View Point

Impacts of Kentucky bluegrass Invasion (*Poa pratensis* L.) on Ecological Processes in the Northern Great Plains

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On the Ground

For every complex problem there is an answer that is clear, simple, and wrong—H. L. Mencken

- Ecological impacts of Kentucky bluegrass invasion have gone unrecognized by land managers and researchers alike.
- Current management practices have contributed to increases in Kentucky bluegrass abundance.
- Invaded areas have altered the ecological processes of net primary productivity, hydrology, nutrient cycling, and species composition.
- Increased understanding of ecological processes and feedback mechanisms of invaded areas will allow managers to develop appropriate adaptive management strategies.

Keywords: invasion, Kentucky bluegrass, northern Great Plains, ecological impacts, invasion.

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Although historical accounts exist, we may never fully comprehend the complex ecological dynamics of the native grasslands that occupied the northern Great Plains before the early 1500s.[1] Although the origin of Kentucky bluegrass (*Poa pratensis* L.), including whether it is native, is unclear, analysis of National Resource Inventory rangeland data indicate Kentucky bluegrass is now present on a majority of ecological sites across northern Great Plains.[2] This invasion previously was documented for specific sites in the Dakotas.[3,4]

The invasion of Kentucky bluegrass has been relatively rapid and occurred primarily over the past 30 years.[4] For example, data from Mandan, North Dakota, indicates a rapid increase in Kentucky bluegrass that occurred at the expense of short-statured native grasses such as blue grama (*Bouteloua gracilis* [Willd. Ex Kunth] Lag. ex Griffiths) (Fig. 1). This has greatly altered feedback mechanisms within and between historic plant community phases. The focus of this article is to outline and explain the function and effect of these changes on ecological processes.

Illustrating Effects Through State and Transition Models

Currently, rangeland management professionals use state and transition models[5] to organize and understand the current ecological status of rangelands. These models show the most commonly occurring plant community phases for a site, which are organized into reference and potential alternative states. The Reference State (State 1) represents our best understanding of the site's ecological dynamics before European occupation (Fig. 2). However, the resulting alteration of the ecological processes by changes to disturbance regimes; invasion of nonnative grasses and leguminous and nonleguminous forbs; and possible contributions of climate change have resulted in many ecological sites being best described by the invaded state (State 3, Fig. 2). Understanding how invasive species such as Kentucky bluegrass alter ecological processes is a key factor in predicting how and when a plant community will transition between states. Such models provide important information for making management decisions.

In the northern Great Plains, the introduction and establishment of exotic cool-season grasses (e.g., Kentucky bluegrass,) trigger the transition from State 1 Reference State to State 2 Native Invaded. Although initially the presence of these exotic species has little effect on the ecological processes

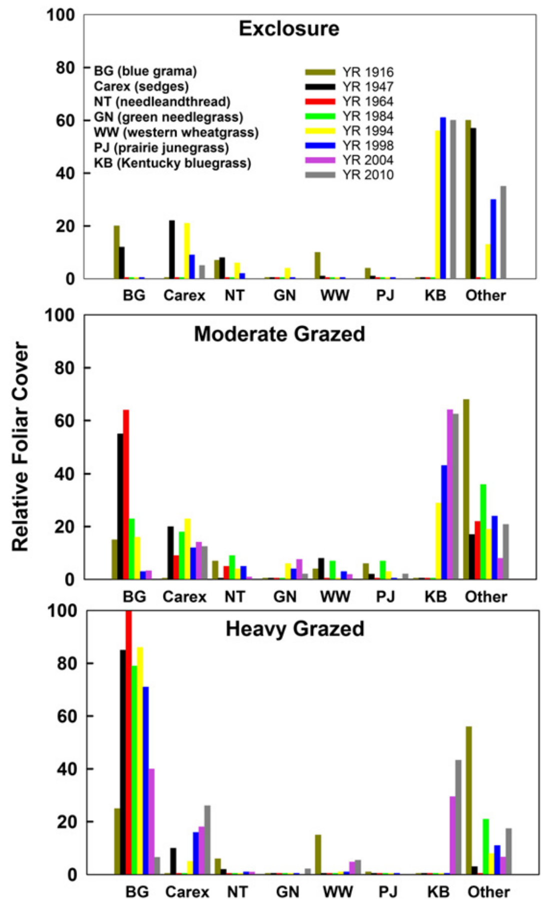

Figure 1. Relative foliar cover of individual species in moderately and heavily grazed pastures and the exclosure. Exclosure data for 1964, 1984, and 2004 were not available.

associated with the site; once present, they have the potential to alter plant community responses to traditional management inputs due to altered feedback mechanisms.

For example, less-frequent fire and altered grazing regimes (e.g., longer duration, less intensive grazing) can cause excess plant litter to accumulate resulting in increased shading and cooling of the soil surface favoring Kentucky bluegrass over native warm-season grasses.[2] As Kentucky bluegrass increases, the number and extent of native grass and forb species decline due to the altered feedback mechanism (Fig. 2). If managers do not account for the altered feedback processes, Kentucky bluegrass will continue to increase. Current expert opinion suggests that when Kentucky bluegrass exceeds 35% and native grasses produce <40% of the annual above-ground biomass production, the community transitions between State 2 and State 3 (Invaded) (Fig. 2).

Plant communities in State 3 are comprised of new plant species combinations, many of which are invasive species but also some remnant native species. Because of the new species combinations, ecosystem processes often are changed, which results in novel ecosystems.[6] Management of novel systems will require knowledge of the altered feedback mechanism and adaptive management techniques to develop new management strategies.[7,8]

Effects of Past Management

Understanding how past management facilitated Kentucky bluegrass invasion and the development of novel ecosystems (e.g., ecosystems that arise from new environmental conditions and new or altered disturbance regimes[8]) will help develop alternative management scenarios for the future. Past management practices likely contributed to the current novel ecosystem, including the following:

1. The long-held tradition of not grazing native rangeland until after June 1. This concept of "range readiness" allowed native cool-season grasses the opportunity to establish the necessary leaf material to replenish carbohydrate reserves used to establish new leaf growth before grazing.[9] Once propagules of Kentucky bluegrass are introduced, the delay in grazing until June 1 provides these early cool-season species the competitive advantage for early season moisture, sunlight, and nutrients. By the time livestock are introduced, Kentucky bluegrass and smooth bromegrass (*Bromus inermus* Leyss.) have matured beyond the native cool-season grasses and therefore, livestock selectively graze the cool-season natives, further increasing the competitive advantage of the introduced species.
2. The use of deferment and rest as management tools. Rest (nongrazing period of ≥ 1 year) and deferment (nongrazing period of <1 year) have long been recognized and prescribed as important management tools for the recovery of plant health and vigor after extreme disturbance events (i.e., wildfire, severe drought, extended periods of severe grazing). They are also key components of grazing prescriptions when the management goal is enhanced grassland bird nesting cover.

   The effect of timing of deferment and duration of rest on vigor and competitiveness of non-native species versus native species must be considered. Spring deferment periods with the objective of improving native cool-season grass vigor will benefit cool-season invasive species. Resting a plant community may trigger the positive driver(s) that facilitate the crossing of a threshold to an alternative state. Although the application of deferment and/or rest may achieve the short-term goal of increased plant vigor and/or nesting cover, the long-term effect on the plant community may be negative in terms of species diversity, carbon sequestration, watershed health, and other ecological services.
3. The reintroduction of fire as a disturbance and management tool. Historically, fire was one of the primary disturbances in maintaining herbaceous dominated plant communities. Fire killed nonsprouting woody species, attracting grazing animals to the burned areas that experienced altered nutrient cycling (depending on fire intensity).[10]

   Plant community shifts from native grass and forb dominance to Kentucky bluegrass dominance reduces fire intensity at the soil surface because of changes in fuel properties such as distribution and moisture,[11] resulting in less nitrogen volatilization.[12] Excess nitrogen in the system can shift the competitive advantage to species

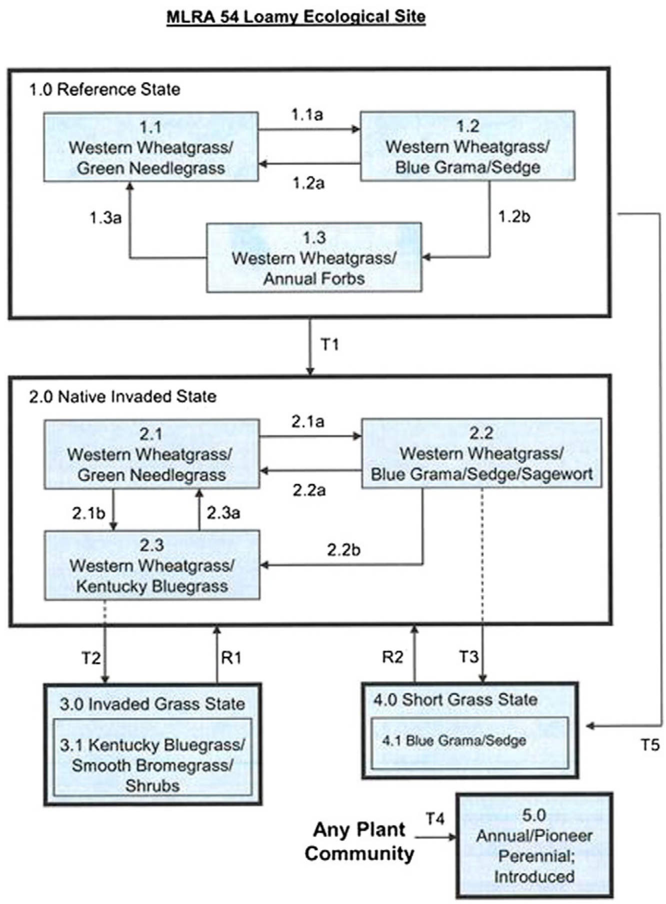

Figure 2. State and transition model for a loamy ecological site in MLRA 54. MLRA 54 is primarily located southwest of the Missouri River in North Dakota.

better adapted to competing in a nitrogen-enhanced system.[13,14] Additional nitrogen may be detrimental to soil mycorrhizal populations; further shifting the competitive advantage to the nonmycorrhizal-dependent Kentucky bluegrass and smooth bromegrass.[13,15]

Therefore, if the management goal is to use prescribed fire and shift the plant community composition toward the reference state by using prescribed fire, the frequency, timing, and intensity of fire events may need to be reconsidered. Past application of fire as a single, infrequent disturbance generally has been ineffective in changing the nitrogen feedback mechanism to favor native grasses. Therefore, burning frequency and intensity may need to be increased and carefully timed and coupled with other disturbance events such as properly managed grazing to change the plant community composition.

Figure 3. (A) Soil profile from invaded state plant community showing approximately 2 inches of Kentucky bluegrass root mat and thatch layer. (B) Reference condition profile with no Kentucky bluegrass root mat or thatch layer.

4. Degree of utilization. The adage of "take half, leave half" has long been the mantra of good range management. Depending on plant community composition and level of grazing management, this rule of thumb may still be applicable. However, to achieve a 50% utilization level when dealing with large pastures and low stocking densities results in overutilization in some areas and low or no use in other portions of the pasture (spot grazing). Field observations and experience indicate that spot grazing can shift the competitive advantage to Kentucky bluegrass. Utilization levels and season of use may need to be adjusted when dealing with invaded plant communities to ensure residual plant litter does not accumulate and shift the competitive advantage to Kentucky bluegrass.

Kentucky Bluegrass Effects on Ecological Processes

When native plant communities are replaced by nonnative species, ecological processes (energy flow, water cycle, and nutrient cycle) become altered.[3] Additionally, the ecological services provided by the altered plant community, including wildlife habitat, forage production, and water flow regulation and aesthetics, will change. These changes could be viewed as either positive or negative, depending on the management goals of the land manager. In this section, we focus on changes in ecological processes rather than the resultant change in ecological services. The potential for Kentucky bluegrass invasion to alter ecological services was addressed previously.[2]

Energy flow

Shifting species abundance from a diverse warm- and cool-season grass and forb mixture to dominance by cool-season Kentucky bluegrass changes energy flow from full season (spring, summer, and fall) to spring and early summer. This could potentially alter the amount of carbon sequestered during the growing season. Changes from deep-rooted native grasses and forbs to shallow-rooted Kentucky bluegrass effects carbon distribution within the soil profile.[16]

Water cycle

Kentucky bluegrass' effects on infiltration rates have been demonstrated on a number of loamy ecological sites in central North Dakota. Changes in infiltration rates are attributed to several factors (singularly or in combination) including:

- Development of a thatch layer (Fig. 3). Thatch is defined as an intermingled organic layer of dead and living roots, stems, stolons, rhizomes, and shoots that develops between the soil surface and the zone of green vegetation.[17]
- Depth and density of thatch layer.[18]
- Capillary discontinuity between the thatch and the A horizon.[19]
- Depth of standing dead plant material above thatch layer.
- Changes in root morphology compared with a native plant community.
- Changes in soil structure, porosity and bulk density.[20]

Nutrient cycle

The shift from a diverse native plant community to a simplified invaded plant community alters nutrient cycling, making mineral forms of nitrogen more available for plant growth. A native plant community often is dominated by plants with a high carbon-to-nitrogen ratio in the leaves, resulting in slower litter decomposition; whereas the simplified plant community is dominated by low carbon-to-nitrogen ratio plants with faster rates of litter decomposition. Additional nitrogen is added to the system via nonnative leguminous forbs such as sweetclover.[21] High nitrogen systems have been shown to favor the dominance of invasive cool-season perennial plants.[22,23]

Additional nitrogen often results in greater overall production provided early growing season moisture is not limited. However, this additional production is limited to the early growing season or is dependent on timely rain events throughout the growing season.

Consequences of altered ecological processes

The inherent native plant diversity associated with rangeland in the northern Great Plains is a major asset to the livestock industry. The diverse mixture of warm- and cool-season grasses, forbs, and shrubs provides grazing livestock access to actively growing, highly nutritious plants throughout the growing season. As plant diversity is reduced by invading cool-season grasses like Kentucky bluegrass,[2] the active growth period for the plant community as a whole shortens and shifts from spring to summer to early spring and early summer.

One of the primary disturbances in the northern Great Plains is drought. With its shallow root system, Kentucky bluegrass was initially thought not be drought tolerant. Therefore, it was hypothesized that a moderate drought both in severity and length would shift the competitive advantage back to more drought-tolerant native species. This would result in a plant community more resembling the reference condition. However, turf science research found Kentucky bluegrass to be one of the most drought-tolerant turf species.[24] Field data collected from the Grand River and Cedar River National Grasslands (Lemmon, SD) after a 5-year drought period showed Kentucky bluegrass was still present in a majority of plant communities and continued to dominate many sites (personal communication, A. Gearhart January 23, 2014), further demonstrating the drought tolerance of Kentucky bluegrass.

Possible Ecological Feedback Mechanisms and Triggers

Feedback describes the ecological processes that reinforce or degrade ecosystem resilience and function. Negative feedbacks contribute to ecosystem stability, whereas positive feedbacks result in ecosystem conversion to an alternate state. Triggers, natural or anthropogenic, represent changes in specific biotic or abiotic variables that initiate threshold development.[25]

Altered nitrogen pools

The northern mixed-grass prairie developed under the influence of grazing and periodic fires and is sustained by limited inputs of water and nitrogen.[26] Plant species and communities are adapted to recycle and conserve essential resources by using high root-to-shoot ratios.[27] Nitrogen was typically tied up in below-ground organic matter, and intense prairie fires would have reduced available nitrogen through volatilization and transfer of organic N from labile to recalcitrant pools.[28] The high carbon-to-nitrogen ratio of most native grasses and forbs would further delay breakdown of organic matter to release mineral nitrogen for plant growth. The inclusion of nonnative legumes in plantings, such as sweet clover (*Melilotus officinalis* L.), may have increased the size and distribution of nitrogen pools in the soil profile.

In response to limited nitrogen availability, some native plants evolved the ability to recycle nitrogen by moving nitrogen from senescing leaves into storage or new leaf growth.[26] Other grasses and forbs developed a symbiotic relationship with soil mycorrhizal fungi, enhancing their ability to compete for moisture and nutrients.[29] These adaptations often gave native plants a competitive advantage over most invasive grass species, which is still visible on select ecological sites with very droughty soils and limited organic matter (e.g., very shallow, shallow gravel). These sites tend to maintain a more diverse native component, whereas adjoining sites with more productive soils often become Kentucky bluegrass dominated.

Many grassland species are associated with arbuscular mycorrhizal (AM) fungi, which strongly influence plant growth and uptake of nutrients.[30] Grasses, which appear to benefit from AM, exhibit coarse root morphology, produce few root hairs, and occur in low nutrient habitats.[31] A lone study[2] reported that dominant tall warm-season grasses formed coarse tap roots and were highly mycorrhizal, whereas plants that formed very fine roots had low levels of infection.[31] Although 96% of the species surveyed in the study were mycorrhizal, Kentucky bluegrass had <15% infection rate, which would imply it is a facultative species.[31] However, results of another study found Kentucky bluegrass was nonmycorrhizal and it showed no significant growth response to mycorrhizal colonization.[32]

Increased nitrogen availability has been reported to facilitate a loss of diversity and may be accompanied by major shifts in species composition and a decrease in carbon-to-nitrogen ratios of above- and below-ground plant tissues. Accumulation of mineral N may include the addition of atmospheric nitrogen[23]; nitrogen added via the invasion of non-native leguminous forbs, such as sweet clover and black medic (*Medicago lupulina* L.)[21]; higher nutrient cycling rates due to species change from high carbon-to-nitrogen ratio native species to low carbon-to-nitrogen ratio invasive species[22,33]; and lack of fires to remove additional nitrogen from the system.[26]

Increased nitrogen in the system directly and indirectly benefits invasive species by increasing available nitrogen and suppressing soil mycorrhizal populations, respectively.[13] In studies where soil mycorrhizal populations are suppressed to <25% by applications of the fungicide Benomyl, cool-season grasses including Kentucky bluegrass, Scribner's panicum (*Dichanthelium oligosanthes* [Schult.] Gould var. *scribnerianum* [Nash] Gould) and sedges (*Carex* spp.) showed increases in cover of >150% over the control plots.[29] Certain forbs within these treated plots also increased >400%, including Missouri goldenrod (*Solidago missouriensis* Nutt.) and Heath aster (*Symphyo-* [L.] G. L. Nesom).[29] Field observations indicate Missouri goldenrod and silverleaf scurfpea (*Pediomelum argophyllum* Pursh.) are generally the most dominant native forbs remaining within heavily invaded Kentucky bluegrass plant communities (personal communication, C. Dixon October 3, 2015).

The response of mycorrhizal populations to nitrogen enrichment is dynamic over time and populations may either increase or decrease.[35] Greenhouse studies found nitrogen enrichment increases AM colonization when phosphorus is limiting and decreases AM colonization when phosphorus is not limiting.[34] The effects of nitrogen enrichment can alter the plant fungal relationship.[34] It is generally assumed that a plant's association with mycorrhizal fungi colonization has mutualistic benefits.[35] However, results from one study[35] noted plant growth responses to mycorrhizal colonization ranged from positive (mutualism) to neutral (commensalism) and even negative (parasitism) and the differing relationships can be related to exotic and local fungal isolates versus local and exotic plant isolates. Parasitism may be more frequent under certain environmental conditions such as in agricultural soils that have been repeatedly fertilized.[36]

Several ranchers and rangeland management professionals indicate a possible link between sweetclover cycles and Kentucky bluegrass increases following the second year of sweetclover growth (personal communication, G. Goven June 10, 2014). Additionally, data from Snider and Hein[37] suggest the amount of nitrogen available in the root biomass of a planted stand of sweetclover was at least 177 kg/ha, which is similar to the fertilizer rate needed for 150 bu per acre corn crop.[38] They reported the majority of sweetclover root biomass was produced in the top 17.78 cm of the soil profile where a majority of the Kentucky bluegrass rootmass is located.

The species composition and diversity changes that occur during Kentucky bluegrass invasion are similar to those noted during fertilization trials conducted on native rangeland in Alberta.[39] With nitrogen fertilization, blue grama, needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), and clubmoss (*Selaginella densa* Rydb.) decreased, whereas western wheatgrass (*Pascopyrum smithii* [Rydb.] A. L ve) and thickspike wheatgrass (*Elymus lanceolatus* [Scribn. & J.G. Sm.] Gould) increased.[39] Weedy grasses including annual bromegrasses (*Bromus* spp.) and Kentucky bluegrass also increased and became especially "troublesome" with fertilization.[40]

Reduced sunlight capture

The accumulation of standing dead plant material and detached litter decreases sunlight penetration to plant crowns and leaves, which can reduce overall productivity[41] and shift the competitive advantage to more shade tolerant cool-season species.[42] Warm-season grass yields have been shown to decrease under increased shading, whereas cool-season grasses, including Kentucky bluegrass, did not show yield reductions under 50% shade.[42]

Plant litter accumulation also affects soil surface temperatures.[41] Although this may be beneficial from a moisture conservation standpoint during periods of drought, it may benefit cool-season grass growth. Optimum temperatures for growth and photosynthesis of cool-season plants is 10°C to 25°C, whereas optimum temperatures for growth and photosynthesis of warm-season grasses range from 30°C to 40°C.[43] Consequently, we believe accumulated plant litter will likely shift the competitive advantage to species best adapted to low light levels and cooler soil surface temperatures.

Increasing thatch and plant litter

As plant litter and thatch accumulate, seedling recruitment of native bunchgrasses and nonrhizomatous native forbs will also be affected. Thatch has less water-holding capacity than soil; is subject to rapid drying; reduces seed-to-soil contact; and, because of the abundance of Kentucky bluegrass roots within thatch, is very competitive for moisture. As an example of the potential effects of a thatch layer on species viability, a dense litter layer resulted in high morality for seedlings of the native perennial grass red threeawn (*Aristida purpurea* var. *longiseta* Steud.)[44] primarily because their roots were unable to reach the mineral soil.[45]

Conclusion

Realistically, restoration of invaded plant communities to the reference plant community state is not possible with our present understanding and technology. Recognition and identification of key thresholds and developing an understanding of the positive and negative drivers associated with these pathways will allow managers to adjust type, timing, and intensity of management disturbances. These management interventions may prevent at-risk plant community phases from crossing an impending threshold. Increased understanding of ecological drivers within invaded grasslands will improve the application of management strategies to favor native species. Increased understanding of ecological processes controlling these pathways may facilitate enhanced diversity in even the most heavily invaded communities.

The rapid increase of Kentucky bluegrass has affected ecological processes and services in the northern Great Plains and has gone largely unnoticed by many land managers and range management professionals. The combination of the "grass is grass" mindset as well as excellent spring growing conditions (cool and wet) and the inconspicuous growth habit of Kentucky bluegrass may have slowed the recognition of these rapid changes. These factors, plus our lack of knowledge on plant community thresholds in the northern Great Plains, may have resulted in threshold being crossed and the establishment of a "novel ecosystem" as previously defined.[8]

Because novel ecosystems respond differently to management and provide different ecosystem services as compared with reference vegetation states, both managers and researchers will need to adapt their mindset to these altered ecological dynamics and their potential economic effects. Consequently, we suggest that adjusting goals and strategies to deal with Kentucky bluegrass invasion is needed among range scientists, range managers, livestock producers, wildlife groups, and conservation organizations. Understanding drivers, thresholds, and long-term consequences of novel system dynamics will require adjusting management objectives, altering management approaches, and designing research objectives to address emerging questions of rangeland management.

> *Probably the most visible example of unintended consequences, is what happens every time humans try to change the natural ecology of a place—Margaret J. Wheatley*

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