Research Paper

Balancing ecosystem service outcomes at the ranch-scale in shortgrass steppe: The role of grazing management

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On the Ground

- Grazing management for providing multiple ecosystem services at the ranch scale requires balancing desired outcomes.
- Abundant challenges involve matching the spatial heterogeneity in soils and associated plant community characteristics with the temporal variability in precipitation.
- Prescriptive grazing (season-long continuous and time-controlled rotational grazing) removes the human experiential knowledge to adapt to changing conditions, whereas adaptive multipaddock (AMP) grazing often invokes high stock densities, which reduce livestock weight gain.
- A "mix-and-match" or blending of both approaches for grazing management in the shortgrass steppe can result in reduced drought risk, enhanced breeding habitat availability for grassland bird species of concern, and sustained livestock production.

Keywords: Adaptive grazing management, Prescriptive grazing management, Resilience, Rotational grazing, Semiarid rangeland, Spatial and temporal variability.

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Introduction

Rangelands provide diverse ecosystem services for society.[1] These services include livestock production, wildlife habitat, carbon sequestration, and many others.[2] At the ranch scale, livestock grazing management decisions incorporate multiscale knowledge of biotic and abiotic factors to influence ecosystem services through the balancing of desired outcomes.[3] Managers, however, face abundant challenges in matching livestock needs to spatially heterogeneous soils and vegetation along with spatially and temporally variable precipitation, both within and between years.[4]

To reduce uncertainty in the shortgrass steppe of the North American Great Plains, traditional grazing management emphasizes risk reduction through prescriptive (nonadaptive) "managing to the middle."[5] Managers commonly achieve this with season-long grazing at conservative stocking rates.[6] This has resulted in sustainable livestock production with substantial multidecadal increases in carrying capacity.[7] However, this grazing management can reduce vegetation structural heterogeneity with negative effects on biological diversity and wildlife habitats.[8] Season-long grazing is a prescriptive grazing strategy that minimizes adaptive capacity, or human ability to adapt to changing conditions within a grazing season based on experiential knowledge.[9] Similarly, time-controlled rotational grazing, often used in scientific comparisons of continuous versus rotational grazing systems,[10] is also prescriptive, and can also lack adaptive capacity.[11]

The success of adaptive multipaddock grazing (AMP) in forage pasture systems with agronomic objectives and high stocking densities[12] has prompted increased attention to incorporating adaptive capacity for making decisions under uncertainty, or adaptive management, defined as including strategic planning and goal setting, resource monitoring, and frequent re-evaluation of management outcomes,[13] at ranch scales in semiarid rangelands. Certainly, incorporation of experiential knowledge of the socio-ecological system assists in the flexible sequencing of livestock movement among pastures within and across years, which in turn can increase variability in vegetation structure for production and conservation outcomes.[14,15]

However, the prevailing debate over grazing management strategies has pitted prescriptive (nonadaptive) versus adaptive approaches in a binary question of which one is "better," with limited consideration of numerous complicating factors. Here, we synthesize prior and current research on grazing management strategies in the shortgrass steppe to determine their role in balancing ecosystem service outcomes at the ranch-scale. Our focus is on livestock production, mitigation of drought risk via grassbanking of forage, and breeding habitat for grassland bird species of concern in the western Great Plains. We qualitatively assess outcomes of different grazing management strategies to challenge the dichotomy of prescriptive versus adaptive strategies and provide insight for managers to balance ecosystem service outcomes at the ranch scale.

Methods

Study site

Grazing management experiments were conducted at the USDA-Agricultural Research Service's Central Plains Experimental Range, a 6,270 ha (15,500 ac) Long-Term Agroecosystem Research network location at the northern end of the shortgrass steppe ecosystem in northeastern Colorado. Mean annual precipitation is 340 mm (13.4 inches) with 70% of this total received during the growing season (April-August).[4] Precipitation during April to August was near normal in 2019 (208.8 mm [8.2 inches], 87% of average) and 2021 (201.4 mm [7.9 inches], 84% of average), but a severe drought occurred in 2020 (142.7mm [5.6 inches], 60% of average). These precipitation levels provide additional context for assessing outcomes for the different grazing management strategies in balancing ecosystem service outcomes in "normal" (2019, 2021) and "drought" (2020) years.

The Central Plains Experimental Range consists of 1) low productivity, <700 kg/ha (625 pounds/ac), pastures dominated by the Loamy Plains ecological site (R067BY002CO) and warm-season (C_4) shortgrasses blue grama (*Bouteloua gracilis*) and buffalograss (*B. dactyloides*), and 2) high productivity (>1,125 kg/ha [1,000 lbs/acre]) pastures dominated by the Sandy Plains ecological site (R067BY024CO) and cool-season (C_3) midgrasses western wheatgrass (*Pascopyrum smithii*) and needle-and-thread (*Hesperostipa comata*).[16] High productivity pastures produce >80% more forage than low productivity pastures.[16] This landscape supports several grassland birds of conservation concern.[17] These include the shortgrass dependent thick-billed longspur (*Rhynchophanes mccownii*) and the grasshopper sparrow (*Ammodramus savannarum*) who require the taller vegetation structure, as measured by visual obstruction readings, of mixed-grass habitat.

Grazing management strategies

A total of five (four prescriptive and one adaptive) grazing strategies were qualitatively evaluated for their influence on ecosystem services. Three prescriptive strategies used season-long (mid-May to end of September) grazing in 130-ha (320 ac) pastures. These included 1) long-term (since 1939) heavy stocking[6,7] in a low productivity pasture (n = 1) with a stocking density of 0.26 steers/ha in 2019 and 2020, and 0.23 steers/ha in 2021 (0.11 steers/ac in 2019 and 2020, and 0.09 steers/ac in 2021); 2) new heavy stocking with prior (before 2019) moderate stocking in low productivity pastures (n = 3) with a stocking density of 0.26 steers/ha in 2019 and 2020, and 0.23 steers/ha in 2021 (0.11 steers/ac in 2019 and 2020, and 0.09 steers/ac in 2021); and 3) long-term moderate stocking in high (n = 3), intermediate (n = 3), and low productivity (n = 4) pastures with a stocking density of 0.19 steers/ha in 2019 and 2020, and 0.16 steers/ha in 2021 (0.08 steers/ac in 2019 and 2020 and 0.07 steers/ac in 2021).[18]

A fourth prescriptive strategy used time-controlled rotation with steers rotated at predetermined calendar dates in 2019 and 2020 with an overall moderate stocking rate and variable stocking density. In this strategy, steers used high productivity pastures (130 ha [320 ac]) during mid-May to June stocked at a density of 0.94 steers/ha (0.38 steers/ac) in both years. In July, steers were moved to low productive pastures (65 ha [160 ac]) where they remained through August at twice the stocking density, 1.88 steers/ha (0.76 steers/ac). In September, steers were moved to additional high productivity pastures (130 ha [320 ac]) at the same density, 0.94 steers/ha (0.38 steers/ac), as in May-June. The intent of this grazing strategy was to use focal grazing during the summer months to produce short vegetation structure for targeted grassland bird breeding habitat in those pastures while simultaneously maintaining taller vegetation structure in the pastures grazed during the spring or fall months. Lower stocking density during the mid-May to June and September grazing periods was designed to mitigate negative livestock gains during the summer months at higher stock density.

Finally, we evaluated an AMP grazing strategy. In this strategy, one (2019) or two (2020 and 2021) herd(s) of steers was rotated among 10,130-ha (320 ac) pastures (4 low, 3 intermediate, and 3 high productivity) for the Collaborative Adaptive Rangeland Management experiment.[18] Eight pastures were grazed in 2019 and 2021 with two rested pastures, and all 10 pastures were grazed in 2020 because of drought conditions. Stock density was 0.23 steers/ha in 2019, 0.19 steers/ha in 2020, and 0.21 steers/ha in 2021 (0.10 steers/ac in 2019, 0.08 steers/ac in 2020, and 0.08 steers/ac in 2021). The overall stocking rate applied to the AMP grazing strategy pastures in any given year was decided by an 11-member Stakeholder Group,[9] informed by monitoring data, seasonal climate forecasts, and an aim to increase total livestock production per unit land area while making progress toward other ecosystem objectives.[3] All grazing management strategies used yearling British-bred steers.

Table 1
Beef production (kg/ha) from grazing management strategies at the Central Plains Experimental Range (Nunn, Colorado) in the shortgrass steppe of the North American Great Plains (2019-2021)

Grazing management strategy	Pastures	Hectares	Beef production (kg/ha)		
			2019	2020	2021
Prescriptive					
1. Long-term (since 1939), season-long heavy stocking	1	130	34.8 (34)	17.3 (34)	28.7 (30)
2. New (since 2019), season-long heavy stocking	3	390	39.3 (108)	26.6 (108)	32.3 (95)
3. Season-long moderate stocking					
Low productivity	4	520	25.6 (92)	22.9 (92)	21.2 (80)
Intermediate productivity	3	390	26.9 (75)	20.3 (75)	23.3 (66)
High productivity	3	390	29.5 (77)	26.3 (77)	26.5 (68)
4. Time-controlled rotation, moderate stocking	10	1300	24.4 (244)	17.7 (244)	n/a
Adaptive					
5. Adaptive multipaddock, moderate stocking	10	1300	24.5 (244)	22.0 (244)	21.0 (214)

Note: Numbers in parenthesis indicate the total number of yearling steers in the respective strategy. In 2020 there was a severe drought during the growing season (40% reduction in precipitation). Grazing season days were 133 in both 2019 and 2021, and 140 days in 2020. Heavy stocking uses stocking densities of 0.23-0.26 steers/ha (0.09-0.11 steers/ac). Moderate stocking uses stocking densities of 0.16-0.19 steers/ha (0.07-0.08 steers/ac). Low productivity pastures have annual herbaceous production <700 kg/ha (625 pounds/ac) and high productivity pastures are >1,125 kg/ha (1,000 pounds/ac), with intermediate productivity pastures between these two values.

Qualitative assessment of ecosystem services

Broad-scale ecosystem services are difficult to assess quantitatively. Because of this, we incorporated qualitative assessments of multiple ecosystem services for the grazing management strategies. These assessments were informed by quantitative data collected on beef production (kg/ha, Table 1), and reduction of drought risk was informed by the number of pastures that received rest during the growing season for rotational grazing[18] or remaining vegetation residue at the end of the grazing season for season-long grazing.[6,19]

Shortgrass and mixed-grass grassland bird breeding habitat was qualitatively assessed using vegetation structure data obtained at the end of the current grazing season.[17] This quantitative data was used to determine qualitative categories of low, moderate, or high for the five different grazing management strategies (Table 2). This structure carries over to the following spring breeding season when nest site selection occurs.

Table 2
Qualitative categories assigned for ranch-scale ecosystem service outcomes from five different grazing management strategies at the Central Plains Experimental Range (Nunn, Colorado) in shortgrass steppe of the North American Great Plains

Grazing management strategy	Ranch-scale ecosystem service outcomes						
	Beef production		Reduction of drought	Shortgrass bird habitat		Mixed-grass bird habitat	
	Normal	Drought	Risk	Normal	Drought	Normal	Drought
Prescriptive							
1. Long-term, season-long heavy	High	Low	Low	High	High	None	None
2. New, season-long heavy	High	Low	Low	High	High	None	None
3. Season-long moderate							
Low productivity	Moderate	Moderate	Moderate	Moderate	Moderate	Low	None
Intermediate productivity	Moderate	Moderate	Moderate	None	Low	Moderate	Low
High productivity	Moderate	Moderate	Moderate	None	None	Moderate	Low
4. Time-controlled rotation, moderate	Low	Low	Moderate	Moderate	Moderate	High	Moderate
Adaptive							
5. Adaptive multipaddock, moderate	Low	Moderate	High	Moderate	Moderate	High	Moderate

Note: Desired utilization target levels from grazing management strategies 1 and 2 would be 60%, with 45% desired for grazing management strategy number 3, and utilization level targets would range from 0 to 60% for grazing management strategies 4 and 5. Grazing season days are typically near 135 days each year. Heavy stocking uses stocking densities of 0.23-0.26 steers/ha (0.09-0.11 steers/ac). Moderate stocking uses stocking densities of 0.16-0.19 steers/ha (0.07-0.08 steers/ac). Low productivity pastures have annual herbaceous production <700 kg/ha (625 pounds/ac) and high productivity pastures are >1,125 kg/ha (1,000 pounds/ac), with intermediate productivity pastures between these two values.

Results and Discussion

Beef production outcomes

The highest beef production values were observed for the new, season-long heavy pastures in all years (Table 1). Beef production declined in the 2020 drought year across grazing management strategies, with the most precipitous decrease (40%-50%) observed in the long-term, season-long heavy pasture. Drought reduced beef production by about half (18%-32% reduction) as much in the new, season-long heavy pastures as in the long-term, season-long heavy stocking strategy. With season-long grazing under moderate stocking in normal years, beef production generally increased as forage productivity of the pasture increased. Beef production values were generally lowest across years for treatments using high stocking densities, including the time-controlled rotational grazing and AMP grazing strategies.

Qualitative assessments of evidence-based potential for beef production are high for season-long grazing at heavy stocking rates, both long-term and new, under normal precipitation, but this switches to low when drought conditions occur (Table 2). Season-long moderate grazing across the low-high productivity gradient in pastures was given a moderate assessment in both normal and drought years. Similarly, time-controlled rotation was assessed as low regardless of the precipitation. AMP grazing was assessed as low under normal conditions, but moderate under drought. This outcome was due to the ability to graze pastures rested the prior year (i.e., grassbanked) or pastures planned for resting in the current year when forage is limited because of low precipitation. Added flexibility with the AMP grazing enabled forage to be grazed that was planned for nonuse (resting).

Reduction of drought risk outcomes

Low reduction of drought risk occurs with heavy stocking rates regardless of precipitation (Table 2). Because the utilization of available forage is high under heavy stocking (~60%), this results in low amounts of remaining vegetation residue at the end of current grazing season to carry over into the next.[6,19] Season-long grazing at a moderate stocking rate was qualitatively assessed at a moderate level because the conservative stocking results in about 45% utilization.[20] A qualitative high reduction of drought risk can be attained through the AMP grazing strategy via either planned resting of pastures or regrowth in pastures after removal of grazing animals in the current grazing season.

Breeding grassland bird habitat outcomes

The effects of grazing management strategies on breeding habitat for two grassland birds of conservation concern, the thick-billed longspur and the grasshopper sparrow, were recently evaluated at this study site.[17] In general, AMP grazing was able to maintain or enhance tall-structure habitats where grasshopper sparrows nested but could not enhance short-statured habitats (Fig. 1). Thick-billed longspur preferentially nest in short-statured grassland dominated by blue grama that has been grazed, where midgrasses and shrubs are absent or rare.[21,22] Such habitat occurred with longer-term (decadal scale) heavy grazing in this rangeland ecosystem.[23] Both the prescriptive time-controlled rotation and the AMP grazing strategies can achieve this habitat at the moderate assessment level (Table 2) in some of the pastures each year if the grazing sequence matches summer grazing periods on the blue grama dominated pastures. Regrowth of vegetation when cattle were not in pastures managed for thick-billed longspur habitat, however, reduced habitat quality. Season-long grazing, particularly in low-productivity pastures and during dry years, can effectively maintain the shortgrass lawns in which this species nests. In particular, the highest densities of thick-billed longspur occurred where season-long grazing was implemented each year with heavy stocking rates on low productivity soils (Table 2).[24]

For mixed-grass habitat, both the prescriptive time-controlled rotation and AMP grazing management strategies provided, in normal years, tall-structure vegetation that increased breeding-season densities of grasshopper sparrow via planned resting of pastures or regrowth capacity after the grazing period (Table 2).[17] In contrast, season-long moderate grazing on productive soils only generated a moderate level of breeding habitat, as taller structure vegetation occurred in only some parts of these pastures because of selective grazing. Heavy stocking rates generally reduced vegetation structure to a level that eliminated grasshopper sparrow habitat (Table 2). Under drought conditions, assessment values declined across the grazing management strategies (Table 2) because of less potential to produce taller vegetation structure and grazing of pastures planned for rest.

Outcome assessment synthesis

Qualitative assessments of potential for each ranch-scale ecosystem service revealed two major findings for these five grazing management strategies. First, all the evaluated grazing management strategies exhibited considerable variability in the assessment categories across the ecosystem services (Table 2). For example, long-term, season-long, heavy grazing was assessed as high for the creation of shortgrass habitat for grassland birds that require short-statured vegetation in normal and drought years. Beef production in normal years was high as well, but low assessments occurred for beef production in drought years, mixed-grass habitat in all years, and the reduction of drought risk. For managers wanting to prioritize a single ecosystem service this demonstrates that one grazing management strategy will have tradeoffs with other ecosystem services. Second, none of the grazing management strategies ranked high for all the ranch-scale ecosystem services. Thus, there is no "best" grazing management strategy to be employed across ranching operations in the shortgrass steppe to optimize all ecosystem services at the ranch scale. In contrast, our evidence-based evaluation of prescriptive and adaptive grazing management strategies indicated managers

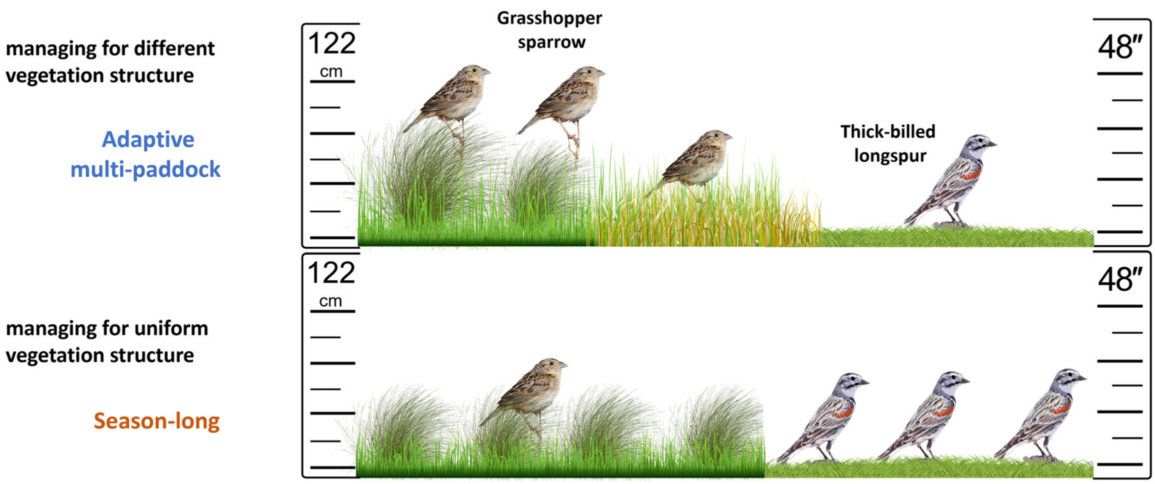

Figure 1. Expected outcomes for breeding grassland bird habitat are depicted with contrasting responses of thick-billed longspur (*Rhynchophanes mccownii*) and grasshopper sparrow (*Ammodramus savannarum*) to vegetation structure on shortgrass steppe. Adaptive multipaddock (AMP) grazing at moderate stocking rates, using stocking densities of 0.16-0.19 steers/ha (0.07-0.08 steers/ac) for a 135-day grazing season, is depicted in the top panel. Season-long grazing (TRM) at moderate stocking rates, using stocking densities of 0.16-0.19 steers/ha (0.07-0.08 steers/ac) in high productivity pastures (annual herbaceous production >1,125 kg/ha [1,000 pounds/ac]) is depicted in the left bottom panel. TRM with heavy stocking rates, using stocking densities of 0.23-0.26 steers/ha (0.09-0.11 steers/ac) in low productivity pastures (annual herbaceous production <700 kg/ha [625 pounds/ac]) is depicted in the right bottom panel. More individual birds depicted in each pasture denote better vegetation structure and greater usage for that bird species compared with pastures that have less individuals based on findings from Davis et al.[17] Bird images are modified from photographs taken by David A. Leatherman, and are not to scale.

could use a blended approach to grazing management to sustain multiple ecosystem services in shortgrass steppe.

A blended approach to grazing management in the shortgrass steppe could result in sustained livestock production, reduced drought risk, and availability of shortgrass and mixed-grass habitat for breeding grassland bird species of concern (Fig. 1), in both normal and drought years. Managers can select grazing management strategies (Table 2), and associated resulting utilization results that are qualitatively assessed as high for the individual ranch-scale ecosystem service outcomes with a subsequent examination of their potential for combined implementation at the ranch scale. Together with shifts in cattle numbers among those strategies in response to varying precipitation levels, it appears possible to balance provisioning of multiple ecosystem services at the ranch scale as opposed to maximizing the provision of any single ecosystem good or service across the ranch (Fig. 2). This pragmatic framework could be integrated into conservation planning and inventory efforts with USDA Natural Resources Conservation Service field staff, extension professionals, consultants, etc. This would incorporate place-based context and local knowledge to better inform management decisions and monitoring efforts, along with identifying operational constraints.

In our example, for normal precipitation years, a hypothetical manager could blend season-long heavy stocking (high for beef production and shortgrass habitat) in some pastures with AMP grazing at moderate stocking (high for reduction of drought risk and mixed-grass habitat) in other pastures (Fig. 2, left panel). This blended approach to grazing management would provide opportunities to fully balance ranch-scale ecosystem service outcomes, with some pastures achieving the high level for each objective. Using adaptive management in some pastures could also assist in overcoming the challenges of matching the spatial heterogeneity of soils and associated plant community characteristics with temporal variability in precipitation.

Across decades of implementing this blended approach to grazing management for balancing multiple ecosystem services, the pastures used for season-long heavy grazing could be rotated to mitigate longer-term changes in plant community composition.[25] Temporary fencing, electric and/or virtual, could be used to increase stocking density for achieving high utilization of shortgrass habitat. AMP grazing could integrate experiential knowledge of the ranch to generate greater spatial heterogeneity in vegetation for diverse grassland bird habitats. For example, timing of grazing in pastures could be sequenced to provide shortgrass habitat for thick-billed longspur over the long term in low productivity pastures, while providing rest for other pastures to enhance mixed-grass habitat for grasshopper sparrow[17] as well as benefits of grassbanking forage for reducing drought risk the following year. It is possible that some ecological site inclusions within a pasture may provide appropriate grassland bird habitat, but these inclusions would need to be of proper spatial scales for the specific grassland bird species.

A manager using a blended strategy may have enhanced flexibility in drought years to reduce stocking in the season-long pastures from heavy in normal years to moderate or possibly lower density to sustain livestock production at the ranch scale. These animals could be shifted to the AMP grazing herd because of available grassbanked forage from prior rest in those pastures (Fig. 2, right panel). Because of drought conditions, shortgrass habitat for thick-billed longspur would be widely abundant on the ranch, but the flexibility afforded

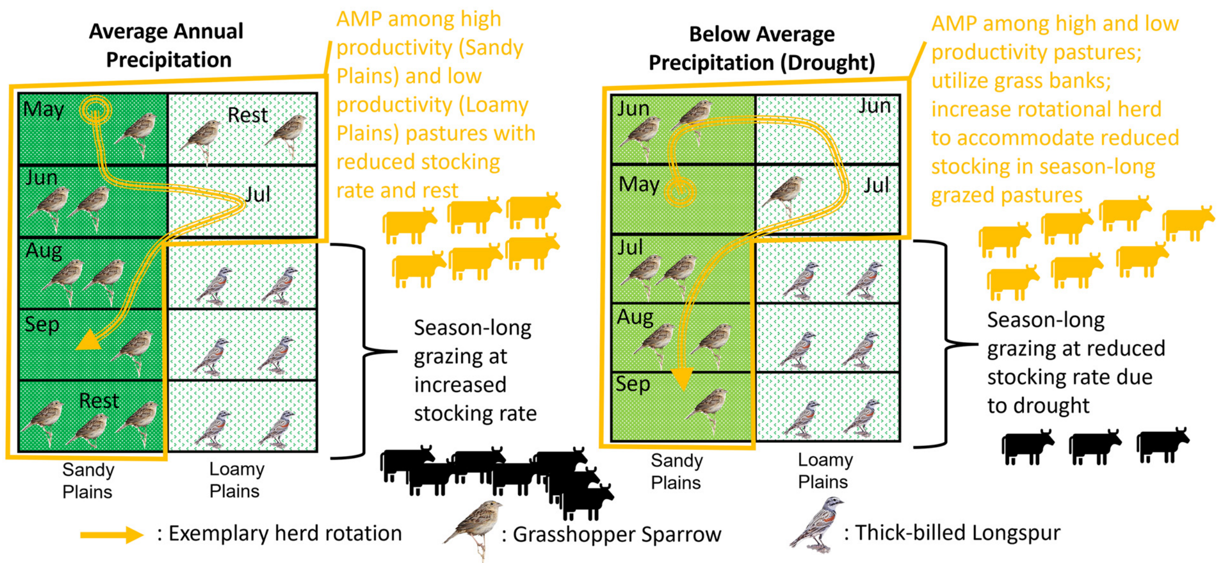

Figure 2. "Mix-and-match" or blended approach for beef cattle grazing management in shortgrass steppe with high productivity pastures, dominated by the Sandy Plains ecological site with annual herbaceous production >1,125 kg/ha (1,000 pounds/ac), and low productivity pastures, dominated by the Loamy Plains ecological site with annual herbaceous production <700 kg/ha (625 pounds/ac), to balance ecosystem service outcomes at the ranch scale. With an average annual precipitation year, herd rotation (yellow arrow) during the grazing season starts in the upper left of the diagram and proceeds through five pastures using adaptive multipaddock (AMP) grazing, with two pastures rested. With a below average precipitation (drought) year, a similar herd rotation would occur but planned rested pastures would be grazed to offset the reduced stocking rate with the season-long grazing pastures. More individual birds for each species depicted in each pasture denotes better vegetation structure and greater usage for that bird species compared with pastures with less individuals based on findings from Davis et al.[17] Solid green (high productivity of annual herbaceous production >1,125 kg/ha [1,000 pounds/ac]) or hatched white (low productivity of annual herbaceous production <700 kg/ha [625 pounds/ac]) backgrounds in pastures represent the contrasting pasture productivity. Bird images are modified from photographs taken by David A. Leatherman, and are not to scale.

by the pasture sequencing (including when grazed, length of grazing period, etc.) in AMP grazing could still provide moderate mixed-grass habitat for grasshopper sparrow, while mitigating effects of the drought on beef production. Depending on the severity and duration of the drought, resting a pasture(s) with AMP grazing may not be possible.

A blended approach adds complexity to multifaceted livestock production systems. However, we contend a mixed prescriptive-adaptive grazing approach is likely already in use by many managers across rangeland ecosystems. For example, >50% of ranchers surveyed in California and Wyoming reported splitting their livestock into two or more groups during the grazing season,[26] with the splitting most likely to occur during the breeding season for cattle. This common practice could separate cow-calf pairs from yearlings (e.g., replacement heifers, steers) or age groups of cow-calf pairs and would provide opportunities to implement a blended approach to grazing management for balancing multiple ecosystem services. Additionally, experiential knowledge of local and pasture scale conditions may inform managers that grazing the same way every year sometimes is the most appropriate strategy for a particular pasture or sets of pastures.

Conclusions

Maintaining livestock production while simultaneously reducing drought risk and providing habitat for multiple grassland bird species of concern at the ranch-scale in the shortgrass steppe is possible. How this is accomplished by managers will not depend on identifying the single "best" grazing management strategy. Rather, incorporating flexibility through a blended approach of "mix-and-match" grazing management strategies provides opportunities to achieve balanced ecosystem service outcomes at the ranch-scale, both in normal and drought years.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors certify that they have no financial interest in the subject matter discussed in the manuscript.

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