes (Van Dyck and Baguette 2005).

Regulating Ecosystem Services. *Alteration of Biological Feedback Mechanisms.* Once established, Kentucky bluegrass can alter the plant–soil feedback mechanisms, reinforcing its presence, providing a competitive advantage for itself, and ultimately displacing other native plant species (DeAngelis 1992; Wedin and Pastor 1993). Changes in litter, soil, and nutrient dynamics associated with Kentucky bluegrass invasion provide a competitive advantage over native vegetation and help it to become the dominant plant species in a community (Figure 4). Based on our observations, once Kentucky bluegrass has been established, a site cannot return to its native grassland state. However, there are benefits to the permanence of Kentucky bluegrass in terms of provisioning services, but the cost of this invasion to other ecosystem services will remain unclear until research gaps have been addressed.

Increased nitrogen deposition (Bobbink et al. 2010) and climate change, which has accelerated nitrogen mineraliza-

tion rates (Rustad et al. 2001), together with changes in grazing and fire-management practices have likely contributed to the invasion and dominance of Kentucky bluegrass in the Northern Great Plains of the United States. These same processes create self-reinforcing feedback mechanisms that contribute to the permanence of Kentucky bluegrass. However, there is a lack of specific research on the mechanisms and feedbacks that promote the introduction, establishment, and subsequent dominance of Kentucky bluegrass on rangeland ecosystems.

Changes to Pollination Services. Although pollinators do not use Kentucky bluegrass directly, the association between Kentucky bluegrass and loss of native plant diversity (Dekeyser et al. 2009; Grant et al. 2009; Miles and Knops 2009b; Tatina 1994) suggests Kentucky bluegrass may be indirectly affecting pollination services. The global economic value of pollination services in agriculture is well recognized, with a large percentage of global food production dependent on pollination by animals (Dixon 2009; Gallai et al. 2009; Klein et al. 2007). Research suggests that plant invasions and loss of native habitat can be detrimental to pollinator diversity affecting pollination services (Bommarco et al. 2010; Moron et al. 2009). Natural habitats and the matrix of vegetation composition at a site support pollinator diversity as well as abundance (Garibaldi et al. 2011). Diversity of vegetation supports a variety of pollinators and provides a pollination service necessary for high yields in many crop species (Holzschuh et al. 2012). However, specifics about pollinator types lost because of Kentucky bluegrass and the impacts of that loss on crop yields is still not understood, and according to our search of available information, there is no published literature available on the subject.

Lack of knowledge on how pollinators are affected by the increased cover of Kentucky bluegrass and the associated loss of native habitat represents a major research gap with great liability for the future of food-provisioning ecosystem services to support human well-being. Therefore, as a precautionary measure, there is a need to protect native habitats to maintain the provisioning of this important service.

Accumulation of Dead and Senescent Material. Layers of dead and senescent Kentucky bluegrass at the soil surface are very conspicuous in invaded areas, especially in areas where grazing or fire exclusion have occurred (Dekeyser et al. 2009; Kendeigh 1941). Results from studies performed in Kentucky bluegrass turf suggest that its thatch layer can act as a buffer that moderates soil temperature extremes, reduces weed invasion, and increases tolerance to trampling (Murray and Juska 1977) reinforcing its persistence.

Dead organic matter is also an important energy source for heterotrophic organisms, and it has an important role in regulating the hydrology of the system (Singh and Gupta 1977). In most natural ecosystems, litter decomposes in mixtures of different species, and the decay rate and nutrient dynamics of litter mixtures are substantially different from those of a single species (Liu et al. 2010), accentuating the importance of maintaining intact native grassland systems.

Cultural Ecosystem Services. Cultural services that humans obtain from ecosystems and that are affected by invaders such as Kentucky bluegrass are difficult to quantify. Cultural ecosystem services potentially affected by such a change would be those in which cultural ties to the land are affected, those related to recreational use of natural areas, and those that affect ecotourism activities (Bardsley and Edward-Jones 2006).

Kentucky bluegrass invasion and its associated reduction in native plant diversity could also have aesthetic effects on natural landscapes. However, Kentucky bluegrass is commonly used as turf grass in monocultures, such as home lawns (e.g., Larsen and Andreasen 2004). Homeowners value these highly manicured areas. This makes the aesthetic value a valuable ecosystem service (Chan et al. 2012; MEA 2005), and one that must to be taken into account in any analysis of the costs and benefits of this exotic invasive species (Robbins 2007). Kentucky bluegrass is valued as a turf species, and this has to be reconciled into our overall assessment of this species. In fact, interdisciplinary work among ecologists, rangeland scientists, and turfgrass agronomists could provide a potential avenue for exploring how to control this species in native ecosystems.

Discussion

Invasion and expansion of Kentucky bluegrass into native rangelands is occurring at a rapid pace, and land managers are presented with a dilemma: manage Kentucky bluegrass and live with the changes it imposes, or attempt to stop its migration and expansion. Kentucky bluegrass is highly nutritious and palatable during part of the year, and it can help slow down erosion in some areas, so some landowners might choose to live with this novel ecosystem. Inaction, however, will likely maintain the current trajectory of invasion, so a change in the traditional management practices that contributed to this invasion is needed if our objective is to try to stop and reverse this trend. The type and magnitude of change required is still uncertain, and more research is needed to determine how to control this grass species in native ecosystems. Invasive exotic plant species create resilient monocultures and current knowledge and technologies do not allow us to restore large expanses of land to its native state at a landscape scale without extreme restoration efforts (Figure 5). Therefore, we need to address existing research gaps as well as identify management approaches that will maintain the flow of ecosystem services that native ecosystems provide. Natural disturbance in the mixed-grass

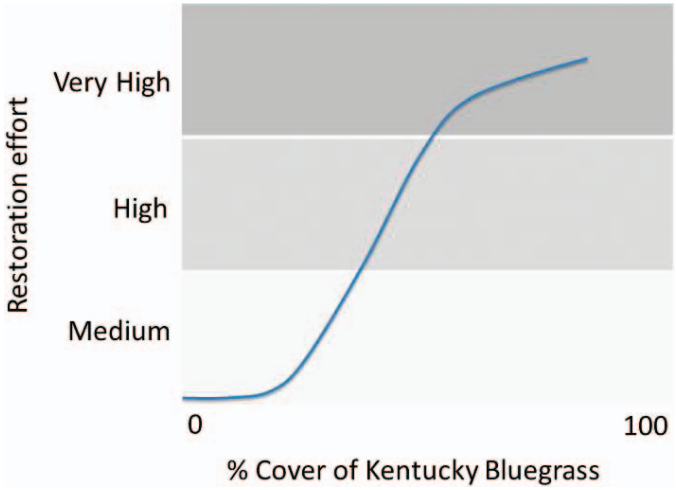

Figure 5. Theoretical representation of how systems invaded by Kentucky bluegrass will become increasingly resilient, bluegrass-dominated systems. Reversion of Kentucky bluegrass–dominated systems to a historic plant community will become harder as Kentucky bluegrass canopy cover increases.

prairie is integral to maintaining spatial heterogeneity and temporal dynamics. The frequency and intensity of disturbances like fire, grazing, and bioturbation create a complex matrix in prairie ecosystems.

The principle knowledge gaps identified in this article include the following:

- Determining how increased nitrogen deposition affects native rangeland vegetation and, more specifically, the effects of increased nitrogen deposition on range expansion of Kentucky bluegrass
- Understanding the consequences of increased exotic species on native species diversity,
- Determining the repercussions of increased invasion and dominance of exotic grass species on native grassland–obligate species and the overall impact on ecosystem services,
- Understanding the consequences of Kentucky bluegrass invasion on pollinator diversity and pollination services,
- Determining how Kentucky bluegrass cover alters the root and thatch layers and its effects on hydrologic function,
- Understanding the mechanisms of Kentucky bluegrass invasion and establishment and finding ways of reversing that trend, while maintaining intact native ecosystems, and
- Understanding the role of human-induced changes to natural disturbances (i.e., fire suppression) in the expansion of Kentucky bluegrass.

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