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Kentucky bluegrass (*Poa pratensis*) Invasion in the Northern Great Plains: A Story of Rapid Dominance in an Endangered Ecosystem

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Kentucky bluegrass was introduced into the present-day United States in the 1600s. Since that time, Kentucky bluegrass has spread throughout the United States and Canada becoming prolific in some areas. In the past century, Kentucky bluegrass has been a presence and often a dominant species in some prairies in the Northern Great Plains. Sometime within the past few decades, Kentucky bluegrass has become the most-common species on the untilled, native prairie sites of much of North and South Dakota. In this article, we hypothesize how Kentucky bluegrass has come to dominate one of the most endangered ecosystems in North America—the prairie—through a historical, ecological, and climatological lens. We urge others to start addressing the invasion of Kentucky bluegrass with both new research and management strategies.

Nomenclature: Kentucky bluegrass, *Poa pratensis* L.

Key words: Climate change, ecosystem impacts, history of invasion, introduced species, invasion, Northern Great Plains.

Kentucky bluegrass (*Poa pratensis* L.) is arguably one of the most recognized and widespread perennial grasses in North America, occurring in all 50 states and all Canadian provinces (Uchytil 1993; USDA–NRCS 2014). This grass, which is a native to the more-temperate and northern latitudes of Eurasia, has been established in favorable climates worldwide because of strongly rhizomatous mat-forming characteristics (Uchytil 1993). Recently, the increased abundance of Kentucky bluegrass in many natural areas, especially in the Prairie Pothole Region (PPR) and other eastern areas of the Northern Great Plains, has resulted in heightened attention to its potential negative attributes (DeKeyser et al. 2013; Grant et al. 2009; Larson and Larson 2010). Although the extent of the invasion is becoming clearer, what is not understood is (1) the history and causes of widespread invasion into natural areas, (2) where the contributing sources of propagules supplying the invasion originate from, (3) the role of changes in climate, and (4) the potential impacts to the ecosystem. In this article, we address these questions using historical documentation concerning Kentucky bluegrass and long-term data sets obtained within the region, and we discuss potential mechanisms for the unanticipated spread of this species.

Kentucky bluegrass was widespread and well known in Europe before receiving the scientific name *Poa pratensis* L. in the 1700s (Schery 1959). Linnaeus appropriately gave the epithet *pratensis*, meaning *meadow*, because of the general proclivity of the grass (Lowe 1858; Wedin and Huff 1996). High palatability and yield made Kentucky bluegrass an important pasture grass for 100s of years in the British Isles (Lowe 1858; Plues 1867). With proper maintenance, Kentucky bluegrass was reported to produce hay for cattle in June and provide an attractive lawn grass (Lowe 1858; Plues 1867).

Because of the popularity and widespread use in Europe and parts of Asia, it has been convincingly speculated that initial introduction into the United States happened during western European colonization (mid to late 1600s) through seed mixtures, hay, and bedding (Bashaw and Funk 1987; Carrier and Bort 1916; Huff 2003; Lowe 1858; Plues

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1867). In fact, the grass was common in Kentucky before European settlement and rapidly spread from that point (Bashaw and Funk 1987; Dunn 2004). Kentucky bluegrass was often unintentionally spread by people because of its use as a packaging material and bedding, but it was also a sought-after grass for utilitarian reasons (Bashaw and Funk 1987; Dunn 2004). Henry Clay (1838) pointed out its popularity as a lawn grass in the southeast and noted a lack of Kentucky bluegrass in Virginia, New York, and Maryland, indicating a limited range at the time (Dunbar 1977). Clay offered to send a friend in New York some Kentucky bluegrass because of a demand in New York for the grass (Dunbar 1977). There are reports of Thomas Jefferson having Kentucky bluegrass planted in his lawn at Monticello (Dunn 2004). By 1847, bluegrass was a widely used pasture grass as far as western New York, suggesting that the popularity of the grass aided in the distribution into more northern states (Buckley 1847; Dunbar 1977). Piper (1916) reported up to 90% of Kentucky bluegrass pastures were "spontaneous" events, generally resulting from disturbance and colonization (Piper 1916). By the early 1900s, Kentucky bluegrass was recognized as the "most important pasture grass in North America" (Piper 1916).

Kentucky bluegrass most likely first occurred in the Northern Great Plains during the mid to late 1800s. By 1896, Kentucky bluegrass was considered "common southward to the central United States" (Wright and Upham 1896). In Iowa, along the Missouri river, bluegrass was classified as a weed by 1909 and was "everywhere" and "common" (Shimek 1909). There were already reports in 1884 of Kentucky bluegrass taking over prairies in southwestern Minnesota and moving westward into Nebraska (Upham 1884). During a survey of western Minnesota and eastern North Dakota, Warren Upham (1890) predicted that bluegrass would spread into the region and become a predominant grass, based on what was being experienced by others in the east. In 1891, herbarium specimens were collected in the eastern municipalities of Fargo, ND, and Wahpeton, ND, along the Red River by L.R. Waldron (Williams 1891). The North Dakota State University (NDSU) herbarium has other specimens collected along railways as far west as Medora, ND, within the first decade of the 1900s (NDSU Herbarium). Bluegrass wasn't noted at all in a botanical survey of two townships of southeastern North Dakota in 1917 (Shunk 1917); however, in the publication *The Flora of North Dakota*, Bergman (1912) called *P. pratensis* "a very common species, general throughout the state in all kinds of situations." By 1933, bluegrass was listed as a common plant in western North Dakota (Edwards and Ableiter 1942). O. A. Stevens noted in his first publication of the *Handbook of North Dakota Plants* that *P. pratensis* "has spread so rapidly that it appears like a native plant" (Stevens 1950).

An Ecological Threat?

These same sources illustrate several attributes of Kentucky bluegrass that shed light on possible plant community and ecosystem impacts. Henry Clay (1838) pointed out that bluegrass would invade disturbed areas (e.g., salt licks) and would then quickly spread to dominate (Dunbar 1977). Clay also discussed its competitive ability, noting Kentucky bluegrass would rapidly outcompete timothy (*Phleum pratense* L.) and clover (*Trifolium* spp.) when seeded together (Dunbar 1977). Lowe (1858) discouraged agriculturalists from using Kentucky bluegrass because some thought the bluegrass root system would impoverish the soil. Others commented on the ability of Kentucky bluegrass to maintain growth early in the spring and late in the fall and to produce a lot of long foliage (up to 60 cm [23.6 in]) (Buckley 1847). Stevens (1950) stated that in the PPR "It invades and practically takes possession of moist prairie."

After the natural and the anthropogenic spread, there was a need among turf managers for a Kentucky bluegrass that was not as susceptible to drought or leaf spot. In the 75 yr before the 1950s, Kentucky bluegrass was distributed using a "stripping" procedure (collecting seeds using a flailing method) from already established stands in Wisconsin, Minnesota, North Dakota, and Kentucky to eastern Kansas (Huff 2003). In the mid 1930s, the first Kentucky bluegrass cultivar, 'Merion', was discovered in a golf course in Pennsylvania and became available in 1947 (Dunn 2004; Stang et al. 2004). The Merion cultivar was widely used until cool-season turfgrass genetic-improvement programs, initially started in 1962 at Rutgers University, began to provide a wider variety of cultivars. The emergence of turfgrass breeding programs at universities throughout the United States has resulted in hundreds of varieties of Kentucky bluegrass being developed. The current method of growth and distribution relies on intensive agriculture and development focused in the Midwest and the Pacific Northwest (90% of U.S. production comes from Washington) in which fields are planted using some combination of burning, irrigation, fertilization, herbicide, and insecticide use (Holman and Thill 2005; Huff 2003). Modern biotechnology advents have made cultivars that are highly competitive and now, genetically engineered to withstand glyphosate (Huff 2003; Kaplan 2011).

More recently the invasion of Kentucky bluegrass has gained a great deal of attention throughout the Northern Great Plains (Bahm et al. 2011; DeKeyser et al. 2013; Grant et al. 2009; Larson and Larson 2010; Murphy and Grant 2005; White et al. 2013). During the past two to three decades, a major shift seems to have occurred in the Northern Great Plains, resulting in large changes in the frequency of Kentucky bluegrass in the prairie (Figure 1). Demonstrating this increase are 28 native prairie sites

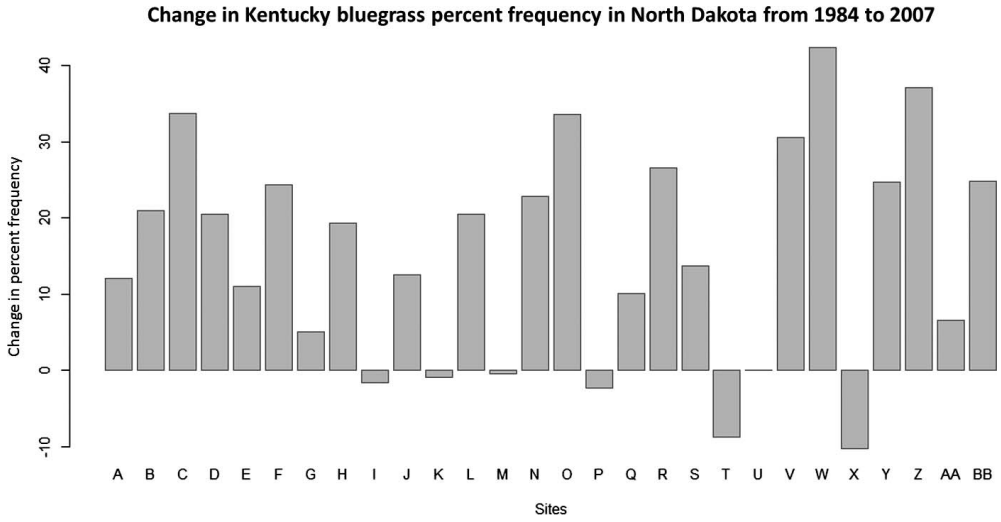

Figure 1. Change in Kentucky bluegrass frequency at 28 native prairie sites in North Dakota. Data from the 2007 and 1984 field collections have been subtracted to show the overall increase in Kentucky bluegrass invasion.

sampled in central North Dakota in 1984 and 2007 (DeKeyser et al. 2009, 2013). Out of the 28, Kentucky bluegrass increased in frequency at 22 sites. Often, this increase is more pronounced than the decreases seen at the six other sites (Figure 1). The overall frequency of Kentucky bluegrass in the 23-yr period increased by 35% across all sites. Anecdotal evidence among many land managers indicates Kentucky bluegrass has increased in frequency during the past 20 yr. A rangeland site, monitored by North Dakota State University and Glenharold Mine in central North Dakota, provides a detailed look into the expansion of Kentucky bluegrass (Figure 2). In two decades, bluegrass rose from not present in 1988 to the most-abundant species in 2009 (Figure 2), demonstrating its ability to quickly establish in a site. Increases in Kentucky bluegrass appear to be at the expense of native species. Unpublished data from the U.S. Department of Agriculture's Agricultural Services (USDA-ARS) in Mandan, ND, indicate increases in Kentucky bluegrass often coincide with decreases in blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], a grazing-tolerant, short-statured, native grass (Figure 3). Finally, a recent study by DeKeyser (unpublished), on U.S. Fish and Wildlife Service native prairie sites in the PPR, showed Kentucky bluegrass was the most-abundant species across 37 sampled sites.

We are mostly concerned with invasion in the PPR, an area stretching from western Minnesota to Montana and north into Canada. In this highly fragmented, endangered ecosystem, major changes in species community

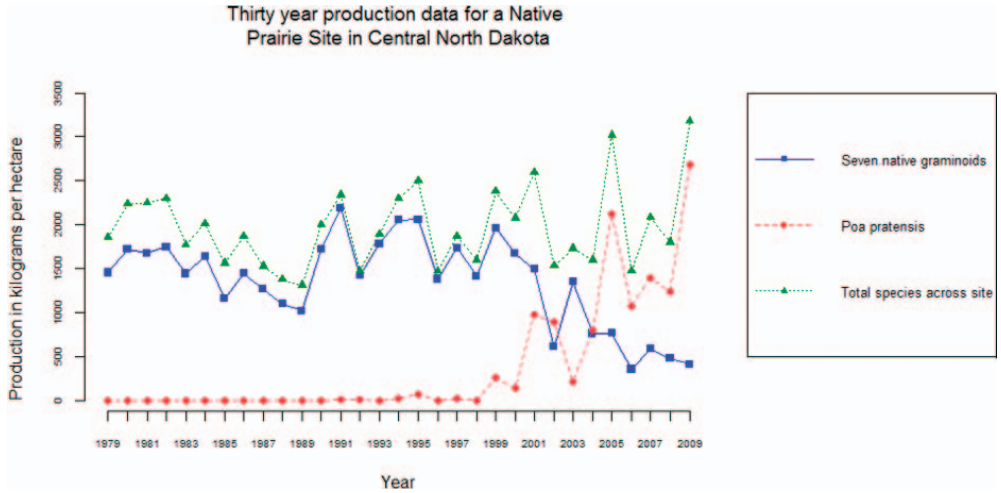

Figure 2. Thirty-year production data (kilograms per hectare) for a native prairie loamy ecological site located in central North Dakota. (Color for this figure is available in the online version of this article.)

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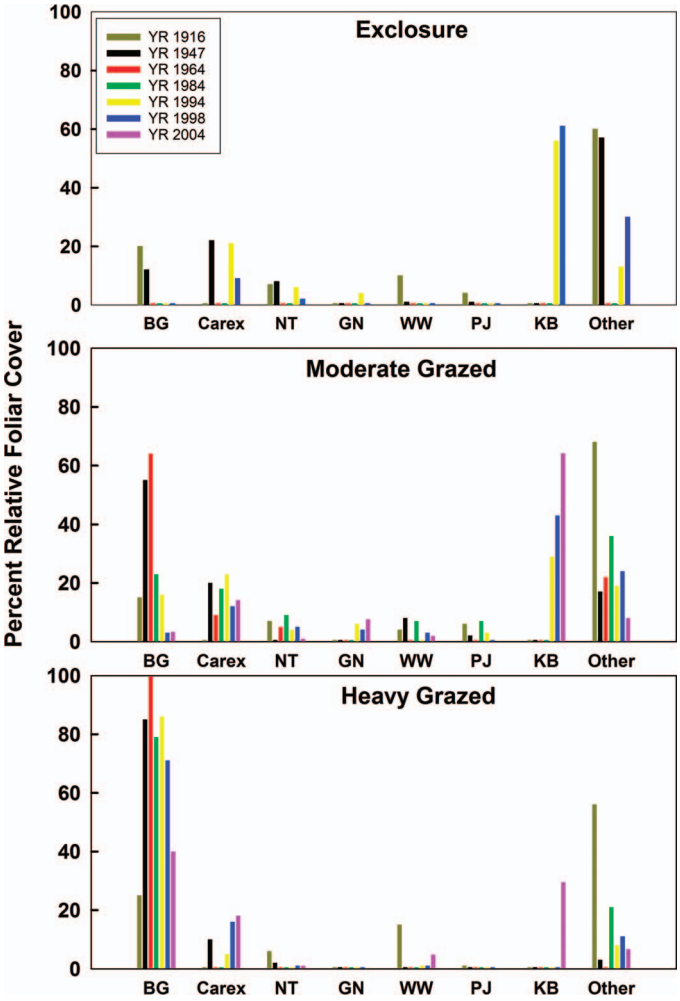

Figure 3. Relative foliar cover for major grass species encountered in an (1) exclosure, (2) moderately grazed, and (3) heavily grazed pasture at the Northern Great Plains Research Laboratory, beginning in 1916. The major species are blue grama (BG), sedges (Carex), needle-and-thread [NT; *Hesperostipa comata* (Trin. & Rupr.) Barkworth ssp. *Comate*], green needlegrass [GN; *Nassella viridula* (Trin.) Barkworth], western wheatgrass [WW; *Pascopyrum smithii* (Rydb.) Á. Löve], prairie junegrass (PJ), and Kentucky bluegrass (KB). Exclosure data for 1964, 1984, and 2004 were not available.

composition are cause for concern, and Kentucky bluegrass exemplifies the major ecosystem shift (Grant et al. 2009; Murphy and Grant 2005; Samson and Knopf 1994). The control of cool-season invasive grasses, such as Kentucky bluegrass, smooth brome (*Bromus inermis* Leyss.), and reed canarygrass (*Phalaris arundinacea* L.) (DeKeyser et al. 2013), is the goal of many parties interested in prairie preservation in the PPR. Daehler (2003) suggested most introduced plants are not "super invaders," so to speak, but rather, their performance is enhanced under certain human-disturbance regimes (Daehler 2003; González-Moreno et al. 2014). Considering the popularity of Kentucky bluegrass among homeowners, cities, forage managers, and turfgrass managers and the highly disturbed and fragmented prairie that remains, it seems likely that human activities have enhanced the invasion of Kentucky bluegrass.

Potential Explanations for the Invasion

Successful invasions need propagules. This is not an issue with Kentucky bluegrass because of the increased propagule pressure from the popularity of Kentucky bluegrass as a lawn and turfgrass. Currently, Kentucky bluegrass is the most popular lawngrass in the United States and is especially popular in temperate regions, such as the Northern Great Plains (Dunn 2004; Haydu et al. 2006; Uchytil 1993). There are approximately 250 individual Kentucky bluegrass cultivars planted in the United States (Honig et al. 2010). Kentucky bluegrass is the largest contributor to the $57.9 billion turfgrass industry, meaning the likelihood for continual escape in the United States is high (Haydu et al. 2006).

Another potential contributor may be changing climate patterns in the Northern Great Plains. The growing season has increased by 12 d during the past 120 yr in parts of North Dakota (Badh et al. 2009). The increase in season length can potentially provide an opening for Kentucky bluegrass to invade in the early spring or late fall when bluegrass is photosynthetically active (Uchytil 1993). The additional growing days occur in the spring and fall, cool season months, with the fall gaining more days than the spring. Kentucky bluegrass produces the most rhizomes in the fall, which may provide reproductive advantages in long, cool fall seasons (Etter 1951). Kentucky bluegrass begins photosynthesizing earlier than many native species in the spring, and an earlier spring may aid in rapid invasion.

Atmospheric CO_2 levels have increased greatly in the past 100 yr (Etheridge et al. 1996; Global Greenhouse Gas Reference Network: National Oceanic and Atmospheric Administration 2014) and Kentucky bluegrass, a C_3 species, may perform more efficiently under these higher CO_2 concentrations. A study of the family Poaceae growing in higher concentrations of CO_2 indicated that although both C_4 and C_3 grass species increased in overall biomass production, C_3 grasses produced approximately 10% more biomass overall (Wand et al. 1999). Additionally, C_3 Poaceae species increased production of tillers by 27% in the higher CO_2 environment (Wand et al. 1999). From a broader perspective, across the plant kingdom, the literature supports herbaceous, fast-growing, C_3 species increasing their biomass more than slow growing C_3 plants or C_4 plants under increased CO_2 conditions (Poorter and Navas 2003). Because Kentucky bluegrass is a fast growing, C_3 grass, known for producing many tillers through rhizomatous growth, the increased levels of CO_2 in the atmosphere likely facilitate its productivity.

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Finally, historic data from central North Dakota have indicated an increase in precipitation during the past 130 yr. In the past 20 yr, 15 yr had above-average precipitation levels (National Climate Data Center–National Oceanic and Atmospheric Administration 2014; National Oceanic and Atmospheric Administration 2014). In particular, precipitation data from Mandan, ND, indicate the 10-yr average annual precipitation for the 1990s and 2000s are 25 and 15% greater than average annual precipitation for the previous 75 yr (Regional Climate Centers et al. 2014). This period corresponds with the previously mentioned increase in Kentucky bluegrass observed in the PPR. Stevens (1950) observed Kentucky bluegrass invading moist prairie, and other historical records indicate Kentucky bluegrass is a hydrophilic, drought-intolerant grass (Huff 2003; Jackson et al. 2002; Lowe 1858; Stevens 1950; Uchytil 1993).

Ecosystem Impacts

As noted in Figure 1, there was a 35% increase in Kentucky bluegrass frequency during the past 23-yr period. The same sites in Figure 1 had an overall drop in species richness from an average of 25 in 1984 to 17 in 2007, and a drop in Shannon's diversity index from 2.5 in 1984 to 1.6 in 2007. Species of graminoids and forbs decreased or were eliminated from the native prairie sites. For example, the native grass blue grama was found at 25 sites in 1984 and only 13 in 2007, prairie Junegrass [*Koeleria macrantha* (Ledeb.) Schult.] was at 24 sites in 1984 and 9 in 2007, threadleaf sedge (*Carex filifolia* Nutt.) was at 20 sites in 1984 and 11 sites in 2007, and sun sedge [*Carex inops* L.H. Bailey subsp. *heliophila* (Mack.) Crins] was at 21 sites in 1984 and only 9 by 2007. Figure 2 further supports the fact that Kentucky bluegrass is replacing native graminoids, where, before 1990, bluegrass wasn't even found at the site, and by 2009, it made up 84% of the annual production. The same native species mentioned previously showed clear reductions in total biomass postinvasion vs. before invasion. Before 1990, blue grama averaged 384 kg ha^{-1} (343 lb ac^{-1}) and, by 2009, was only 24 kg ha^{-1}, prairie Junegrass averaged 252 kg ha^{-1} before 1990 and was 6 kg ha^{-1} by 1990, and sedge species combined were 166 kg ha^{-1} before 1990 and only 4 kg ha^{-1} by 2009. The loss of these species in the plant community is also a loss of valuable functional forms important to ecosystem processes. For example, blue grama is one of the few common, warm-season grasses of the cool season–dominated Northern Great Plains. Heitschmidt and Vermeire (2006) showed that blue grama can more than make up for losses of production from spring drought, if precipitation returns during blue grama's active growing period in July and August. The loss of this species because of Kentucky bluegrass invasion, may negatively affect the prairie's ability to maintain steady production because of variable weather patterns.

There is little argument that Kentucky bluegrass is probably the predominant grass of the PPR today (Grant et al. 2005; Murphy and Grant 2005; USDA 2014). Alarmingly, the USDA (2014) noted that Kentucky bluegrass, along with Canada bluegrass (*Poa compressa* L.), has spread throughout the Northern Great Plains, including occupying most private rangelands in North Dakota (82%) and South Dakota (61%). Setter and Lym (2013) showed more than a 250% increase in Kentucky bluegrass in the seedbank of certain soils on federal lands in western North Dakota during a 10-yr period. This rate of increase shown by all of the aforementioned research arguably surpasses other invasive species within the region, including leafy spurge (*Euphorbia esula* L.) (Dunn 1979) and spotted knapweed (*Centaurea stoebe* L.) (Sheley et al. 1998). The potential loss of species richness and species diversity becomes shocking. There is still a great deal unknown about the effects of this Kentucky bluegrass invasion; beyond the loss of species, it is suspected that bluegrass may affect nitrogen cycling, pollinator diversity, and hydrology (Toledo et al. 2014).

The Need for Understanding

More attention must be focused by the ecological community on the invasion of Kentucky bluegrass in the Northern Great Plains. Even though Kentucky bluegrass's presence has been increasing, the mechanism of the invasion is not known because Kentucky bluegrass is usually not classified as an invasive species (Kaplan 2011; U.SDA-NRCS 2014); therefore, little research has been focused on this important aspect. The long-lasting, ecological impacts of Kentucky bluegrass invasion are also uncertain and need to be identified. The effect this invasion has on soil and community biology of the grasslands will be important information needed for future preservation of this important and endangered ecosystem (Samson and Knopf 1994). Kentucky bluegrass is now a major component of the Northern Great Plains, and what that means for biodiversity and community composition will be a key area of research in the upcoming decades.

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