Adaptive Grazing Management in Semiarid Rangelands: An Outcome-Driven Focus

Authors: Derner, Justin D., Budd, Bob, Grissom, Grady, Kachergis, Emily J., Augustine, David J., et al.

Source: Rangelands, 44(1) : 111-118

Published By: Society for Range Management

URL: https://doi.org/10.1016/j.rala.2021.02.004

Research Article

Adaptive grazing management in semiarid rangelands: An outcome-driven focus

By Justin D. Derner, Bob Budd, Grady Grissom, Emily J. Kachergis, David J. Augustine, Hailey Wilmer, J. Derek Scasta, and John P. Ritten

On the Ground

- Adaptive management should explicitly involve stakeholders, emphasize multiple iterations of identifying and prioritizing outcomes, and tightly link science-informed monitoring to decision-making benchmarks for effective feedback loops.
- Short-term monitoring procedures should be simple, quick, and based on consistent methods that are focused on locations where meaningful change is expected or uncertainty is high.
- Long-term monitoring procedures should emphasize consistent methodology across years that provides broader ecosystem context for multiple ecosystem services (e.g., watershed protection and grassland bird habitat).
- Incorporating timely feedback from monitoring improves the capacity for rapid decision-making when benchmarks are attained and management should be modified.

Keywords: adaptive management, complex systems, ecosystem management, monitoring, rangeland management, social-ecological systems.

Rangelands 44(1):111–118
doi 10.1016/j.rala.2021.02.004

Rangelands are complex systems that present many management challenges[1] because they are frequently managed for multiple objectives. Rangelands provide several different ecosystem goods (e.g., livestock production) and services (e.g., wildlife habitat, plant diversity, and watershed function) that benefit society.[2] Rangelands exhibit substantial variation in topography, soils, plant communities, and annual and seasonal patterns of precipitation. Consequently, land managers often use adaptive management—strategic planning and goal setting, resource monitoring, and frequent evaluation of management success—in spatially explicit efforts to learn from implementing management practices and make adjustments when needed.[3,4] Adaptive management is more transparent and defensible when it includes clear objectives linked to processes, well-defined monitoring thresholds, and objective actions triggered by these monitoring thresholds.[5] The effectiveness of adaptive management and its benefits are largely undocumented for the majority of ecosystem services.[6]

Land managers strive to achieve specific outcomes to direct grazing management decisions. They do this within the context of variable spatiotemporal patterns of historic drivers on landscapes, management capacity including experience, skills, and resource availability, and changing operational constraints of the ranch enterprise.[7] Grazing management decisions often include knowledge of livestock behavior[8] and learning processes of managers; both components have been underutilized in grazing management.[9] Successful grazing management, therefore, depends on diverse knowledge sources to better understand rangeland dynamics, ecological processes and mechanisms, management skills and experience, and awareness of social and policy influences relative to outcomes.

Here, we present a rangeland management strategy emphasizing adaptive management for outcomes. The strategy includes the following five components: 1) identification and prioritization of outcome(s), including setting quantitative metrics if possible, as this is often recognized in the courts as a major failure of adaptive management[4]; 2) understanding rangeland dynamics through recognition of ecological processes influencing attainment of outcome(s); 3) consideration of logistical, labor, institutional, and economic constraints; 4) monitoring relevant metrics to gauge progress toward outcome(s); and 5) modifying management when needed in response to monitoring information to increase the probability of attaining the outcome(s) (Fig. 1). It is important to recognize that adaptive management encompasses a spectrum from less formal to more formal decision-making processes. In addition, interactions and feedback loops occur among the components resulting in a nonlinear process.

We use three case studies from semiarid rangelands in Colorado and Wyoming to illustrate applications of the outcome-driven approach, a spectrum of decision-making processes, and variability in the level of detailed observations and monitoring information among operations. Ultimately, these cases illustrate a range of options for engaging multiple parties with diverse perspectives in a discussion of adaptive management and applications for rangeland management. The first case is a privately owned ranch, Rancho Largo, located in southern Colorado consisting of 5,204 ha (12,860 acres) of deeded private property and 469 ha (1,160 acres) of state lease property in shortgrass steppe.[10] The second is the Red Canyon Ranch, owned by The Nature Conservancy, encompassing 1,983 ha (4,900) acres of deeded lands and 11,938 ha (29,500 acres) of leased land in central Wyoming, and consists of sagebrush grasslands and mountain meadows. These two enterprises provide contrasting examples of land ownership and adaptive management approaches in different rangeland ecosystems. One of the authors (Grady Grissom) is partner/manager for Rancho Largo, and another (Bob Budd) is the previous manager on the Red Canyon Ranch. They provide insights into the operations, management challenges, and outcomes on these respective properties. The third case is the Collaborative Adaptive Rangeland Management (CARM) project, which encompasses 2,590 ha (6,400 acres) of the USDA-Agricultural Research Service's Central Plains Experimental Range.[11,12] This federally owned property in northeastern Colorado is at the northern end of shortgrass steppe. The CARM project involves participatory decision-making by an 11-member Stakeholder Group comprised of ranchers, state/federal government agency personnel, and representatives from nongovernmental conservation organizations.[11,12]

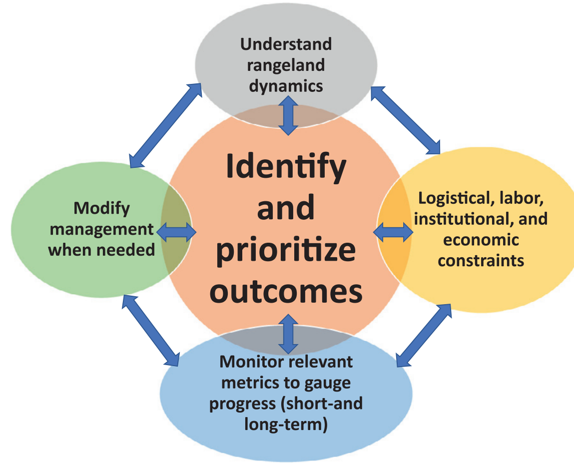

Figure 1. Schematic presentation of an outcome-driven focus to adaptive grazing management in semiarid rangelands. Interactions and feedback loops among components are illustrated with bidirectional arrows.

Component 1: Identify and prioritize outcomes

The key component in adaptive management for an outcome-driven focus is to identify and prioritize outcomes for the operation. Where possible, including quantitative metrics for prioritizing outcomes will enhance success of adaptive management.[4] Rather than a generic outcome of "increasing the abundance of desired cool-season perennial forage grasses," the suggestion is to increase specificity such as "increase by 20% the abundance of desired cool-season perennial forage grasses above the baseline levels" or "increase the abundance of desired cool-season perennial forage grasses to within 10% of the values reported in the desired vegetation state for that ecological site."

For Rancho Largo, prior (pre-2000s) management goals focused primarily on economic outcomes with transitioning to ecological outcomes occurring over a series of years.[10] Observations and monitoring of the percent of cool-season perennial grasses defoliated by cattle beginning in the early 2000s informed the initial development and subsequent revising of ecological outcomes. Rotating cattle among pastures provided grazing deferment of several weeks to months during a portion of the growing season. Using multiyear data on percentage of plants being defoliated, the ranch implemented longer grazing deferments (e.g., whole growing season) to facilitate growth of key forage grasses. Monitoring data helped to identify and prioritize the outcome of increasing abundance of cool-season perennial grasses, such as western wheatgrass (*Pascopyrum smithii*) and needle-and-thread (*Hesperostipa comate*) (Fig. 2). This demonstrates the iterative process that land managers use to identify and prioritize outcomes for their operations.

In contrast to the privately owned ranch, Red Canyon is comprised of mixed land ownership (private, Bureau of Land Management, State of Wyoming, and US Forest Service). A Coordinated Resource Management team prioritized outcomes for improving riparian and wetland habitats, livestock performance, and diverse wildlife habitat (Fig. 3). A 5-year planning horizon, within a 30-year overall plan, guided management toward these outcomes. Annual adjustments were based primarily on environmental conditions (rain, drought, thaw, early snow, etc.) and monitoring data (see Component 4 below). In years of particularly extreme weather, management adjustments occurred more often (monthly, weekly) as needed. By evaluating the need for various management options at these temporal scales, necessary changes involving timing and duration of grazing periods were implemented to address short-term needs without forsaking longer-term outcomes.

Our third case offers yet another form of adaptive management. At inception, the 11-member Stakeholder Group for the CARM project identified three broad outcomes involving vegetation, profitable ranching operation, and wildlife.[11] Within each broad outcome, more specificity was identified for desired changes over time. For vegetation, outcomes included 1) increase the percentage of cool-season grasses and nonshortgrass plants, 2) increase variation in vegetation structure, composition, and diversity within and among pastures, and 3) maintain or increase size of shrubs (e.g., four-wing saltbush, *[Atriplex canescens]*). Outcomes for profitable ranching operation were 1) maintain or increase livestock weight gain, 2) reduce economic impact of drought, and 3) maintain or reduce operating costs. Wildlife outcomes centered on

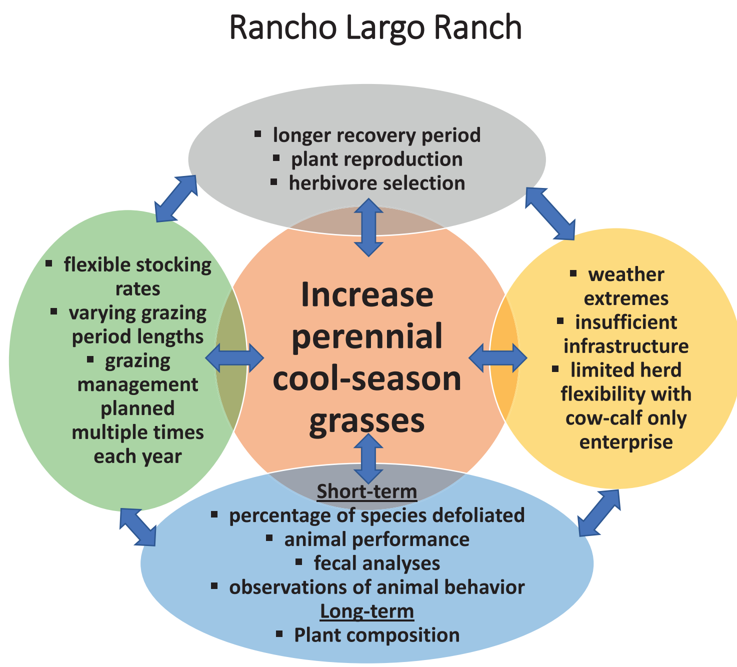

Figure 2. Example of an outcome-driven focus to adaptive grazing management of semiarid rangelands using the Rancho Largo ranch. Interactions and feedback loops among components are illustrated with bidirectional arrows.

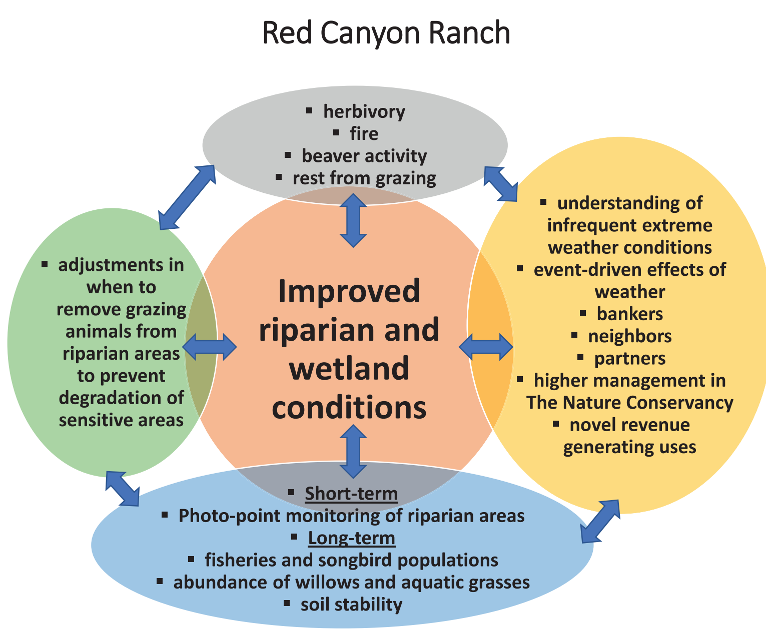

Figure 3. Example of an outcome-driven focus to adaptive grazing management of semiarid rangelands using the Red Canyon Ranch. Interactions and feedback loops among components are illustrated with bidirectional arrows.

key grassland bird species. For example, populations were to be maintained for thick-billed longspur (*Rhynchophanes mccownii*), Western meadowlark (*Sturnella neglacta*), and horned lark (*Eremophila alpestris*). Increased populations of the following grassland birds were also an outcome: 1) grasshopper sparrow (*Ammodramus savannarum*), 2) Cassin's sparrow (*Pucaea cassinii*), 3) Brewer's sparrow (*Spizella breweri*), 4) lark bunting (*Calamospiza melanocarys*), and 5) mountain plover (*Charadrius montanus*). Quantitative metrics of the magnitude of "increase" or "reduce" were not determined by the Stakeholder Group for the first 5 years of this project. One additional outcome involved the control of prairie dog populations (*Cynomys ludovicianus*) to prevent possible confounding effects with the livestock grazing treatments that began in 2014.

Component 2: Understand rangeland dynamics

Achieving ecological outcomes is dependent on rangeland dynamics including causes of current conditions, the range of natural variability, and seasonal and interannual dynamics and responses. Across these three cases, five major ecological processes that affect rangeland dynamics include 1) herbivory, 2) fire, 3) drought (and associated precipitation variability), 4) ecosystem engineers (e.g., beaver [*Castor canadensis*], prairie dogs), and 5) rest from livestock grazing for all or a portion of the year. A variety of resources can identify and analyze these processes, including historic records, photos, interviews, experiential knowledge, existing monitoring data, scientific research, and professional experience and judgment.

A fundamental understanding of the frequency, intensity, and variability of major climatic drivers, including extreme conditions, in addition to "average" or "normal" conditions,[13] is necessary. Event-driven effects of weather occur[14] at multiple temporal scales, and management needs to be adaptive to mitigate negative effects of unfavorable events and accentuate positive effects of favorable events. Monitoring is vital to this component of the process because appropriate metrics (see Component 4 below) can inform assessments of management and weather/climatic influences on attainment of outcomes. The use of adaptive management to enhance attainment of outcomes a priori rather than relying on ex post facto decisions supports more insightful discussions concerning contingencies associated with ecological processes. This may yield additional opportunities to accelerate trajectories toward outcomes.

Component 3: Consider logistical, labor, institutional, and economic constraints

After identifying and prioritizing outcomes (Component 1) and having knowledge of the rangeland dynamics associated with the ecosystem(s) (Component 2), this component entails considerations of the constraint(s) that operations may encounter that could successfully prevent achieving their outcomes, and how to overcome the constraint(s). For example, an operation may have a logistical constraint in managing for multiple outcomes, an availability of labor constraint to modify management when needed (Component 5), an institutional constraint associated with complexity in managing private-public interspersed lands, and/or an economic constraint in being able to have flexibility in animal numbers and types of animals (cow-calf pairs, yearlings, sheep, goats, etc.) to match animal demand with forage availability.

For Rancho Largo in the early 2000s, a constraint to achieving longer rest periods and increasing flexibility of grazing among seasons was insufficient infrastructure[10] (Fig. 2). Increasing the number of pastures available, through additional permanent and temporary fencing, provides greater flexibility for longer recovery periods while maintaining desired grazing periods and changing seasons of plant defoliation among pastures.

The traditional cow-calf operation at Rancho Largo limited herd size flexibility within and among years because breeding stock is generally not liquid. This constrains the ability to manage dynamic relationships among forage quality, forage quantity, livestock demand, and livestock selectivity.[15] In 2003, the size of the base cow herd was reduced by 65% and a yearling enterprise was incorporated to provide the operation more flexibility through more liquid assets. A custom grazing (e.g., agistment) enterprise was incorporated in 2005 for additional flexibility. Enterprise diversification provides options to retain calf ownership following weaning, purchase yearlings, sell cattle, or custom graze cattle to better match forage demand with forage production. Increasing flexibility in the livestock enterprise minimizes financial risk associated with destocking and restocking due to variable precipitation. During drought periods, the base cow herd can be retained, and yearlings or custom grazed cattle can be destocked in an adaptive manner using monitoring data to prevent rangeland degradation. Restocking occurs adaptively with yearlings or custom grazed cattle as environmental conditions become more favorable. Flexible herd management using yearlings or custom grazed cattle maintains a consistent base cow herd size and enables increased economic returns under conditions of climatic variability.[15] However, this strategy does convey additional costs and marketing risks that may deter some ranchers and managers.

For Red Canyon Ranch, constraints originated from diverse goals and values of family members, neighbors, partners, and state and national entities including The Nature Conservancy (Fig. 3). Despite these barriers, the ranch wanted to develop and manage for education, recreation, research, and other programs that rely on rangeland ecosystems but did not traditionally contribute to ranch revenue. These novel revenue sources were then valued by the ranch as if they were commercial enterprises; costs were quantified and represented in the economic analysis of the entire operation. Where possible, the expenses associated with these novel programs were allocated specifically to those activities rather than being absorbed by the entire ranch enterprise. As a result, the ranch enterprise became better aligned to achieve the outcomes identified in the Coordinated Resource Management plan of improved riparian and wetland habitats, livestock performance, and diverse wildlife habitat.

For the CARM project, logistical constraints identified early in the process related to the experimental context. The goal was to compare two grazing strategies in terms of achieving the outcomes related to vegetation, ranching operations, and wildlife—1) traditional, season-long grazing and 2) adaptive, multipaddock grazing where one large herd of yearling steers, at 10-fold the traditional stocking density, would adaptively rotate among 10 pastures. The need for replicated treatments and other study design sideboards created challenges including fencing and water infrastructure. Fences were re-configured to provide more similar "pairs" of pastures for the application of the two grazing strategies. Water tank capacity was upgraded, and solar systems replaced some of the windmills. Social and institutional constraints were also evident from the beginning with the recognition of differences in experiential knowledge, education level, understanding of ranching, and priority of outcomes among the 11-members of the Stakeholder Group.[11,12] A constraint apparent after the first two grazing seasons—assessing economics of livestock gain and quantifying operating costs, as the cattle are provided by private ranchers—was addressed by adding an agricultural economist to the team and supporting graduate students.

Component 4: Monitor relevant metrics to gauge progress toward the outcomes

The key here is the clear definition of the relationship between monitoring data and management decisions,[16] including identification of the adaptive management benchmarks and subsequent actions[5] to achieve the outcome(s). In cases where nontraditional ecosystem services are desired as outcomes, monitoring protocols beyond traditional procedures may be required. Adaptive management benchmarks and related monitoring may be based on short-term responses or long-term responses,[16] depending on the logical link between management action, indicator, and rangeland dynamics. For example, short-term response observations and indicators (e.g., stubble height, utilization[16]) may provide an appropriate benchmark for the subsequent action to adjust livestock movement among pastures within a grazing season. Long-term responses (e.g., plant functional group composition, soil organic matter[16]) are also needed for evaluating if outcomes have been achieved and adjusting management strategies after a year or longer. Identifying benchmarks that are grounded in objective and science-informed monitoring and lead to subsequent actions can greatly increase the accountability for adaptive management.[17] Setting these benchmarks to avoid crossing ecological thresholds requires a fundamental understanding of rangeland dynamics and the influence of weather/climatic variability on them at the operation level[13]; thus, a conservative approach may incorporate a continuum of benchmarks rather than a single one.[17]

Rancho Largo monitors the percentage of each plant species defoliated and the average intensity of defoliation during each grazing period as a short-term response indicator.[10] These monitoring observations inform actions to achieve desired defoliation patterns and livestock performance. These short-term observations work within the overall focus on achieving the outcome of increasing the abundance of cool-season grasses through the long-term response indicator of plant composition (Fig. 2). For example, in years with adequate winter precipitation but dry spring conditions, the only green plants offered to livestock in April and May are the deeper-rooted cool-season grasses in drainage areas (i.e., run on sites or overflows). Under these conditions, short-term observations typically show very intense defoliation of cool-season grasses in these topographical areas and minimal leaf residual remaining on these species for regrowth potential. The use of temporary fence can limit severe defoliation of these cool-season grasses by reducing the grazing period (i.e., duration of grazing). This situation contrasts with years in which enough spring precipitation occurs resulting in defoliation being less intense on cool-season plants in the drainage areas because of greater availability of green plants on uplands.

Additional short-term observations target animal performance and inform cattle movements through 1) periodic weighing of cattle, 2) fecal analyses for seasonal nutritional information, and 3) observations of animal behavior. Animals also respond to numerous cues that cannot be measured on large landscapes in real time, and successful managers respond to these animal cues. For example, visual observation of livestock selecting less desirable plants is an early indicator that livestock nutritional needs are not being fully met. Subsequently, weight gains will be reduced unless higher quality forage is offered by moving animals to a different pasture. Short-term observations and monitoring procedures should be simple, quick, and based on consistent methods that are focused on locations where meaningful change is expected, or uncertainty/risk is high. In contrast, long-term monitoring procedures should emphasize consistent methodology across years that provides broader ecosystem context for multiple ecosystem services (e.g., watershed protection and grassland bird habitat).

For Red Canyon, the short-term response indicator was photo-point monitoring to assess vegetation change in riparian and wetland areas, as an increase in willows (*Salix* spp.) and aquatic grasses were outcomes. Photo points were supplemented by additional data collection that was designed to reflect changes in condition. For instance, measuring expansion of willow communities was relatively easy with photos, while measurement of aquatic grasses required on-the-ground measurement. Photo points and data collection were generally paired both temporally and spatially on sites where change was desired. Relatively inexpensive photo-point monitoring methods were used because they effectively demonstrated the attainment of outcomes. Long-term response indicators included use of photo-point monitoring to improve plant and animal composition and soil stability (Fig. 3). Here, more detailed data was also collected via partnerships and collaborations with other entities (e.g., Wyoming Game and Fish, National Audubon Society, and land grant universities) to verify changes determined visually and photographically. In addition, some of the most instructive data came from partners through the monitoring of target species, particularly songbird and fish population responses.

For CARM, prioritizing extensive monitoring of short-term response indicators requires a large investment in personnel to collect this monitoring data. For example, visual obstruction readings, taken to estimate vegetation biomass, are taken before cattle entry into each pasture and weekly to serve as a key short-term indicator for moving livestock to the next pasture in the grazing sequence (see below), as well as when cattle exit each pasture (Fig. 4). Livestock are individually weighed at the start and end of each season, and

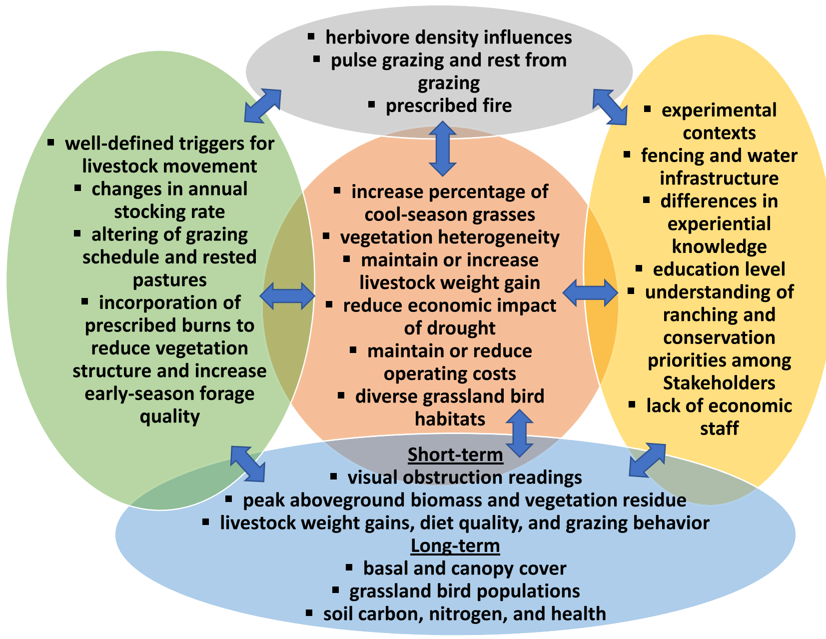

Figure 4. Example of an outcome-driven focus to adaptive grazing management of semiarid rangelands using the Collaborative Adaptive Rangeland Management (CARM) project.[11] Interactions and feedback loops among components are illustrated with bidirectional arrows.

opportunistically throughout the grazing season to determine average daily gains, seasonal gain, and gains per unit land area. Diet quality is monitored weekly with fecal samples collected and analyzed for crude protein and digestible organic matter. Livestock energy use is estimated from pedometers and use patterns of pastures and grazing behavior being assessed with GPS collars. All these measures help the stakeholders better understand how rotation decisions affect the quality of forage consumed, and hence the weight gains by cattle.

Long-term indicators of vegetation change include measurements in June each year of basal and foliar cover using line point intercept methods and plant density of key cool-season forage grasses (Fig. 4). In early August, peak aboveground biomass is harvested by key forage species and plant functional groups. Residual vegetation biomass at the end of the grazing season is estimated by converting visual obstruction readings through a regression equation.

Grassland bird habitat is monitored with visual obstruction readings in June and October. Grassland bird populations are monitored with field point counts of a series of prelocated points, and nests are surveyed for survival of chicks. These serve as long-term indicators of whether wildlife outcomes are being achieved. Long-term monitoring efforts also focus on soil carbon and nitrogen, and soil health. Baseline samples were obtained in the pretreatment year (2013) and have been sequentially re-sampled every 3 years.

Component 5: Modify management when needed

The final component in the outcome-driven approach is to modify management when needed after analyses of monitoring data that indicate whether benchmarks have been attained.[18] The previous components of clear identification and prioritization of outcomes (Component 1), understanding of rangeland dynamics (Component 2), considering constraints and overcoming them (Component 3), and obtaining monitoring information that can be regularly analyzed and evaluated (Component 4) are all important in identifying feedback loops between adaptive management and achieving outcomes when management actions are undertaken. We acknowledge that additional consideration of all four components is likely to occur in a nonlinear manner[12] before moving to making a change in management when needed (this Component).

For Rancho Largo, observations of seasonal herbivore selectivity of plant species, species-specific responses to defoliation, and plant reproduction by desired grasses, shrubs, and forbs are key metrics for adaptive management[10] (Fig. 2). Grazing plans and stocking rates are evaluated two to four times annually based on the amount of precipitation received in previous months, predicted precipitation patterns, and current and anticipated market conditions. At each evaluation, available pastures are determined using records of prior grazing, including species-specific grazing patterns, and the extent of plant recovery and regrowth. The length of a grazing period is adaptively determined by evaluating several indicators, rather than predetermined based on historical patterns.

Photo-point monitoring (see above), due to its rapid availability, low cost, and permanence, provides crucial monitoring information at Red Canyon that informs adaptive management benchmarks and subsequent actions within and between years. For example, the ability to quickly capture current conditions with photos coupled with rapid assessment techniques (e.g., stubble height measurements) and professional judgment is advantageous for the timely removal of grazing animals from riparian and wetland habitats before degradation could occur. This monitoring approach is especially beneficial for adaptive management after extreme events such as heavy spring snow. Using short- and long-term monitoring metrics provides adaptive management capacity for modifying management when needed to prevent degradation to these environmentally sensitive areas and allow them to rapidly respond in a desired manner when environmental conditions are favorable.

For the CARM project, explicit adaptive management within and between grazing seasons is directly attributable to well-defined benchmarks for livestock movement between pastures.[11] These include residual biomass thresholds for ecological sites using visual obstruction readings, maximum days in a grazing period, and cattle behavior. Benchmarks also include changes in annual stocking rate decisions and planned grazing sequences with the Stakeholder Group selection of which pastures to rest, and incorporation of prescribed burns to reduce vegetation structure and enhance early grazing season forage quality. Adaptive management contributes substantially to improving livestock gains.[18]

Conclusions

We present a rangeland management strategy emphasizing adaptive management for outcomes for three livestock operations in the western Great Plains. The outcome-driven approach explicitly involves stakeholders, provides management flexibility for a suite of ecosystem goods and services, and tightly links science-informed monitoring to decision-making benchmarks for effective adaptive management feedback loops. These three cases showcase the importance of ranch planning and adaptation processes in identifying and prioritizing outcomes, understanding rangeland dynamics, considering the diverse array of constraints, determining short- and long-term monitoring indicators, and modifying management when needed as monitoring data indicates that benchmarks have been attained. The varying approaches to achieving outcomes within these three cases also emphasize the importance of management experience and knowledge. The producer-managed Rancho Largo case, which started with a "grazing system" lacking these five adaptive management components, is attaining outcomes as these five components are incrementally adopted.[10] Red Canyon moved directly toward outcomes as assembling an experienced Coordinated Resource Management team enabled explicit embracing of adaptive management. The 11-member Stakeholder Group in the CARM project, built on a participatory research framework, which incorporates diverse management experience and knowledge within a management-science partnership involving experimental methods for identifying and prioritizing outcomes.[11,12] All of these cases illustrate the value of committing to adaptive management rather than adopting specific grazing systems and illustrate the complexities of adaptive land management.[16,19] Understanding of the ecosystem dynamics and mechanisms is process-based with planning processes including considerations of varying management alternatives and monitoring of management outcomes, and management is modified when needed based on systematic observations and monitoring data.

Outcome-based management can support the provision of multiple ecosystem services and multiple outcomes, regardless of enterprise structure, management system, or grazing system, and reduce vulnerability to ecological or social change.[20] Implementation of outcome-driven grazing management with attention to planning processes including prioritizing outcomes will be valuable for landscapes with disparate land ownership (federal, state, and private) and management objectives, jurisdictions of land management, and legal responsibilities. It can provide a basis for collaborative adaptive management and a shared reference for diverse stakeholders. The participatory approach of the CARM project with a 11-member Stakeholder Group demonstrates the importance of explicit integration of stakeholders in all aspects of decision-making for adaptive management.[11,12]

The recently implemented initiative of the Bureau of Land Management, the Outcome-Based Grazing Demonstration Projects Grazing Authorizations (https://www.partnersinthesage.com/outcome-based-grazing), emphasizes the efficiency and timing of information feedback from monitoring, enabling rapid decisions when benchmarks trigger management actions. We recognize that the monitoring program needed for adaptive management at the ranch level for outcomes is much more challenging and resource intensive than for individual pastures or allotments. Our three cases provide examples of such monitoring programs that can serve as examples for other ranch-level outcome-driven approaches incorporating adaptive management.

These three cases illustrate a range of options for engaging multiple parties in discussions of outcome-focused adaptive management for rangeland management. We envision that the five interacting components described above could be used as a framework for application of adaptive management with grazing associations and other collaboratives involving large landscapes, diverse interests, and many outcomes. Increasing the transparency of adaptive management through collaborative efforts, including robust monitoring and subsequent actions to modify management when needed, should result in greater accountability for adaptive management and less litigation.[5]

Declaration of Competing Interest

J.D.D. is an employee of the USDA Agricultural Research Service but certifies that he has no financial interest in the subject matter discussed in the manuscript. J.D.S. is a current member of the Rangelands Steering Committee but was not involved in the review or decision process for this manuscript. The content of sponsored issues of Rangelands is handled with the same editorial independence and single-blind peer review as that of regular issues.

Acknowledgments

This research was a contribution from the Long-Term Agroecosystem Research (LTAR) network. LTAR is supported by the United States Department of Agriculture. Funding for this study was provided by the USDA-Agricultural Research Service.

References

1. Boyd CS, Svejcar TJ. Managing complex problems in rangeland ecosystems. *Range Ecol Manage*. 2009; 62:491–499.
2. Havstad KM, Peters DPC, Skaggs R, et al. Ecological services to and from rangelands of the United States. *Ecol Econ*. 2007; 64:261–268.
3. Hollins CS. *Adaptive environmental assessment and management*. John Wiley & Sons; 1978.
4. Wang H, Grant WE, Teague R. Modeling rangelands as spatially-explicit complex adaptive systems. *J Environ Manage*. 2020; 269.
5. Fischman RL, Ruhl JB. Judging adaptive management practices of U.S. agencies. *Conserv Biol*. 2015; 30:268–275.
6. Briske DD, Derner JD, Milchunas DG, Tate KW. An evidence-based assessment of prescribed grazing practices. In: Briske DD, ed. *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps*. United States Department of Agriculture, Natural Resources Conservation Service; 2011:21–74.
7. Budd B, Thorpe J. Benefits of managed grazing: a manager's perspective. *Rangelands*. 2009; 31(5):11–14.
8. Searle KR, Hunt LP, Gordon IJ. Individualistic herds: individual variation in herbivore foraging behavior and application to rangeland management. *Appl Anim Behav Sci*. 2010; 122:1–12.
9. Brunson MW, Burritt EA. Behavioral factors in rotational grazing systems. *Rangelands*. 2009; 31(5):20–25.
10. Grissom G, Steffens T. Case study: adaptive grazing management at Rancho Largo Cattle Company. *Rangelands*. 2010; 35(5):35–44.
11. Wilmer H, Derner JD, Fernandez-Gimenez ME, Briske DD, Augustine DJ, Porensky LM, CARM Stakeholder Group. Collaborative adaptive rangeland management fosters management-science partnerships. *Range Ecol Manage*. 2018; 71:646–657.
12. Fernandez-Gimenez ME, Augustine DJ, Porensky LM, et al. Complexity fosters learning in collaborative adaptive management. *Ecol Soc*. 2019; 24:29.
13. Landres PB, Morgan P, Swanson FJ. Overview of the use of natural variability concepts in managing ecological systems. *Ecol Appl*. 1999; 9:1179–1188.
14. Fuhlendorf SD, Smeins FE. Long-term vegetation dynamics mediated by herbivores, weather and fire in a *Juniperus-Quercus* savanna. *J Veg Sci*. 1997; 8:819–828.
15. Torell LA, Murugan S, Ramirez OA. Economics of flexible versus conservative stocking strategies to manage climate variability risk. *Range Ecol Manage*. 2011; 63:415–425 0.
16. Herrick JE, Duniway MC, Pyke DA, et al. A holistic strategy for adaptive land management. *J Soil Water Conserv*. 2012; 67:105A–113A.
17. Danielsen F, Burgess ND, Jensen PM, Prihofer-Walzl. Environmental monitoring: the scale and speed of implementation varies according to the degree of people's involvement. *J Appl Ecol*. 2010; 47:1166–1168.
18. Nie MA, Schultz CA. Decision-making triggers in adaptive management. *Conserv Biol*. 2012; 26:1137–1144.
19. Derner JD, Augustine DJ, Briske DD, et al., CARM Stakeholder Group Can collaborative adaptive management improve cattle production in multipaddock grazing systems? *Range Ecol Manage*. 2021; 75:1–8.
20. Savory A. *Holistic Resource Management*. Island Press; 1998.

Authors are: Supervisory Research Rangeland Management Specialist, US Department of Agriculture, Agricultural Research Service, Rangeland Resources and Systems Research Unit, Cheyenne, WY 82009/Fort Collins, CO, 80526, USA; Executive Director, Wyoming Wildlife and Natural Resource Trust, Cheyenne, WY, 82001, USA; Rancher, Rancho Largo, Walsenburg, Colorado, 81089, USA; Ecologist and Terrestrial Assessment, Inventory, and Monitoring (AIM) Lead, Bureau of Land Management, Denver, CO, 80225; Ecologist, US Department of Agriculture, Agricultural Research Service, Rangeland Resources and Systems Research Unit, Cheyenne, WY 82009/Fort Collins, CO, 80526, USA; Research Social Scientist, US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Juneau, AK, 99801, USA; Assistant Professor and Extension Range Management Specialist, Department of Ecosystem Science and Management, University of Wyoming, Laramie, WY, 82071; Professor, Department of Agricultural and Applied Economics, University of Wyoming, Laramie, WY, 82071