**Adaptive Grazing Management to Sustain Multiple Ecosystem Services in Rangeland Ecosystems**

**Introduction**

Worldwide, rangelands traditionally have been managed to provide food and fiber through practices aimed at achieving sustainable forage and livestock production (Havstad et al. 2007; Dunn et al. 2010). Rangeland science has historically taken a practice-based approach to examining forage and livestock production, despite the inherent complexity of rangelands and the diversity of products and services they can provide (Walters and Holling 1990; Boyd and Svejcar 2009). Implicit in the practice-based approach is the assumption that application of practices to enhance livestock production will also produce desirable co-benefits for other ecosystem goods and services such as wildlife habitat, plant diversity, soil carbon, and watershed function. However, the conservation benefits of many grazing practices implemented on rangelands are not well established (Briske et al. 2011). With growing societal interest in provision of ecosystem services from rangelands, including biodiversity conservation, rangeland managers are increasingly challenged to incorporate ecosystem complexity and variability into management approaches, and evaluate the degree to which we can provide for multiple ecosystem services (Millennium Ecosystem Assessment 2003; Havstad et al. 2007; Toombs et al. 2010; Briske 2011).

Rangeland ecosystems are characterized by substantial temporal variability in weather overlaid on spatial variability associated with topography and soils. Semiarid rangelands in particular are characterized by more extreme intra- and inter-annual variation in precipitation than mesic rangelands (Augustine 2010), and droughts continue to create major financial hardship for livestock producers around the world. Strategies for coping with drought include reducing livestock numbers, leasing forage, temporarily grazing rangeland beyond its capacity, and increasing supplemental feed, but these involve significant economic or ecological costs. Alternative approaches to increase enterprise flexibility in responding to drought are clearly needed. Matching livestock numbers to forage conditions by employing a mixed strategy of yearling and breeding herds has been shown to substantially increase livestock production and economic returns (Torell et al. 2010), but is contingent on highly accurate seasonal precipitation forecasts. Managing livestock spatial distribution with the goal of resting certain pastures and “grassbanking” the forage during periods of above-average precipitation could also enhance ranch-scale carrying capacity during subsequent droughts, but has not been evaluated at scales relevant to livestock producers.

Ongoing and predicted effects of climate change will only increase the critical need for strategies to enhance enterprise flexibility and resilience to drought. Changing climate is expected to bring increased incidence of extreme weather, warmer temperatures, increased atmospheric [CO2], and changes in the size and frequency of precipitation events (Wang 2005; IPCC 2007), the consequences of which are likely to vary regionally within the Great Plains (Polley et al. 2012). Warming and drying are anticipated to reduce soil water availability, net primary productivity, and other ecosystem processes in the southern Great Plains and the southwestern US, while warmer and generally wetter conditions are predicted to enhance these processes in the northern Plains. In the central Plains, warming and increased atmospheric [CO2] are predicted to have offsetting effects on forage production and quality (Morgan et al. 2011), whereas changes in the frequency and size of precipitation events, and increased incidence of prolonged droughts, are expected to increase temporal variability in forage production (Heisler-White et al. 2008). Grazing management will need to become more adaptive at individual sites to maintain production amidst this increased climatic variability (Morgan et al. 2008; Follett et al. 2011).

The adaptive management of livestock spatial distribution not only has potential to increase enterprise resilience to drought, but could also provide benefits for other ecosystem services such as biodiversity conservation and soil carbon sequestration. Historically, rangelands worldwide were characterized by pulsed disturbances from native grazers and fire, often including strong positive grazer-grazer and fire-grazer feedbacks, which generated spatial and temporal heterogeneity in vegetation structure and composition (Fuhlendorf et al. 2012). Such structural and compositional heterogeneity was likely a key factor generating and sustaining faunal biodiversity (Tews et al. 2004; Fuhlendorf et al. 2006). Today, rangeland management strategies that focus on matching livestock numbers to forage availability at the enterprise scale, such as through conservative stocking or flexible use of yearling herds (Torell et al. 2010) do not consider the potential importance of within-enterprise variability to both livestock production and other ecosystem services. Indeed, most rangeland management strategies developed over the past century have attempted to match livestock distribution and numbers to forage distribution and amount across the landscape as effectively as possible each year. To the extent that such matching is achieved, these grazing strategies reduce heterogeneity in vegetation structure and composition across the landscape, with potential negative consequences for native biodiversity.

Grassland birds that breed in the Great Plains are one of the most consistently and rapidly declining guilds of bird species in North America (Knopf 1996; Brennan and Kuvlevsky 2005). Grassland birds comprise the majority of the vertebrate species of conservation concern in the Great Plains states (Montana, Wyoming, North and South Dakota, Nebraska, Kansas, Colorado, Oklahoma, Texas and New Mexico), and are a priority for conservation on public lands such as the National Grasslands (USDA-FS) and National Wildlife Refuges (USFWS) throughout the region. Grassland bird assemblages are often strongly influenced by changes in the structure and spatial heterogeneity of vegetation (Knopf 1996; Fuhlendorf et al. 2006). Birds of the Great Plains evolved with dynamic disturbances associated with herbivores, fire, and drought, that together shaped their habitats, food, and predator communities (Samson et al. 2004, Fuhlendorf et al. 2006, Derner et al. 2009). Anthropogenic influences have altered these historical disturbance regimes and habitats and may be contributing to the ongoing, long-term decline in grassland bird abundance and diversity (Brennan and Kuvleskey 2005, Askins et al. 2007).

In the western Great Plains, substantial areas persist as native grassland, and conversion to cropland or other uses has been minimal over the past four decades (Samson et al. 2004). Here, most remaining grasslands support livestock production. The development of effective management strategies to enhance grassland bird diversity and population persistence requires an understanding of how different disturbances influence the distribution, abundance, and vital rates of bird species. Livestock management that facilitates even utilization of forage across the landscape within a given growing season can suppress vegetation heterogeneity, and thereby degrade breeding habitat for certain groups of bird species (Brennan and Kuvlevsky 2005; Askins et al. 2007). **A key question is whether management strategies focused on heterogeneous utilization of forage in space and time can enhance plant diversity, plant structural heterogeneity, and reproductive success of declining grassland birds, thereby contributing to the long-term conservation of grassland biodiversity, while at the same time sustaining beef production and enhancing soil carbon content.** Strategies that employ high stock densities combined with long-term rest periods may increase resilience of ranch operations to drought while generating the vegetation heterogeneity needed to enhance breeding habitat for grassland birds of conservation concern.

We propose to examine whether adaptive grazing management principles, employed in an experimental framework to increase enterprise resilience to drought, can synergistically enhance **4 important ecosystem services**. First, we will quantify effects on **livestock production**, which will continue to be an essential provisioning service from rangelands. Second, we will quantify effects on **soil carbon** content, which is an essential supporting service in rangelands that affects forage production and soil moisture dynamics. Finally, we will examine two important components of biodiversity: **plant diversity** and **grassland bird diversity**. Plant diversity serves a critical supporting service in the structure and function of rangeland ecosystems because it can influence forage production, soil organic matter formation, and resilience of forage and beef production to drought. Furthermore, we hypothesize that spatial heterogeneity in plant species, and associated heterogeneity in plant architecture and phenology, increases niche diversity for native fauna, particularly for grassland birds. Bird diversity is an important ecosystem service as it supports tourism in the region (on both public and privately owned rangelands), and sustaining grassland bird diversity is a management goal of state and federal agencies in the region.

**Rangeland Ecosystem Services**

Management strategies that enhance livestock production while sustaining or enhancing soil health are critically needed to sustainably feed a growing world population. At the same time, society increasingly values rangelands for other ecosystem services, including sustaining biodiversity. A key challenge is whether innovative management strategies can be developed that simultaneously enhance livestock production, sustain soil health and conserve biodiversity.

The relationship between biodiversity and ecosystem services is complex and operates at multiple levels. Some components of biodiversity, such as plant diversity in rangeland ecosystems, can serve as key regulators of ecosystem process (e.g., forage production and nutrient cycling rates). Biodiversity is also recognized as an ecosystem service that can be valued economically, and as a final ecosystem output that is valued by society through laws and policies that mandate its continued existence (Mace et al. 2012). Birds are recognized as providing multiple types of ecosystem services (Wenny et al. 2011). Economically, birds are an important component of biodiversity as more than 20% of the U.S. population participates in birdwatching, and trip-related expenditures by birdwatchers totaled $14.9 billion in 2011 (USFWS 2013). Grassland birds support a growing ecotourism industry in the Great Plains, creating new tour guide companies and providing alternative revenue for ranchers that host birdwatchers. Such ecotourism is focused on properties with less common bird species and where a wide diversity of species can be viewed. From a regulatory standpoint, the recent listing of the lesser prairie-chicken as threatened under the Endangered Species Act, and the associated economic impacts that such listing will have on ranches within the species range, highlights the need to develop livestock management strategies that help reverse, rather than contribute to, ongoing declines in grassland bird populations. Ecologically, birds comprise a large proportion of the vertebrate species pool in rangelands, and are numerically important as insectivores and omnivores in these ecosystems. Culturally, birds are charismatic species that connect urban and suburban populations with rural rangelands in a manner that transcends food production. Grassland birds represent a cultural ecosystem service because they provide recreation, inspiration for art and music, and spiritual value. Reversing the long-term decline of grassland birds in central North America is a major challenge for land management and state wildlife agencies, and will require the development of innovative strategies that integrate our understanding of grassland bird habitat needs with agricultural production systems at the landscape scale.

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