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Special Section: The USDA LTAR Common Experiment—Research to Support a Sustainable and Resilient Agriculture

The LTAR Grazing Land Common Experiment at the Central Plains Experimental Range: Collaborative adaptive rangeland management

David J. Augustine[1] | **Justin D. Derner[2]** | **Lauren M. Porensky[1]** | **David L. Hoover[1]** | **John P. Ritten[3]** | **Sean P. Kearney[1]** | **Liwang Ma[1]** | **Dannele Peck[4]** | **Hailey Wilmer[5]** | **the CARM Stakeholder Group**

[1]USDA-ARS, Rangeland Resources and Systems Research Unit, Fort Collins, Colorado, USA

[2]USDA-ARS, Rangeland Resources and Systems Research Unit, Cheyenne, Wyoming, USA

[3]AgNext, Colorado State University, Fort Collins, Colorado, USA

[4]USDA-ARS, Northern Plains Climate Hub, Fort Collins, Colorado, USA

[5]USDA-ARS, Range Sheep Production Efficiency Research Unit, Dubois, Idaho, USA

Correspondence
David J. Augustine, USDA-ARS, Rangeland Resources and Systems Research Unit, 2150 Centre Ave, Fort Collins, CO 80526, USA.
Email: David.Augustine@usda.gov

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Collaborative Adaptive Rangeland Management Stakeholder group composed of representatives from the Crow Valley Livestock Cooperative, Inc. (Steve Anderson, Dana Bowman, Andy Lawrence, Jeff Wahlert), USDA-NRCS (Rachel Meade), USDA-Forest Service (Stephanie Magnuson, Kim Obele), Colorado State Land Board (Matt Pollart, Rachel Turner), Colorado State Extension (Annie Overlin), Environmental Defense Fund (Ted Toombs), Bird Conservancy of the Rockies (Angela Dwyer, Seth Gallagher), and The Nature Conservancy (Terri Schultz).

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Abstract

Semiarid rangelands throughout the western Great Plains support livestock production and many other ecosystem services. The degree to which adaptive multi-paddock (AMP) grazing management approaches can help achieve desired ecosystem services remains unclear. At the Central Plains Experimental Range in northeastern Colorado, a management-science partnership with a diverse stakeholder group is comparing collaborative adaptive rangeland management (CARM), designed to incorporate AMP principles, to traditional rangeland management (TRM), consisting of season-long grazing during the growing season. Each treatment was implemented on a set of 10, 130-ha pastures paired by soils, topography, and plant communities to evaluate how CARM affects vegetation (composition and production), livestock production (steer weight gain), and wildlife habitat (vegetation structure for grassland birds). For the first 5 years of the experiment, CARM cattle were managed as a single herd using AMP grazing with planned year-long rest in 20% of the pastures. Relative to TRM, CARM enhanced heterogeneity in vegetation structure across the landscape, benefiting two grassland bird species. However, this came at the cost of 12%–16% lower steer weight gains in CARM versus TRM and declining populations of a third bird species of conservation concern in both treatments. Here we discuss how increased

Abbreviations: AMP, adaptive multi-paddock grazing; CAM, collaborative adaptive management; CARM, collaborative adaptive rangeland management; CPER, Central Plains Experimental Range; TRM, traditional rangeland management.

understanding of ecological and social processes during the experiment's first 5 years led to changes in the CARM treatment and management objectives during the next 5 years. We also discuss how innovations in remote sensing, environmental sensors, ecosystem modeling, social learning, and economic analyses are being integrated into and supported by the CARM experiment.

Plain Language Summary

The Long-term Agroecosystem Research Network consists of 18 sites distributed across the United States where scientists are conducting long-term research on how prevailing and alternative agricultural management practices affect multiple ecosystem services. Here, we describe the primary experiment being conducted at the Central Plains Experimental Range in northeastern Colorado. This ranch-scale experiment is comparing continuous, season-long grazing management, which is a prevailing practice in the region (i.e., traditional rangeland management [TRM]), with an alternative grazing management approach that was developed by a diverse stakeholder group in collaboration with USDA-ARS scientists (collaborative adaptive rangeland management [CARM]).

1 | REGIONAL CONTEXT

In the Great Plains of North America, widespread conversion of native grassland to dryland cropping systems was initiated by the Homestead Acts beginning in 1862. Over the next 150 years, new technologies like central pivot irrigation as well as varying economic forces and national policies continued to drive grassland conversion to cropland (Wright & Wimberly, 2013). However, semiarid ecoregions of the western Great Plains were less conducive to cropland agriculture than the eastern Great Plains due to the limited and unpredictable rainfall. The "Western Great Plains Range and Irrigated Region" is the highest elevation and driest region of the Great Plains and is subdivided into 18 Major Land Resource Areas (MLRAs) characterized by temperature regimes and soils (United States Department of Agriculture, Natural Resources Conservation Service, 2022). The Central Plains Experimental Range (CPER) in northeastern Colorado is located near the center of the broad latitudinal gradient encompassed by the Western Great Plains Range and Irrigated Region, and is within the southern portion of the Central High Plains MLRA (67B; Figure 1). The northern portion of the Central High Plains MLRA (67A) and the Upper Arkansas Valley Rolling Plains MLRA (69) are located north and south of 67B, respectively, and share many similarities in terms of soils, climate, and dominant vegetation (Bean et al., 2021). CPER and the broader region (MLRAs 67A, 67B, and 69, encompassing 10,599,700 ha) are dominated by C_4 perennial grasses (*Bouteloua gracilis* and *Bouteloua dactyloides*) with subdominant C_3 perennial graminoids (*Pascopyrum smithii*, *Hesperostipa comata*, and *Carex* spp). Approximately 35% of this region is in cropland, while almost 60% of the region consists of rangelands managed for livestock production (Augustine et al., 2021). CPER (6,270 ha; USDA Agricultural Research Service) and the adjacent Pawnee National Grassland (78,130 ha; USDA Forest Service) were created from lands settled by homesteaders, which were purchased back by the US government following the Dust Bowl. CPER was established in 1937 to conduct research on sustainable management of the shortgrass rangelands for beef cattle production.

Annual precipitation at CPER during 1940–2021 averaged 340 mm. Across the three MLRAs, mean annual precipitation varies from 280 to 520 mm (United States Department of Agriculture, Natural Resources Conservation Service, 2022). Soils are primarily Aridisols and Entisols formed in a mosaic of alluvium and eolian sediments. The most widespread ecological sites both within CPER and the broader region are loamy plains (dominated by C_4 shortgrasses, USDA-NRCS, 2007a) and sandy plains (co-dominated by C_4 and C_3 perennial graminoids; USDA-NRCS, 2007b). Less extensive areas with unique plant communities at CPER include Salt Flat, Overflow, and Sandy Bottomland ecological sites. Livestock production is primarily in the form of cow-calf operations and grazing of yearlings. Cattle raised at CPER are yearling steers (*Bos taurus*) provided by Crow Valley Livestock Cooperative, Inc., which graze on station from mid-May to October, at which point they are transferred to regional feedlots for finishing on grain diets.

2 | THE COMMON EXPERIMENT AT CPER

2.1 | Motivating factors

Rangeland-based livestock production systems face uncertain and dynamic climatic, ecological, and social drivers of change. Especially challenging is the highly variable and unpredictable rainfall, which induces substantial forage fluctuations. Many producers in the region receive technical assistance from the USDA-Natural Resources Conservation Service (NRCS), which aids in developing prescribed grazing plans. These plans address drought preparedness and whether and how to move livestock spatially and temporally to sustain the plant community. For over a century, rangeland scientists have evaluated various rotational grazing management approaches, which involve movement of livestock through multiple paddocks during the growing season (Briske et al., 2008; Derner & Hart, 2007). However, these studies did not address manager decision-making and learning processes central to adaptive management (Wilmer et al., 2018) and were rarely conducted at spatial scales broad enough to encompass the environmental heterogeneity characteristic of most ranching operations (Teague & Barnes, 2017). As a result, innovative research and monitoring approaches are needed to explore how adaptive decision-making and livestock movements at relevant spatial scales can be used to achieve multiple desired outcomes (Briske et al., 2011; Teague & Barnes, 2017; Wilmer et al., 2018). Our work applies collaborative adaptive management (CAM), which embeds collaboration among stakeholders into adaptive decision-making about grazing management (Fernandez-Gimenez et al., 2019; Wilmer et al., 2018). Implementing CAM along with traditional management within an experimental framework is also critical for disentangling the effects of management from other factors affecting long-term outcomes.

Another key question is how livestock grazing management affects, and can potentially enhance, conservation efforts for diverse wildlife species that exist on shortgrass rangelands. During the 1990s, several species were proposed for listing under the Endangered Species Act (ESA), including the black-tailed prairie dog (*Cynomys ludovicianus*), swift fox (*Vulpes velox*), mountain plover (*Charadrius montanus*), and ferruginous hawk (*Buteo regalis*). While these species were ultimately not listed, concern still exists regarding their declining populations, particularly grassland birds (Brennan & Kuvlevsky, 2005). Currently, bird species inhabiting CPER and identified in Colorado's State Wildlife Action Plan as "species of greatest conservation need" include the mountain plover, burrowing owl (*Athene cunicularia*), thick-billed longspur (*Rynchophanes mccownii*), grasshopper sparrow (*Ammodramus savannarum*), Brewer's sparrow (*Spizella breweri*), and ferruginous hawk (Colorado Parks and Wildlife, 2015).

Core Ideas

- We compare typical season-long grazing management (traditional rangeland management [TRM]) with collaborative adaptive rangeland management (CARM).
- The CARM treatment was co-produced with a diverse group of stakeholders and employed adaptive rotational grazing.
- Relative to TRM, CARM enhanced vegetation heterogeneity and grassland bird habitat, but cut steer weights 12%–16%.
- Reduced weight gain in CARM arose from altered foraging behavior that reduced diet quality at high stock density.
- In response, stakeholders now employ two rotational herds in the CARM treatment to reduce stock density by 50%.

2.2 | Experimental design

Beginning in 2012, scientists and collaborators at CPER invited 11 stakeholders representing ranchers, public land managers, and nongovernmental conservation organizations to make management decisions on 1300 ha of the CPER. The four ranchers were all members of the Crow Valley Livestock Cooperative, Inc., which grazes cattle on CPER and Pawnee National Grassland. The group also includes one representative each from USDA-Forest Service, USDA-NRCS, Colorado State Land Board, Colorado State University Extension, Environmental Defense Fund, the Bird Conservancy of the Rockies, and The Nature Conservancy. The 1300 ha allocated to the collaborative adaptive rangeland management (CARM) treatment included 10, 130-ha pastures, each of which was paired to a second 130-ha control pasture. Pasture pairs were designed to be as similar to one another in terms of soils, topography (quantified via digital elevation maps and a derived topographic wetness index), and vegetation composition (Figure 1). One pasture in each pair was randomly assigned to the traditional rangeland management (TRM) treatment, which is a season-long grazing approach widely used in the region (Bement, 1969; Hart & Ashby, 1998), and one was assigned to the CARM treatment. The stakeholder group was given full agency in deciding how to collaboratively and adaptively manage yearling cattle in the CARM pastures over a proposed 10-year period (Figure 1).

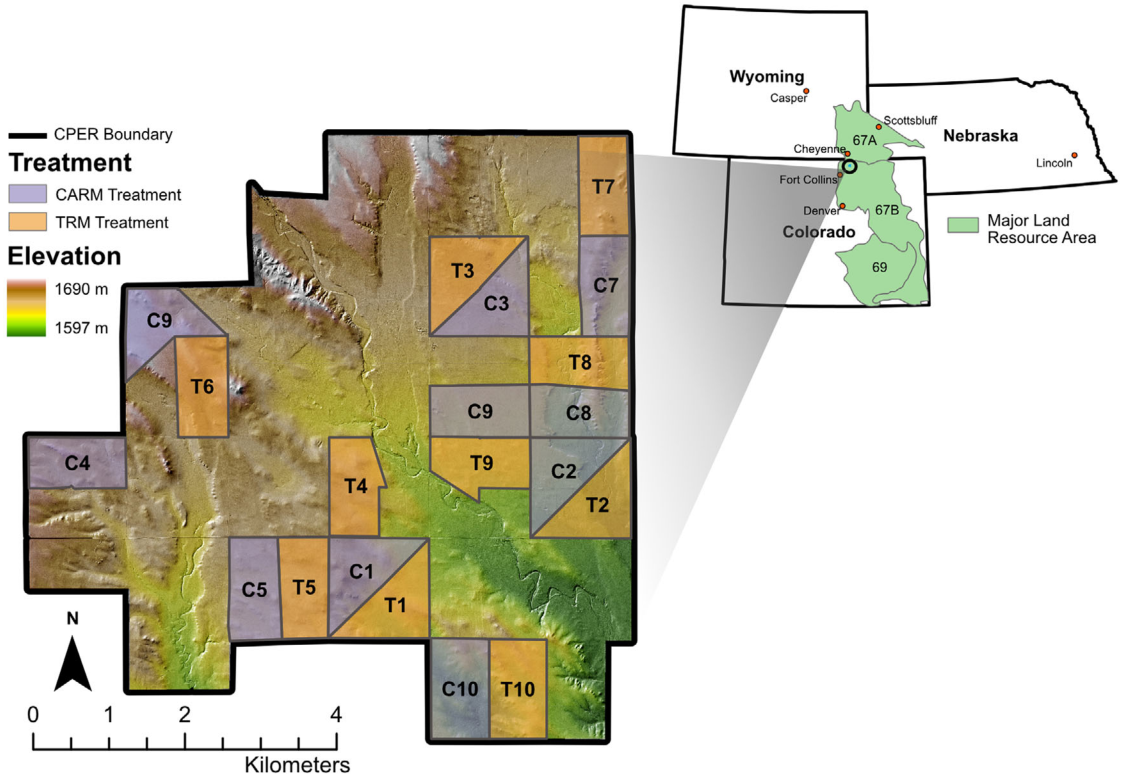

FIGURE 1 Location of the Central Plains Experimental Range (CPER) in Major Land Resource Area 67B, and map of the two grazing management treatments in the common experiment. The experiment contains 10 blocks (indicated by numbers), each of which contains one 130-ha pasture assigned to the collaborative adaptive rangeland management (CARM) treatment, and one 130-ha pasture assigned to traditional rangeland management (TRM) treatment.

Key elements of the study design included (1) sufficiently large pastures for cattle to respond to within-pasture heterogeneity in soils and topography (Gersie et al., 2019), (2) variability among pastures in plant phenology and productivity that could influence grazing decisions (C4-dominated vegetation on loamy plains predominant in pairs within the western half of the study area and C3-dominated vegetation on sandy plains predominant in the eastern half), and (3) 1 year of pre-treatment measurements (livestock weight gain; vegetation composition, structure, and productivity; grassland bird densities) collected in 2013 when all pastures were managed under TRM (Augustine et al., 2020).

The stakeholder group developed a suite of management objectives related to vegetation, profitable ranching, and wildlife (see Wilmer et al., 2018) and decided that CARM pastures would employ single herd of steers managed using adaptive, rotational grazing with planned year-long rest in 20% of the pastures. TRM pastures were grazed continuously by yearling steers at one-tenth the stocking density of the CARM herd. Each year, the stakeholder group met with the scientist team three times to review the prior year(s) monitoring results and discuss inferences that could be drawn (Wilmer et al., 2018). Stakeholders then decided on stocking rate, grazing sequence, pastures targeted for season-long rest, and specific criteria (i.e., triggers) used to rotate cattle in response to pasture conditions during the growing season (see Section 3.4 and D. J. Augustine et al., 2020). The annual stocking rate in the TRM treatment was the same as that decided for CARM each year. For a detailed description of the experimental site and design (soils, climate, stocking rates, and rotation criteria), see Wilmer et al. (2018) and Augustine et al. (2020). Here, we focus on how lessons learned during the first 5 years led to adaptive changes in the CARM treatment design and management objectives.

3 | STAKEHOLDER ENGAGEMENT: ADAPTIVE DECISION-MAKING

3.1 | Initial successes

During the first few treatment years, CARM created notably more among-pasture heterogeneity in vegetation structure (Fernandez-Gimenez et al., 2019), which was desired to generate greater diversity in wildlife habitats across the landscape (Toombs et al., 2010). Subsequent analyses showed that increased vegetation structure in CARM pastures that were rested during the prior year substantially increased the breeding-season density of grasshopper sparrows (a species of conservation concern). Conversely, low vegetation structure in pastures grazed by the large, rotational CARM herd enhanced breeding densities of horned larks (*Eremophila alpestris*; Davis et al., 2020). Given these findings, stakeholders continued to use season-long rest during the second 5 years of CARM to enhance heterogeneity and grasshopper sparrow habitat.

Adaptive application of prescribed patch burns prior to the growing season can potentially enhance livestock diet quality and weight gain (Augustine & Derner, 2014; Fuhlendorf et al., 2009; Limb et al., 2011) and create breeding habitat for mountain plovers (Augustine & Derner, 2012). The stakeholder group was given the option to plan patch burns in CARM pastures in years with sufficient fuel loads. To maintain the integrity of an experimental design where only spatiotemporal patterns of cattle movement differed between CARM and TRM treatments, any patch burns conducted in a CARM pasture were matched with a same-sized burn in the paired TRM pasture. Dormant-season burns (32 ha, or 25% of a pasture) were conducted prior to the growing seasons of 2015, 2017, and 2018, and the CARM herd was rotated onto patch-burned pastures early in the growing season these years. Diet quality monitoring revealed a substantial positive effect of patch burns in the high forage production year of 2015, but weaker effects in near-average production years of 2017 and 2018 (Jorns et al., 2024). Based on prior studies, we expected that the 32-ha patch burns may only support one or two pairs of breeding mountain plovers (Augustine & Derner, 2012). We documented mountain plover presence on burns in 2015 and 2017, and at least one successful mountain plover nesting attempt on a burn in 2017. Based on these findings, the stakeholder group continued considering application of patch burns in the second 5-year period based on dormant-season fuel loads. They added a criterion to implement burns only if soil moisture was above the long-term average in March. The lack of predictability in spring precipitation in this ecosystem continues to be a challenge for both setting stocking rates and using patch burn grazing.

3.2 | Challenges and tradeoffs

Importantly, the benefits of CARM came at the expense of a significant reduction in livestock weight gain relative to steers in the TRM treatment each year. With high precipitation and forage production, the CARM herd was supported for the entire growing season by grazing only seven of 10 pastures in 2014 and four of 10 pastures in 2015, allowing remaining pastures to be rested to achieve the heterogeneity and bird habitat objectives. Weight gains of CARM cattle were 15.6% and 16.2% lower than TRM cattle gains in 2014 and 2015, respectively (Augustine et al., 2020). This outcome was linked to less selective foraging behavior and reduced diet quality of CARM cattle managed as a single large herd at high stock density versus TRM cattle managed in 10 small herds at 10-fold lower stock density (Augustine et al., 2023; Jorns et al., 2024). With these results in hand, the stakeholder group investigated whether adjustments in rotation criteria could alleviate the effect of higher stock density on foraging behavior and weight gains. Specifically, they tested more rapid rotations in wet years (leaving no more than two CARM pastures ungrazed) and more timely rotations among C_3 versus C_4-dominated pastures based on vegetation phenology. Despite initial adjustments in 2016, cattle weight gains were still 13.6% lower in CARM. In 2017 and 2018, additional increases in rotation rates (i.e., shorter time grazing in individual pastures) did not change the outcome; CARM weight gains remained 11.7% and 13.8% lower than TRM (Augustine et al., 2020). In response, scientists initiated another grazing study in nearby similarly sized pastures outside the common experiment, where yearlings were managed at high stock density but non-adaptively rotated (i.e., fixed grazing period length and random sequence). This study showed the adaptive rotation criteria used in CARM did enhance weight gains more than expected based on stock density alone, but gains in CARM were still lower than weight gains that could be achieved in TRM (Derner et al., 2021). Further, decreased weight gains led to discussions about livestock markets, specifically the livestock price slide. Livestock of lower weights typically sell for higher prices per unit of weight (although still lower per head values), which dampened the financial cost of decreased weight gain in CARM (Windh et al., 2020). However, when coupled with increased infrastructure costs (i.e., fencing and water tanks) required for CARM implementation (Windh et al., 2019), the financial repercussions were still significant.

Two other key management objectives for CARM that were not achieved in the first 5 years were to enhance (1) production of C_3 perennial grasses and (2) habitat for thick-billed longspurs, which breed in low-statured, C_4-dominated pastures. During the first two treatment years, whenever a C_4-dominated pasture was rested for an entire growing season, vegetation height increased and breeding densities of thick-billed longspurs decreased significantly in the subsequent year (Davis et al., 2020). Unlike the horned larks, which adjusted their distribution across the landscape in response to prior-year grazing management, thick-billed longspurs showed strong philopatry to their existing breeding range and did not shift to new pastures in response to changing vegetation height. Rather, thick-billed longspurs continued to select specific upland plains dominated by C_4 shortgrasses every year, albeit at lower densities when vegetation height increased in these areas due to rest from grazing (Davis et al., 2020). The thick-billed longspur habitat objective was clearly spatially incompatible with management to enhance C_3 grass production, which covaried positively with grass height. In response to these findings, the team decided in 2017 to graze the three CARM pastures with the highest density of breeding thick-billed longspurs (all on the loamy plains ecological site) every year to maintain short-structured vegetation and C_4 grass dominance. Full growing-season rest would still be applied periodically to the remaining seven CARM pastures, with the objective to increase height and production of mid-height C_3 perennial grasses.

During these initial years, the stakeholder team grappled with why changes in rotation timing and sequence did not generate the hypothesized improvements in animal weight gains and cool-season graminoid production. To address stakeholder hypotheses, the research team tracked tiller defoliation rates for the dominant C_3 perennial grass, western wheatgrass, during years three and four. Averaged across all 10 pastures, the proportions of tillers defoliated once and more than once in a growing season were nearly identical in both treatments (Porensky et al., 2021). In other words, at the tiller scale, rest was already "built in" to the TRM system via the moderate stocking rate. This study, initiated by the stakeholder group, provided a clear mechanism to explain why CARM did not enhance C_3 perennial grass production (Augustine et al., 2020). However, the team also recognized that livestock grazing effects on vegetation often take more than 5 years to manifest in this ecosystem (e.g., Porensky et al., 2017; Wilmer et al., 2021). Additionally, the switch to annual grazing of the three pastures targeted for thick-billed longspurs had only been implemented in the third year of the study, and more time was needed to evaluate the outcome.

3.3 | Social learning

Discussions among the CARM team in the early years highlighted the role of collective learning from experimental results in making future adjustments to livestock management. Social learning objectives included (1) co-production of new knowledge by the stakeholder group and researchers, (2) increasing respect, understanding, and trust within the team, and (3) applying new knowledge from CARM outside the experiment (Wilmer et al., 2022). The elevation of social learning as an explicit objective influenced decisions regarding changes to grazing management in subsequent years (discussed below) and decisions to revise management objectives to be more context-specific and measurable. In the fourth year of treatments, the CARM team began revising original management objectives to spatially resolve management for both short-statured habitat (for thick-billed longspurs) and taller-structured plant communities (for increased production of mid-height C_3 grasses; Wilmer et al., 2019). Evidence of shared learning also included stakeholders and researchers acknowledging and examining one another's worldviews (Fernandez-Gimenez et al., 2019), and continued stakeholder participation during the COVID-19 pandemic via digital/remote meetings. After 2019, we also observed an increase in sister projects implementing lessons from CARM, including a CAM project led by University of Nebraska researchers at Barta Brothers Ranch.

3.4 | Adapting toward a new approach

Deciding how and when to adjust management regimes is a major challenge in agriculture broadly, and especially in rangeland systems where management interacts with variable weather to affect outcomes at multiple spatial and temporal scales. Within the first five treatment years, the CARM team annually adjusted the stocking rate (varying from 214 to 280 steers per treatment), varied the rotation sequence to rest different pastures over time, and increased rotation rates in non-drought years with the aim to enhance cattle diet quality and weight gain. Regardless of the rotation criteria, CARM weight gains were 12%–16% lower than TRM in all 5 years. Furthermore, longspur density declined with time in both the CARM and TRM treatments, and C_3 perennial grass production remained similar in both treatments (Augustine et al., 2020). These shortcomings became a catalyst for learning as the CARM team questioned whether to fundamentally change the rotational approach. However, any fundamental change to CARM management had to be balanced against the desire to learn more about how the current system would perform under a range of conditions, including drought, which did not occur in the first 5 years (Fernandez-Gimenez et al., 2019).

To balance the desire to learn with the desire to adapt, the CARM team decided on a hybrid approach for the subsequent 5 years of the experiment. They continued the single herd rotation in year 6 (encompassing additional weather variability), and then split the CARM cattle into two herds (each planned to graze four CARM pastures) to reduce the stock density by half for the next 4 years. This split addressed what prior analyses identified as the most likely factor reducing cattle weight gain (i.e., high stock density). Maintaining the rotational strategy continued to allow for rest in one or two of the CARM pastures in non-drought years, and still provided flexibility for adapting the rotation sequence to variation among pastures in plant composition and phenology.

Following the experiment's first major drought in 2020, the CARM team revised the grazing management plan to more explicitly address drought using a network of precipitation and soil moisture gauges to monitor the amount of cumulative precipitation received to date relative to the long-term mean. In the revised plan, forage biomass thresholds that triggered cattle rotation would be reduced if precipitation was <88.5% of the long-term mean, and then reduced even further if precipitation was <75% of the long-term mean. If precipitation was below average and CARM cattle had grazed all pastures before the end of the grazing season, the stakeholders and scientists would meet to review current pasture conditions and decide if any CARM pastures would be re-grazed or transferred to feedlot earlier than originally planned.

Analyses of results from the last 4 years of the experiment (2020–2023) are currently testing for longer term CARM effects, particularly how the two-herd rotation affects vegetation, bird habitat, and livestock production. During these years, CARM also experienced highly variable weather, including two drought years, which is allowing the team to evaluate outcomes in relation to extreme weather variability.

4 | FUTURE DIRECTIONS

Ranching operations often cover extensive landscapes where forage conditions are difficult to monitor frequently. Satellite-derived rangeland monitoring products are increasingly available to assess drought severity (e.g., US Drought Monitor, https://droughtmonitor.unl.edu; VegDRI, https://vegdri.und.edu) and past forage production (Rangeland Analysis Platform https://rangelands.app). However, managers often want to know the current standing forage biomass and quality. We used ground data collected in the CARM experiment to calibrate a new model that predicts daily standing herbaceous biomass at a 30-m pixel resolution from harmonized Landsat 8 and Sentinel-2 satellite imagery (Kearney, Porensky, Augustine, Gaffney, et al., 2022). We integrated this and other models into an interactive map that allows the CARM team to display historical and current (within 4–7 days) satellite-predicted forage conditions, providing near-real-time decision support for cattle movements. Satellite time series were also used to estimate forage quality (Irisarri et al., 2022), which in combination with biomass can provide reliable estimates of yearling cattle growth rates (Kearney, Porensky, Augustine, Derner, et al., 2022). The Agricultural Policy/Environmental eXtender model, which incorporates spatially explicit simulations of vegetation and livestock growth, is also being calibrated and employed in concert with the CARM experiment (Cheng et al., 2021, 2022), with ongoing calibration to cover a broader range of weather and management. Our goal is to use the model as a decision tool to evaluate alternate management scenarios, retrospectively evaluate past decisions made in CARM, and evaluate how climate change could affect forage and livestock.

Finally, reduced cattle weight gain in CARM raised questions about the temporal pattern of cattle weight gain over the growing season, spurring economic analyses of cattle management strategies. These analyses illustrated that transferring yearlings to feedlots in early September, rather than October, can significantly increase revenue (Baldwin et al., 2022). Moving ahead, the team is working to further understand and mitigate tradeoffs among objectives in western Great Plains rangelands by integrating technological advances with new site-based learnings about reduced stock density, drought, and economics.

AUTHOR CONTRIBUTIONS

David J. Augustine: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; writing—original draft; writing—review and editing. **Justin D. Derner**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; supervision; writing—review and editing. **Lauren M. Porensky**: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; writing—review and editing. **David L. Hoover**: Data curation; formal analysis; funding acquisition; investigation; project administration; visualization; writing—review and editing. **John P. Ritten**: Formal analysis; investigation; methodology; writing—review and editing. **Sean P. Kearney**: Data curation; formal analysis; investigation; software; visualization. **Liwang Ma**: Formal analysis; software; writing—review and editing **Dannele Peck**: Funding acquisition; project administration; writing—review and editing. **Hailey Wilmer**: Conceptualization; formal analysis; investigation; methodology; project administration; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

David J. Augustine https://orcid.org/0000-0003-3144-0466

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