Using Prescribed Fire and Rotational Grazing to Create Heterogeneity in Grazing Patterns and Assess Plant Community Changes on Kentucky Bluegrass-invaded Mixed-grass Prairie

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Introduction

Heterogeneity is the principal driver of biodiversity in rangeland ecosystems and is frequently positively correlated with population and community stability (Wiens 1997, Hovick et al. 2015, McGranahan et al. 2016). Rangelands are described as inherently heterogeneous, where composition, productivity and vegetation structure vary with disturbances, topo-edaphic features, and species interactions at multiple spatial and temporal scales (Patten and Ellis 1995, Fuhlendorf and Smeins 1998, 1999, Fuhlendorf and Engle 2001, Limb et al. 2010a). Conserving resources and promoting biodiversity are imperative to the long-term sustainability of rangeland resources, particularly on private lands where profitable livestock production is a primary objective (West 1993). The traditional view within rangeland management is that proper grazing management requires spatially uniform moderate grazing, therefore minimizing excessively grazed and non-grazed areas (Vallentine 2001). While spatially uniform moderate grazing may minimize soil disturbance and increase ground cover, and might improve habitat for some faunal species, spatially uniform moderate grazing often fails to create sufficient habitat heterogeneity to support species with requirements at both extremes of the vegetation structure gradient thus constraining potential biodiversity (Knopf 1994; Fuhlendorf et al. 2006).

Biological invasions occur when non-native species are introduced to a new ecosystem where they establish and spread (Mack et al. 2000; Andersen et al. 2004). Anthropogenic disturbance, such as land fragmentation due to urbanization and cultivation, and improper rangeland management, disrupts natural ecosystem function and aids in the establishment of invasive plant species (Cully et al. 2003). Establishment of invasive plant species consequently leads to lower crop production, increased herbicide use, decreased forage quantity and quality, lower diversity and richness, and degraded wildlife habitats (Grant et al. 2009). Biodiversity declines may be particularly detrimental in imperiled ecosystems such as grasslands that now comprise only 0.1% or less of their native range (Samson et al. 2004).

Kentucky bluegrass (*Poa pratensis*; hereafter bluegrass) invasion is threatening grassland ecosystems of the northern Great Plains (Toledo et al. 2014). Increased bluegrass abundance (Miles and Knops 2009) is threatening the biodiversity of grasslands and is associated with declines in the abundance of native plant species (Cully et al. 2003). The invasion occurred rapidly over the past 30 years, likely in response to land management practices that allow or promote its proliferation through alterations to the region's historic grazing and fire regimes (Toledo et al. 2014). Increases in growing-season length, atmospheric CO_2 concentrations, and above-average precipitation also may contribute to its increased dominance (DeKeyser et al. 2015). Its origin in the United States is not clear (Carrier and Bort 1916), but bluegrass was not a part of the region's plant community historically (Barker et al. 1986).

At this time, there is a lack of empirical evidence to suggest how bluegrass-invaded communities respond to grazing management in the northern Great Plains and how working landscapes respond to grazing after burning. The influence of both grazing and fire on the evolution of the Great Plains grassland ecosystem is widely recognized (Fuhlendorf et al. 2009; Samson et al. 2004). Also, patch-burn grazing management can promote structural and compositional diversity (Fuhlendorf and Engle 2001, 2004). Studies in the tallgrass (Anderson et al. 1970; Owensby and Smith 1979; Smith and Knapp 1999) and mixed-grass prairie (Bahm et al. 2011; Engle and Bultsma 1984; Kral et al. 2018) ecoregions indicate that burning can decrease bluegrass. However, the benefits of burning bluegrass are highly dependent on precipitation and soil type (Engle and Bultsma 1984), and reductions in mixed-grass prairie are short term (Bahm et al. 2011; Kral et al. 2018). Analyzing the effects of management (both grazing and continued burning) after burning, therefore, is relevant to determine if it can provide effective bluegrass control.

Controlled livestock distribution and reduced grazing intensity can be implemented to enhance wildlife habitat and promote conservation of certain landscapes and some wildlife species. However, traditional approaches to rangeland management to enhance conservation are generally thought to reduce profits from livestock grazing enterprises because traditional approaches reduce the number of grazing animals (Dunn et al. 2010). Current rangeland management decouples fire from grazing. Further, the decoupling decreases feedbacks created through disturbances leading to homogeneity in rangeland ecosystems. When these disturbances are suppressed, restricted vegetation succession creates stagnant and homogeneous landscapes. Homogeneity reduces the number of structural and compositional habitats needed to sustain plant and animal populations, resulting in loss of biological diversity. Therefore, conservation-based livestock grazing practices that are both profitable and promote biodiversity are clearly needed (O'Connor et al. 2010).

Combining the spatial and temporal interaction of fire and grazing (pyric-herbivory) is a conservation-based approach to management that increases rangeland biodiversity trophic levels and taxonomic orders by creating heterogeneous vegetation structure and composition (Fuhlendorf et al. 2006; Churchwell et al. 2008; Coppedge et al. 2008; Engle et al. 2008; Fuhlendorf et al. 2010). Discrete fires shifting in time across a landscape concentrates grazing while leaving unburned portions of the landscape largely undisturbed. The undisturbed areas have relatively tall and dense vegetation. Focal grazing on the recently burned areas maintains relatively short vegetation, and transition areas recovering from focal disturbance support diverse vegetation. The three different patch-types create a structurally and compositionally heterogeneous landscape (Fuhlendorf and Engle 2001 and 2004). Conservation-based livestock grazing and restoration practices that are profitable, reduce exotic plant species and promote biodiversity are clearly needed (O'Connor et al. 2010). Therefore, this project will focus on **1)** Developing methods to reduce exotic grass species and restore native species on Northern Great Plains rangelands, and **2)** Determine the effect of heterogeneity-based management on livestock production.

Methods: General Design

This study is conducted at the North Dakota State University Central Grassland Research Extension Center (CGREC) in south-central North Dakota (lat 46°46'N, long 99°28'W). As part of the North Dakota Agricultural Experiment Station, CGREC's mission is to extend scientific research and Extension programming to the surrounding rural communities. It consists of 2,160 hectares of native grassland and annual crops. The study area is representative of much of the Great Plains ecoregion with large tracts of native grassland used for livestock production intermixed with annual small-grain and row-crop agriculture. The CGREC is in the Missouri Coteau ecoregion of the northern Great Plains that occupies 125 million hectares, of which approximately 40% is perennial rangeland grazed by livestock. The Missouri Coteau ecoregion is characterized by irregular, rolling, rocky plains and depressional wetlands. The climate is temperate and experiences an average yearly rainfall of 40.3 cm (Limb et al. 2018).

Vegetation at CGREC has been sampled recently and in the past (Limb et al. 2018). It is typical of a Northern mixed-grass prairie that has been invaded by Kentucky bluegrass, which includes a diverse forb community that could support a diverse pollinator community. While we are currently sampling that pollinator diversity at CGREC, preliminary data suggests numerous pollinator species, capturing 33 bee and 27 butterfly species from June to August 2015. This and more recent sampling suggest that bee and butterfly diversity still exists within the mixed-grass region in and around the proposed research sites. Thus, our efforts will allow for pollinator colonization and even population expansion.

Agro-ecosystem management strategies that promote sustainable production and ecosystem services are dependent on practical solutions based on sound ecological principles. In rangelands, this research is complicated by the need for large-scale replication that is allowed to take place over multiple years. We have the unique situation of being able to take advantage of a tremendous amount of work (and financial cost) that already has been used to create four management treatments that have each been replicated four times, each at a relatively large spatial scale (65-ha replicates).

Within this design framework, we compare four management treatments in their ability to optimize livestock production while promoting plant-pollinator interactions. Treatments are based on current management frameworks but use a combination of well-established and novel designs. The four treatments are *(a) patch-burn grazing (PBG 1 season of burn (SOB)), (b) patch-burn grazing (PBG 2 seasons of burn), (c) modified twice-over rest-rotation grazing (MTRG), and (d) season-long grazing (SLG)*.

(a) Patch-burn grazing (PBG) 1 season of burn is a management framework intended to mimic historic disturbance regimes where focal grazing occurs on recently burned areas while lightly grazed areas allow for accumulation of plant biomass (i.e., fuel) for future fires (Fuhlendorf and Engle 2001). Fires will occur in the spring of each year when fuel moisture levels have decreased sufficiently for fire to carry. Patch-burn pastures (appx. 65 ha each) are divided into four relatively equal-size patches (appx. 16 ha each) with one of the four patches being burned each spring. These fire-return intervals are designed to mimic the historical disturbance regime of mixed-grass prairie.

(b) Patch-burn grazing 2 seasons of burn. Season of burn can differentially alter how the plant community responds to fire (Kral et al. 2018). Moreover, considering multiple seasons can be important for promoting floristic diversity in grasslands and overcoming logistical challenges of spring-only fires (McGranahan et al. 2016). The second treatment is similar to the previous PBG treatment in that one quarter of each pasture will be burned each year. However, in this case, half of a patch (a sub-patch equal to one eighth of a pasture,- appx. 8 ha) is burned in the spring (same timing as PBG 1 SOB), and the other half of that patch (the sub-patch=1/8 of a pasture) is burned in the summer.

(c) Modified twice-over rest-rotation grazing (MTRG). Our third treatment is similar to the PBG treatments in that it is designed to produce structural heterogeneity across a pasture. However, unlike the PBG treatments, our modified twice-over rest-rotation grazing treatment utilized fencing to dictate cattle distribution and influence grazing. Pastures are divided into four relative equal patches and cross fenced to create four discrete sub-pastures that cattle cannot move between (without being purposefully moved). Across the sub-pastures, cattle are rotated through twice and allowed to graze for a total 74, 54, 27 and zero days (total 155-day grazing season) in each rotation of the heavy, moderate, light, and rest sub-pastures, respectively. In subsequent years, grazing intensity will be rotated to different patches such that the non-grazed patch will become the heavy-use pasture, the heavy-use pasture will transition to the non-grazed, the moderate to the light and the light to moderate grazing. This rotation will create annual heavy disturbance in one sub-pasture and reduce annual heavy

disturbance in the same location, which could result in changes to forage quality and loss of plant species (Fuhlendorf et al. 2017).

(d) Season-long grazing (SLG) is intended to reflect status quo management for the region and will serve as a controlled comparison for the other treatments. This is a typical management approach for this region, and it serves as an important comparison because it homogeneously applies the disturbance (grazing) throughout the entire patch. Thus, it is expected to lack the heterogeneity and structure of other treatments and therefore not benefit livestock.

Common among the four treatments, cow/calf pairs grazed within pastures from mid-May to late October each year at a full-use stocking rate (2.47 animal unit months/ha) in all treatments designed to achieve 40% to 60% degree of disappearance. Stocking rates were determined using a 25% and 30% harvest efficiency on the season-long and managed treatments, respectively. All treatments provide fresh water access and mineral supplements for cattle. With the exception of MTRG, all treatment units (pastures) have exterior fencing only with no interior fences to separate individual patches. The MTRG used interior fencing to separate patches and maintain livestock at a particular stocking rate throughout the year. Soil type and vegetation communities are similar among replicates, as defined by Natural Resources Conservation Service (NRCS) ecological site descriptions and equivalent land-use histories (USDA-NRCS 2018).

Vegetation quadrat samples will be performed using 0.5 x 0.5m quadrats to determine the cover of native and introduced grasses and forbs. We also will measure heights of vegetation, litter and thatch layers, and we will use 10 quadrats per survey set. To evaluate objectives, three 0.25 m^2 plots were caged and paired with three uncaged plots at each monitoring location (6 total plots/ monitoring site, 24 total plots per pasture) prior to the onset of grazing. At the peak of forage production for the year in mid-July, two new plots were picked to match each of the original uncaged plots, and the original plots were clipped. One of each pair of new plots was caged, and at the end of the grazing period, the herbage from each remaining plot will be clipped. Herbage clipped from inside caged plots at peak growing season provides an estimate of peak biomass. Differences between biomass in the caged plots at the end of the grazing period and uncaged plots from the peak sampling represent the growth (or disappearance) from peak. Samples are oven-dried to a constant weight and weighed to determine the amount of herbaceous production and percent utilization of the forage.

All cattle were weighed before they went on the pastures and again when they were removed. We quantified their performance management treatments by measuring weight gain of both calf and cow. Calves were weighed within 24 hours of birth and again when weaned at the end of the growing season. The difference in those weights provided calf total and daily weight gain. Two-day individual body weights of cows were measured at the beginning and the end of the grazing season, with that difference providing a measurement of cow weight gain.

Results: Update

Vegetation Production, Degree of Disappearance and Plants Species Change

Standing crop ranged from 3,800 to 4,500 lb/ac on the season-long and patch-burn treatments in 2017 and 2018 (Figure 1).

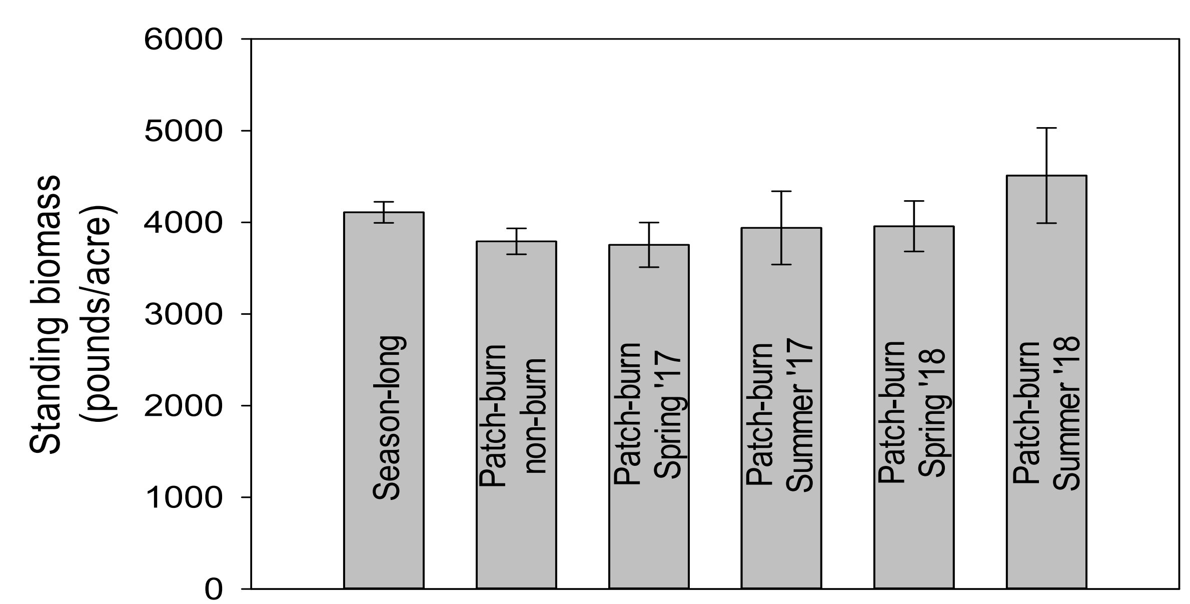

Figure 1. Standing crop at or near the end of the grazing season on the season-long and patch-burn treatments at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

Biomass (no litter) production on the modified twice-over rotation rest-rotation treatment ranged from 2,780 to 2,840 lb/ac in 2018 (Figure 2).

The goal of a patch-burn grazing and modified rotational grazing treatment is to create heterogeneity in disturbance and structure across the landscape. Livestock grazing on the season-long treatment averaged 33% in 2017 and 2018. Within the patch-burn grazed spring burn treatment, degree of disappearance averaged 43% in the non-burned areas compared to 48% and 59% on the burned patches in 2017 and 2018, respectively (Figure 3). In the patch-burn grazed spring+summer burn treatment, degree of disappearance averaged 43% in the non-burned areas compared to 51% and 54% on the burned patches in 2017 and 2018, respectively (Figure 3).

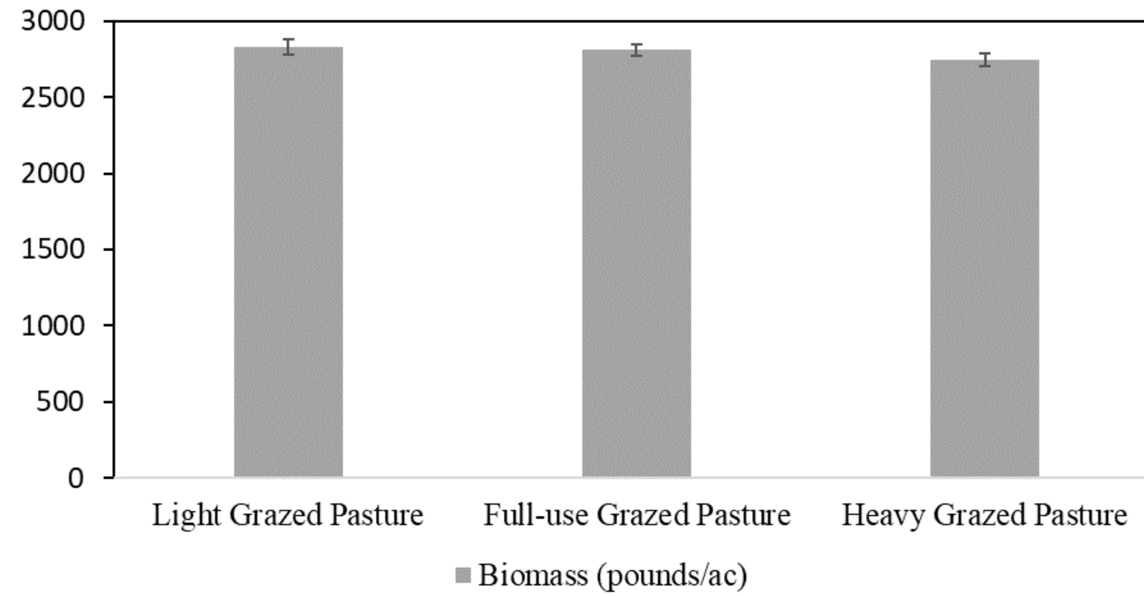

Figure 2. Biomass (no litter) produced at the end of each grazing period on the modified twice-over rotation-rest rotation treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2018.

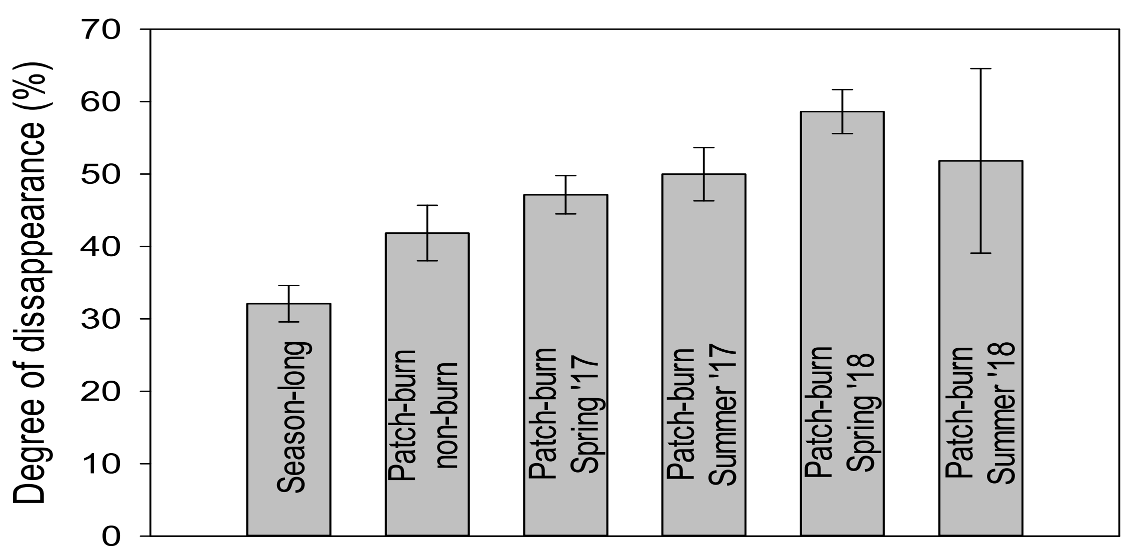

Figure 3. Degree of disappearance on the season-long and patch-burn treatments at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

Within the modified twice-over rotation rest-rotation treatment, degree of disappearance was 21%, 32% and 61% in the light, full and heavy use pastures in 2018, respectively (Figure 4).

The full-use pasture was stocked to create a similar degree of disappearance as the season-long treatment, which averaged 33%. The goal is to achieve a degree of disappearance on the season-long treatment and full-use pasture of 40% to 50%; however, the 2018 growing-season precipitation was 127% of average. This additional precipitation created higher-than-expected vegetation growth, thus, degree of disappearance was below the targeted level.

There was no change ($P > 0.05$) in species richness (Figure 5), species evenness (Figure 6) or species diversity (Figure 7) after one year of treatment. Species richness and diversity were higher on the patch-burn treatments pretreatment compared to the season-long.

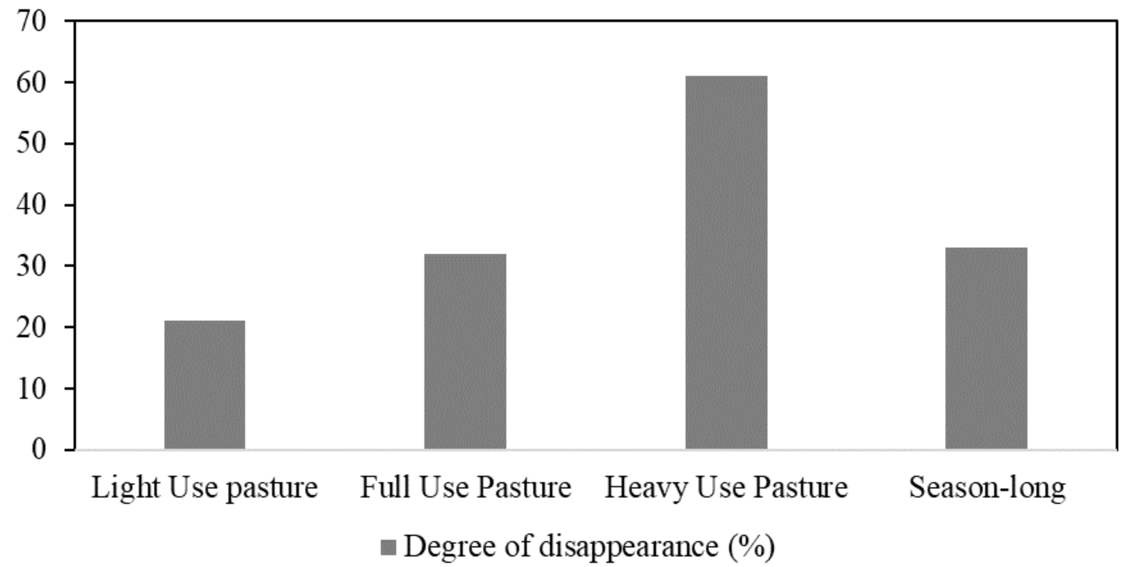

Figure 4. Degree of disappearance on the modified twice-over rotation rest-rotation treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2018.

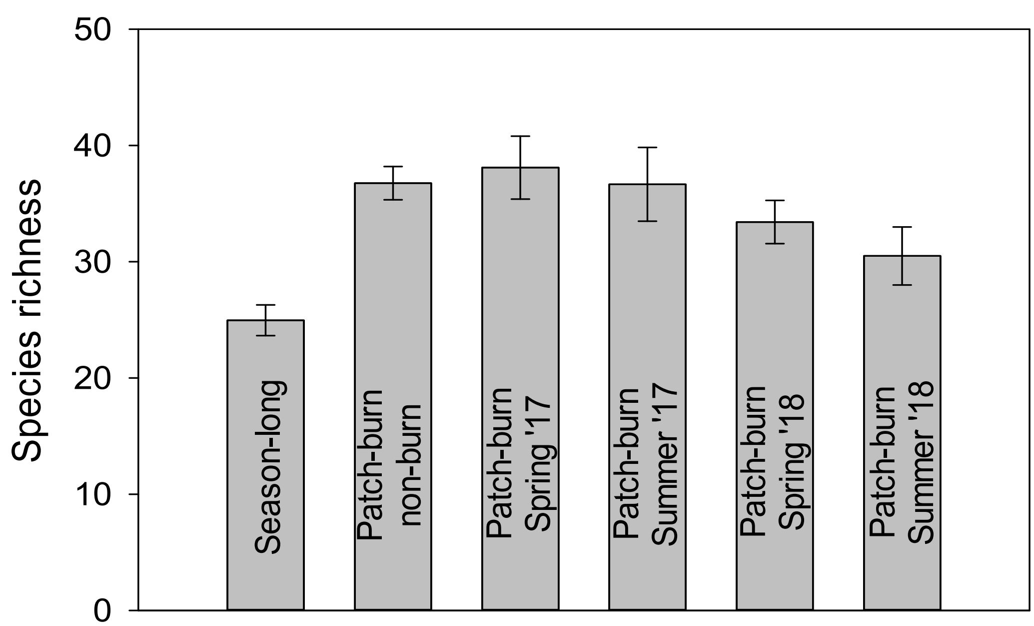

Figure 5. Species richness by treatment and year on the season-long and patch-burn treatments at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

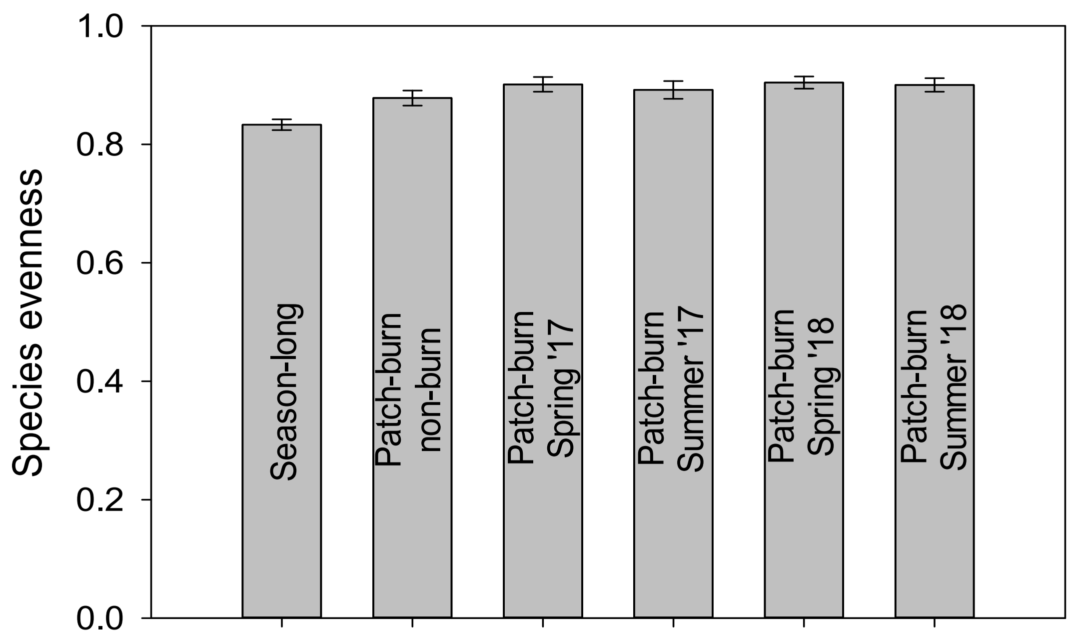

Figure 6. Species evenness by treatment and year on the season-long and patch-burn treatments at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

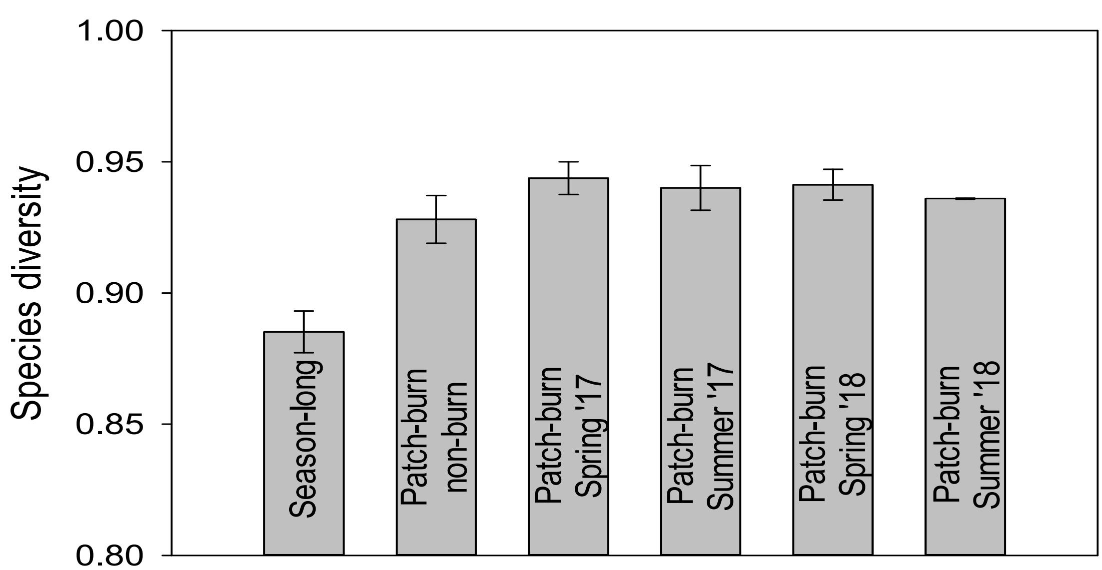

Figure 7. Species diversity by treatment and year on the season-long and patch-burn treatments at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

Livestock Reproduction and Performance

Percent bred cows was similar (P > 0.05) among treatment in 2017 and 2018, ranging from 88% to 96% in 2017, and 92% to 96% in 2018 (Figure 8). Interestingly, 98.2% were bred during the first two cycles in 2018.

Calf performance, in terms of average daily gain, was similar (P > 0.05) among treatments in 2017 and 2018 (Figure 9). Calf average daily gain (lb/day) ranged from 2.41 on the modified twice-over rest rotation treatment in 2018 to 2.72 on the spring patch burn grazing treatment in 2017.

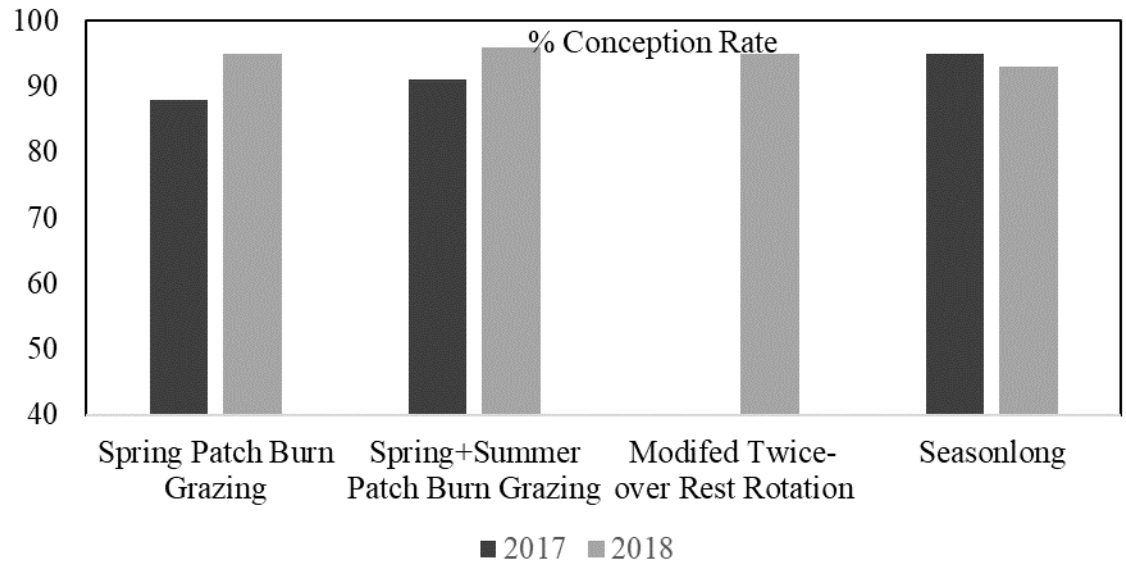

Figure 8. Conception rates of cows bred on pasture by treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2018.

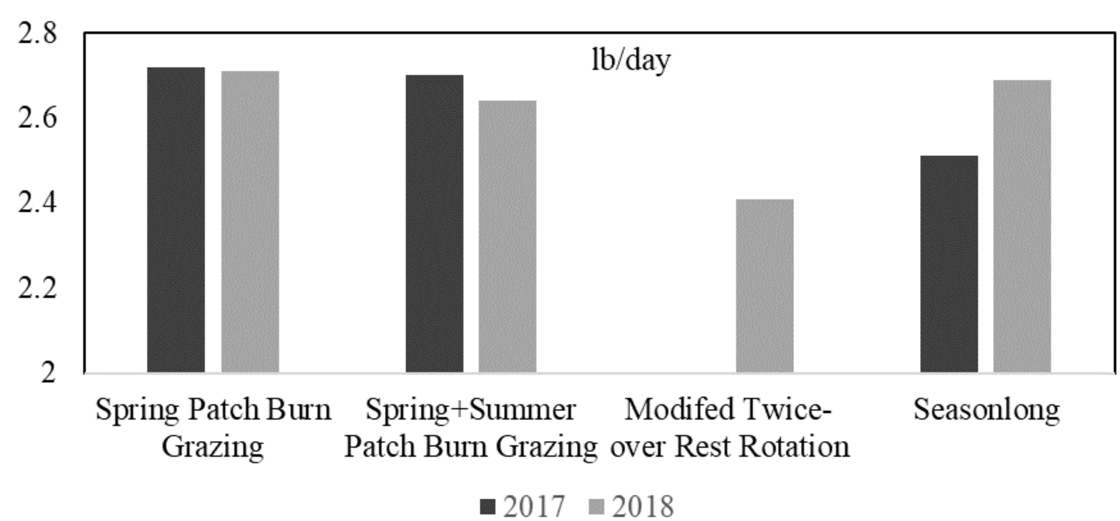

Figure 9. Calf average daily gain (lb/day) by treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

Cow performance, in terms of average daily gain, was greatest ($P \leq 0.05$) on the patch-burn graze treatments in 2017 compared to the season-long (Figure 10). The patch-burn grazing treatments both had positive average daily gains (0.72 and 0.67 lb/day) compared to cows losing weight on the season-long treatment (-0.51 lb/day). There was no difference between treatments in cow performance in 2018 (Figure 10).

Vegetation Growth Responses from Grazing and Recovery

We looked at new plant growth, as it relates to recovery, following a grazing event versus non-grazing paired plots. This only was conducted on the heavy-use pasture of the modified twice-over rotation rest rotation treatment in 2018. A total 33 days recovery occurred between the first and second rotations of grazing. Vegetation that was grazed and had the 33-day recovery grew 72% and 94% more new grass, and 12% and 14% more new forbs on the shallow loamy and loamy ecological sites, respectively, compared to the non-grazed paired plots (Figure 11). The first rotation occurred from May 23 to June 22.

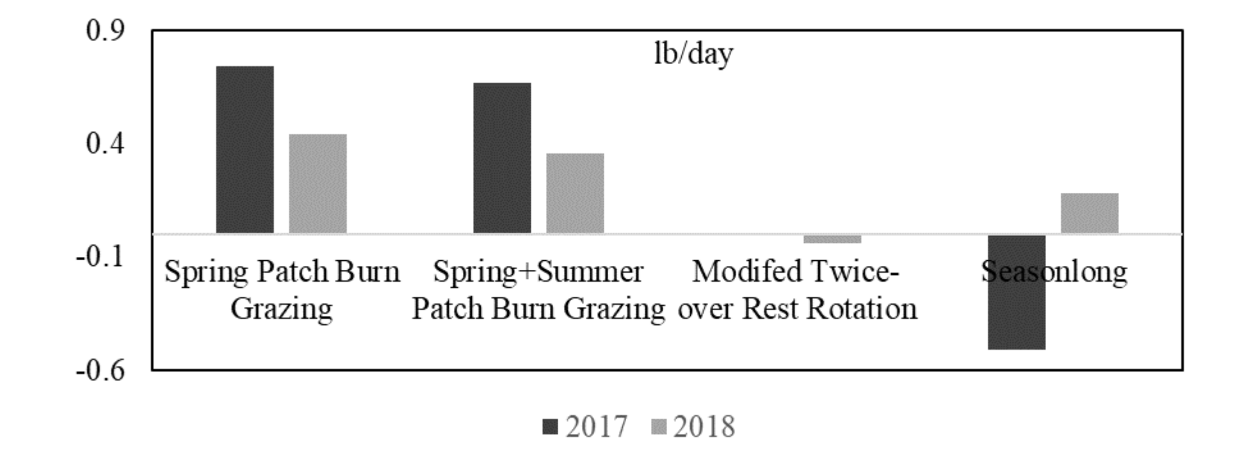

Figure 10. Cow average daily gain (lb/day) by treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2017 and 2018.

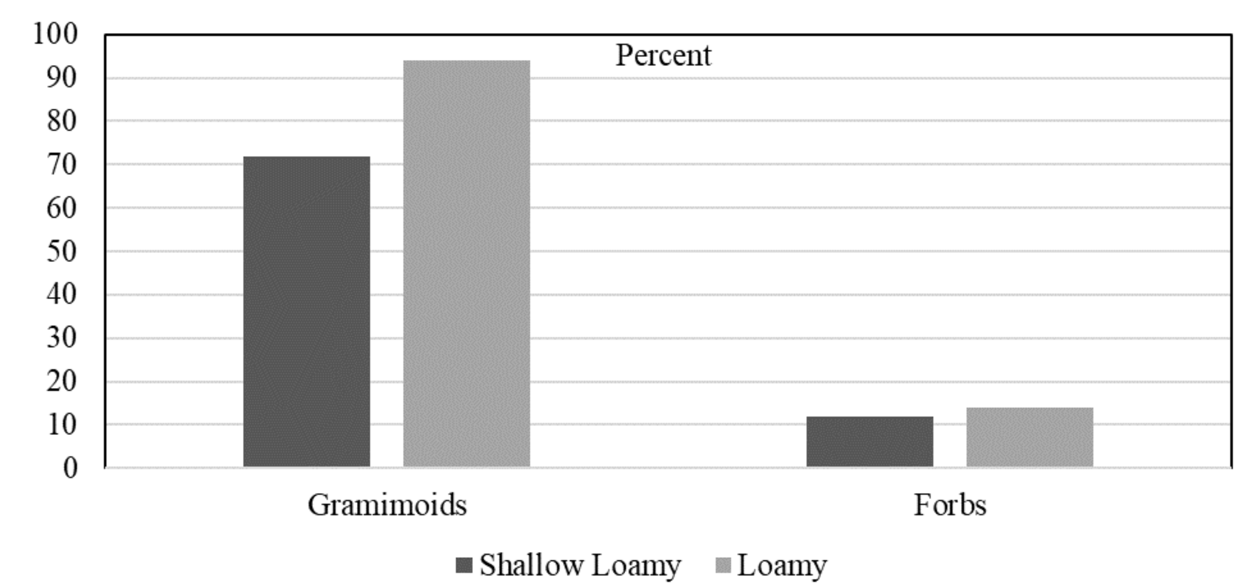

Figure 11. Percent new growth on grazed plots of the heavy-use pasture compared to non-grazed plots on the modified twice-over rotation rest rotation treatment at the Central Grasslands Research Extension Center near Streeter, ND, in 2018.

Literature Cited

Andersen, M.C., H. Adams, B. Hope, and M. Powell. 2004. Risk assessment for invasive species. *Risk Analysis* 24:787-793.

Anderson, K. L., E. F. Smith, and C.E. Owensby. 1970. Burning bluestem range. *Journal of Range Management* 23:81-92.

Bahm, M.A., T.G. Barnes, & K.C. Jensen, 2011. Herbicide and fire effects on smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) in invaded prairie remnants. *Invasive Plant Science and Management* 4:189-197.

Barker W.T., T.M. Barkley, M. Bolick, R.E. Brooks, S.P. Churchill, R.L. Hartman. 1986. Flora of the Great Plains. University Press of Kansas, Lawrence, Kansas, USA.

Carrier, L., and K.S. Bort 1916. The history of Kentucky bluegrass and white clover in the United States. *Agronomy Journal* 8:256-266.

Churchwell, R.T., C.A. Davis, S.D. Fuhlendorf, and D.M. Engle. 2008. Effects of patch-burn management on dickcissel nest success in a tallgrass prairie. *Journal of Wildlife Management* 72:1596-1604.

Coppedge, B.R., S.D. Fuhlendorf, W.C. Harrell, and D.M. Engle. 2008. Avian community response to vegetation and structural features in grasslands managed with fire and grazing. *Biological Conservation* 141:1196-1203.

Cully, A.C., J.F. Cully Jr, and R.D. Hiebert. 2003. Invasion of exotic plant species in tallgrass prairie fragments. *Conservation Biology* 17:990-998.

DeKeyser, E.S., L.A. Dennhardt, & J. Hendrickson. 2015. Kentucky bluegrass (*Poa pratensis*) invasion in the Northern Great Plains: a story of rapid dominance in an endangered ecosystem. *Invasive Plant Science and Management* 8:255-261.

Dunn, B.H., A.J. Smart, R.N. Gates, P.S. Johnson, M.K. Beutler, M.K. Diersen, and L.L. Janssen. 2010. Long-term production and profitability from grazing cattle in the northern mixed grass prairie. *Rangeland Ecology and Management* 63:233–242.

Engle, D.M., and P.M. Bultsma. 1984. Burning of northern mixed prairie during drought. *Journal of Range Management* 37:398 -401.

Engle, D.M., S.D. Fuhlendorf, A. Roper, and D.M. Leslie Jr. 2008. Invertebrate community response to a shifting mosaic of habitat. Rangeland Ecology and Management 61:55-62.

Fuhlendorf, S.D., and D.M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. *Bioscience* 51:625–632.

Fuhlendorf, S.D., and D.M. Engle. 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology* 41:604–614.

Fuhlendorf, S.D., Smeins, F.E., 1998. The influence of soil depth on plant species response to grazing within a semi-arid savanna. *Plant Ecology* 138, 89-96.

Fuhlendorf, S.D., Smeins, F.E., 1999. Scaling effects of grazing in a semi-arid grassland. *Journal of Vegetation Science* 10, 731-738.

Fuhlendorf, S.D., W.C. Harrell, D.M. Engle, R.G. Hamilton, C.A. Davis, and D.M. Leslie Jr. 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecological Applications* 16:1706–1716.

Fuhlendorf, S.D., D.M. Engle, J. Kerby, and R.G. Hamilton. 2009. Pyric–herbivory: rewilding landscapes through re-coupling fire and grazing. *Conservation Biology* 23:588–598.

Fuhlendorf, S.D., D.E. Townsend II, R.D. Elmore, and D.M. Engle. 2010. Pyric–herbivory to promote rangeland heterogeneity: evidence from small mammal communities. *Rangeland Ecology & Management* 6:670–678.

Fuhlendorf, S.D., R.W.S. Fynn, D.A. McGranahan, and D. Twidwell. 2017. Heterogeneity as the basis for rangeland management, in: Briske, D.D. (Ed.), Rangeland Systems: Processes, Management and Challenges, Springer Series on Environmental Management. Springer International Publishing, pp. 169–196.

Grant, T.A., B. Flanders-Wannaer, T.L. Shaffer, R.K. Murphy, and G.A. Knutsen. 2009. An emerging crisis across northern prairie refuges: prevalence of invasive plants and a plan for adaptive management. *Ecological Restoration* 27:58-68.

Hovick, T.J., Elmore, R.D., Fuhlendorf, S.D., Engle, D.M., Hamilton, R.G., 2015. Spatial heterogeneity increases diversity and stability in grassland bird communities. *Ecological Applications* 25, 662-672.

Knopf, F.L. 1994. Avian assemblages on altered grasslands. *Studies in Avian Biology* 15:247-257.

Kral, K.C., R. Limb, A. Ganguli, T. Hovick, and K. Sedivec. 2018. Seasonal prescribed fire variation decreases inhibitory ability of *Poa pratensis* L. and promotes native plant diversity. *Journal of Environmental Management* 223:908-916.

Limb, R.F., D.M. Engle, T.G. Bidwell, D.P. Althoff, A.B. Anderson, P.S. Gipson, and H.R. Howard. 2010. Restoring biopedturbation in grassland with anthropogenic focal disturbance. *Plant Ecology* 210:331-342.

Limb, R. F., T.J. Hovick, J.E. Norland, and J.M. Volk. 2018. Grassland plant community spatial patterns driven by herbivory intensity. *Agriculture Ecosystems & Environment* 257:113-119.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout and F. Bazzaz. 2000. Biological invasions: causes, epidemiology, global consequences, and control. Issues in Ecology No.5. Ecological Society of America; Washington, D.C.

McGranahan, D. A., T.J. Hovick, R.D. Elmore, D.M. Engle, S.D. Fuhlendorf, S.L. Winter, J.R. Miller, and D.M. Debinski. 2016. Temporal variability in aboveground plant biomass decreases as spatial variability increases. *Ecology* 97:555-560.

Miles, E.K. and J.M.H. Knops. 2009. Shifting dominance from native C4 to non-native C3 grasses: relationships to community diversity. *Oikos* 118:1844-1853.

O'Connor, T.G., P. Kuyler, K.P. Kirkman, and B. Corcoran. 2010. Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range and Forage Science* 27:67–76.

Owensby, C.E., and E.F. Smith. 1979. Fertilizing and burning Flint Hills bluestem. *Journal of Range Management* 32:254-258.

Patten, R.S., Ellis, J.E., 1995. Patterns of species and community distributions related to environmental gradients in an arid tropical ecosystem. *Vegetatio* 117, 69-79.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. *Wildlife Society Bulletin* 32:6-15.

Smith, M.D., and A.K. Knapp. 1999. Exotic plant species in a C-4 -dominated grassland: Invasibility, disturbance, and community structure. *Oecologia* 120:605-612.

Toledo, D., M. Sanderson, K. Spaeth, J. Hendrickson, and J. Printz. 2014. Extent of Kentucky bluegrass and its effect on native plant species diversity and ecosystem services in the Northern Great Plains of the United States. *Invasive Plant Science and Management* 7:543-552.

USDA-NRCS. 2018. United States Department of Agriculture-Natural Resources Conservation Service. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/ . Accessed 29 October 2018.

Vallentine, J.F. 2001. Grazing management, second edition. Academic Press, San Diego, CA, 659 pp.

West, N.E. 1993. Biodiversity of rangelands. Journal of Range Management 46:2-13.

Wiens, J.A. 1997. The emerging role of patchiness in conservation biology. Pages 167-186 in S.T.A. Pickett, R.S. Otsfeld, M. Shachak, and G.E. Likens, editors. The ecological basis for conservation: heterogeneity, ecosystems, and biodiversity. Chapman and Hall, New York, New York, USA.