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Rotational Grazing on Rangelands

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Rotational Grazing on Rangelands

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Front and Back Cover: Rotational grazing systems are often implemented with the objective of increasing utilization in diverse rangeland landscapes (Hartt Creek, Carbon County, Wyoming, USA). Photo courtesy of Bob Budd.

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Rotational Grazing and the Profession and Practice of Rangeland Management

By Joel Brown and Mort Kothmann

Rotational grazing systems and the research upon which they are based are an integral part of the profession of rangeland management, both the science and the art. A quick overview of the literature shows how frequently rotational grazing is referred to in the two primary journals of the Society for Range Management. Using the search engine associated with the archives of *Rangelands* from 1979–2003[i] and searching for "rotation grazing" returned 252 articles with those words in the title or keyword list. The use of the phrase "grazing system" returned 718 articles with those words in the keywords or title. About 1,500 articles were published over this period.

Likewise, a search of the *Journal of Range Management* archives from 1948–2003[ii] showed a similar emphasis. The search phrase "grazing system" returned 1,513 articles, and "rotation grazing" returned 645 relevant articles. There were approximately 5,500 articles published in *JRM* over this period. While these are not in-depth analyses by any means, they are a good indication of the emphasis that has been placed on a systematic approach to grazing management over the history of our profession.

In a recent paper, Briske et al.[1] ignited a controversy with their conclusions that rotational grazing (in various forms) was not superior to continuous grazing when the metrics of interest were plant or livestock production. Their review cited 47 experiments varying from 2 years to >25 years in length conducted and published over the past six decades. Although they were hardly the first to question the effectiveness of rotational grazing in stimulating plant or livestock productivity,[2-4] many have disagreed with these findings. That disagreement has been expressed among the ranchers who employ one of many forms of rotational grazing, advisors and consultants who have promoted and assisted in the implementation of grazing systems, administrators who have incentivized grazing systems with public resources, and researchers who have investigated and observed grazing systems. This controversy should not be downplayed. Quite the contrary, this is how science and professions advance. A group of researchers states a well-defined hypothesis, examines the relevant experimental literature, and rejects that hypothesis and proposes alternative explanations. We believe that the challenge now before us is not to refute or reject the findings of Briske et al. (although that is certainly a possibility), but to take those findings and construct new hypotheses to explain the observations and to test them with broadly accepted and credible designs and methodologies.

The challenges associated with developing those tests are substantial and should not be lightly regarded. First, research often lacks immediate application, if not overall relevance, to issues of interest to managers. In their attempts to isolate and evaluate a narrow range of important biophysical drivers, researchers can confuse or lose the connection to real-world management decisions. Although the ecological processes investigated may be critical, they can be several steps removed from those that field practitioners observe and measure, and they can appear to have only minimal connection to commercial-scale decision making. By controlling variability, whether through the use of a growth chamber, glasshouse, common garden, small plots, or experimental fields, researchers run the risk of becoming irrelevant to the most important processes in management: adaptation and change. In fact, Briske et al.[1] explicitly cited three areas (i.e., conservation goals, human dimensions, and spatiotemporal scale effects) largely excluded from the experimental design in the studies they reviewed.

On the other hand, practitioners can develop exceedingly creative solutions to seemingly insurmountable problems. However, because they seldom quantify existing conditions and protocols associated with implementation, the ability to communicate the principles of "how to" to other practitioners, advisors, and researchers can be very poor and can

[i] See *Rangelands* archive at: https://www.uair.arizona.edu/holdings/journal?r=http://rangelands.library.arizona.edu/

[ii] See *Journal of Range Management* archive at: https://www.uair.arizona.edu/holdings/journal?r=http://jrm.library.arizona.edu/

A parable about ranchers and scientists

Two ranchers went out for a balloon ride one day. A strong wind arose and blew them way off course. They had to use all of their skills and a little bit of luck to survive the wind storm and land the balloon safely. As they were about to finally touch down, they spotted a couple of scientists collecting field data. "Hey, where are we?" the ranchers yelled out. "In a rainbow-striped balloon, about 20 feet off the ground, descending at a rate of 5 feet per second," the scientists quickly yelled back. Moral of the story: the scientists were exceedingly precise, but not particularly helpful. The ranchers were as happy as they could be, but they still had no idea where they were.

wind up being little more than enthusiastic opinions. An emerging body of literature on the sociology of natural resource management identifies time and changes in spatial scale as powerful confounding forces in the perceptions of landowners in relation to resource conditions and factors driving change. This subsequently diminishes their ability to interpret their observations and to reconcile their opinions with overwhelming evidence to the contrary.[5,6] Testimonials will only go so far in convincing even mild skeptics.

Our hope in organizing and editing this special issue of *Rangelands* is not, as we said earlier, to refute or rebut the findings of Briske et al.[1] and the substantial literature upon which it was based, but to provide explanations that may provide some insight into reconciling the conflicting views associated with their implementation and, most importantly, to identify new approaches to evaluation (both managerial and experimental). This series of papers is unlikely to reconcile opposing views about the effectiveness of grazing systems as a tool to achieve vegetation and livestock objectives. Only well-designed, well-implemented, and well-analyzed research can do that. That research may be done at a variety of scales and through the collection of both traditional and nontraditional data, but it will be good science. No amount of passion will overcome evidence.

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References

1. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
2. Heady, H. F. 1961. Continuous vs. specialized grazing systems: a review and application to California annual type. *Journal of Range Management* 14:182–193.
3. Holochek, J. L., H. Gomez, F. Molinar, and D. Galt. 1999. Grazing studies: what have we learned? *Rangelands* 21:12–16.
4. McNaughton, S. J. 1993. Grasses and grazers, science and management. *Ecological Applications* 3:17–20.
5. Anderson, D. H., and P. J. Jakes. 2004. Landowner perceptions of ecosystem health in upper great lakes states riparian landscapes. Cooperative Park Studies Program. University of Minnesota. Available at: http://cpsp.cfans.umn.edu/Research/Riparian00.htm. Accessed 2 October 2009.
6. Tibby, J., M. B. Lane, and P. A. Gell. 2008. Local knowledge and environmental management: a cautionary tale from Lake Ainsworth, New South Wales, Australia. *Environmental Conservation* 34:334–341.

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Grazing Methods: A Viewpoint

By Mort Kothmann

Grazing management has long been a central focus of rangeland management and research. However, a communication gap exists between some managers and researchers. Voisin[1] stated that the art of applied grazing management exceeded the current level of science. Some managers continue to hold this opinion. Scientists base their conclusions on replicated research of fixed treatments, while managers develop their practices through much trial and error (e.g., adaptive management) without controls or replication. This difference, in source and perspective of "facts," produces a communication gap between researchers and practitioners. While scientists may see themselves as the final filter through which defined practices might become acceptable and sustainable, managers commit to developing a program that "works" on their property.

Recent publications highlight this communication gap. Briske et al. concluded, "Continued advocacy for rotational grazing as a superior strategy of grazing on rangelands is founded on perception and anecdotal interpretations, rather than an objective assessment of the vast experimental evidence."[2] Pat Pfiel stated, "I've applied *rotational-grazing principles* to the properties we've managed and shown it works well."[3] Frank Price, describing the development of his grazing management over the past 30 years, stated, "The biggest problem for me is that I can never come up with a grazing plan that I can stay with—I am continually changing grazing rotations, time, and stock numbers... But that is one of the reasons that this program works. It is not a system. It is a continually changing program that moves with the weather, livestock and markets."[4]

Scientists and ranchers need to improve their communications. Briske et al. state, "... management commitment and ability are the most pivotal components of grazing system effectiveness and ... grazing systems do not possess unique properties that enable them to compensate for ineffective management..."[2] In my opinion, ranchers using various rotational grazing methods agree with that statement. The key ingredient to success is "management" that applies principles adaptively, rather than a fixed "system." Research applies grazing as "treatments" (e.g., fixed grazing schedules, stocking rates, and management) to avoid confounding "grazing management" with other variables. On the other hand, ranchers view grazing schedules and stocking rates as *variables* to be integrated adaptively with other management practices to meet a variety of objectives. Ranchers evaluate the success of grazing management within the context of total system performance and goals, not just plant and animal production in response to fixed grazing treatments.

This paper focuses on two primary grazing management objectives for rangelands: 1) restoring and maintaining healthy rangelands, and 2) animal production. Three general grazing methods, continuous stocking, deferred stocking, and rotational stocking, are described and discussed with respect to vegetation responses and animal production. I do not believe that there is a "best" grazing method. My objective is to frame the discussion of grazing methods in a broad context and to provide some key concepts that managers can selectively utilize as they develop their grazing program. I invite scientists to view these concepts and principles as hypotheses and to design research to test them in adaptive models.

Measuring Success

Key Concept: Evaluating grazing methods based on the management objectives they were designed to achieve.

Vegetation standing crop and animal production are the two variables most commonly used to compare continuous stocking with rotational grazing in research studies.[2,5] However, research has shown that the primary vegetation response to grazing is change in species composition, not changes in net primary production.[6-8] Vegetation changes that increase the proportion of desirable forage species will increase grazing capacity and the reliability of forage production although net primary production may not increase. The evaluation of grazing strategies needs to consider responses of the total system relative to the management objectives, not just plant and animal production in response to isolated grazing practices.

Both temporal and spatial scales should be considered when evaluating grazing methods. Animal production responds to immediate conditions. However, rangeland restoration may take many years or decades, depending on the climate, soils, and the degree of degradation. On severely degraded arid and semi-arid rangelands, recovery of ecological processes that restore rangeland health may take decades and may initially require reduced stocking levels. Most grazing research has not evaluated long-term changes in species composition on degraded rangelands.

Grazing Methods

Key Concept: Grazing strategies should match the unique combination of physical, biotic, and management resources and the specific management objectives of each ranch.

No two ranches have the same resources or management objectives; therefore, why should they have the same grazing management plans? Grazing plans also change over time as the manager learns and as rangeland vegetation and health change. There is not one unique best-management plan or grazing system "template." A rancher can mix grazing methods, with different grazing methods applied at the same time on different parts of the ranch or on the same area over time. The complexity of grazing methods and management varies greatly across a gradient from continuous fixed stocking to adaptively managed, intensive, rotational grazing. "Intensive" grazing management as used here refers to the intensity of management required, not to the degree of use on forage.

The question a manager needs to ask is this: "Will this management plan enhance progress towards my goals?" Understanding the capabilities and desires of the manager is the first critical ingredient in designing a grazing method that will be successful and sustainable. At a research field day in west Texas during the 1980s, a scientist was presenting information on a grazing system with many pastures per herd and frequent livestock rotation when one of the ranchers commented, "If I had wanted to operate a dairy, I would have bought a dairy!" Obviously, he was not a good candidate for a grazing plan that requires intensive management. Managers should carefully assess their goals and aptitudes before designing a grazing management plan. Fitting a grazing plan to the manager's abilities, interests, and resources is critical to its ultimate success.

Continuous or Season-Long Stocking

Key Concepts:

- *Continuous stocking allows animals to graze selectively with minimal disturbance.*
- *Continuous stocking provides maximum short term livestock gains.*
- *Selective grazing for preferred species and areas may cause rangeland deterioration.*
- *Restoring the health of degraded rangelands is difficult under continuous stocking.*

Continuous stocking is the simplest grazing method a rancher can apply. It may be year-long or season-long, and animals have unrestricted access to the entire grazing area throughout the grazing season. Continuous stocking is the grazing method of choice for many ranchers. The following attributes make continuous stocking an attractive method for ranchers:

- It requires minimal management decisions and inputs.
- It focuses the primary grazing management decision on managing stocking level (animal numbers).
- It requires little or no additional investment in infrastructure.
- It produces good short-term animal performance by permitting selective grazing on preferred areas, plant species, and plant parts.

Over the short term, continuous stocking enhances animal production by allowing maximum opportunity for selective grazing with minimal handling disturbance. However, over the long term, it can lead to rangeland degradation and declining animal production. Low stocking densities under continuous stocking allow livestock to repeatedly graze preferred plants and areas while other plants and areas receive little or no use. This stratifies forage quality, which intensifies selective grazing and eventually results in degradation. The primary management options under continuous stocking are to increase or decrease animal numbers (e.g., total grazing pressure) and/or increase fencing and water development or other attractants or herding to change distribution of grazing pressure on the landscape.

Continuous light to moderate stocking can sustain rangeland health if there is little area- or species-selective grazing, though preferred areas (e.g., near shade or water) will still probably suffer. However, it is difficult to improve moderate to severely degraded rangelands with continuous light stocking because these ranges usually have significant problems with area- and species-selective grazing. Continuous stocking does not provide deferment to reduce the detrimental effects of selective grazing. Another disadvantage of continuous stocking is the difficulty of successfully implementing vegetation improvement practices (e.g., range seeding, prescribed burning, and brush control).

Deferred Stocking

Key Concepts:

- *Deferment is a conservation practice for restoring and maintaining rangeland health.*
- *Deferment is not a practice to increase livestock production within a grazing season.*
- *Deferment applied with other range improvement practices can enhance vegetation response.*
- *Repeated deferment over a period of years can increase rangeland carrying capacity, if it improves range condition.*

Deferred stocking, as used in this paper, includes all grazing methods that provide periodic deferment, either in a systematic rotation or by managerial decision. Deferment is a continuous period without grazing during the growing season that allows preferred plant species to reach reproductive maturity. It may be as short as 60 days or longer than a year, depending on the environment and vegetation. Deferred stocking emphasizes deferring pastures, not rotating livestock. Deferment is a practice that increases populations of desirable species and restores ecosystem processes for rangeland health. It allows closely grazed plants and patches to recover vigor and accumulate biomass. More than 100 years ago, Jared Smith[9] recognized the need for proper

stocking and periodic deferment to maintain healthy rangelands and to improve deteriorated rangelands. Deferment combined with proper stocking is a relatively simple practice that facilitates the restoration and maintenance of rangeland health. It is a conservation practice, not a practice to increase livestock production in the short term.

Deferment is often used to enhance other vegetation improvement practices (e.g., prescribed burning, seeding, and brush management) and specialized wildlife management. The synergism between deferment and other improvement practices frequently produces the greatest benefits derived from a "grazing system."[10]

The rate of species composition change (i.e., plant succession) is directly related to water and nutrient availability. In arid and semi-arid climates, plant succession progresses slowly and intermittently, only proceeding when environmental conditions are favorable for plant growth, vegetative reproduction, and/or seed production. In low-rainfall areas, it may take decades to significantly increase small populations of desirable plants on severely degraded rangeland. The length of deferment should increase as the amount of precipitation decreases. Plant succession proceeds much more rapidly in high-rainfall regions, unless the lack of a seed source limits it. Rangelands with long-lived woody species will require treatment with chemical and/or mechanical methods, prescribed herbivory, and/or prescribed fire practices to reduce the dominance of woody species and to allow the herbaceous species to increase. Deferred grazing used in combination with these practices enhances their success.

A key to the successful use of deferred grazing is maintaining a relatively low grazing pressure. Stocking levels need to be set low enough to prevent heavy use of grazed pastures, which will help maintain good individual animal performance. The smaller the fraction of the total area that livestock have access to, the shorter the grazing periods must be to maintain grazing pressure at an acceptable level. There is a tradeoff between increasing the duration and frequency of deferment to enhance plant succession and allowing livestock more access to forage to maintain good animal production. Deferment increases the average plant maturity and reduces average forage quality. Successful deferred stocking strikes a balance between the frequency and duration of deferment to enhance range improvement and the frequency and duration of grazing to enhance animal performance. The desired balance will depend on the relative weight given to range improvement and livestock production objectives.

Rotational Stocking

Key Concept: Rotational stocking is more flexible, has more management variables, requires more intensive adaptive management, and can be managed to meet a wider variety of vegetation and animal management objectives than continuous stocking or deferred stocking.

Rotational stocking rotates livestock through three to many paddocks per herd and uses high stocking density (i.e., livestock have access to one-third or less of the total land area at any point in time). There are four principal components of rotational stocking: 1) stocking level, 2) number of paddocks per herd, 3) length of rest periods, and 4) length of grazing periods. Each component has a wide range of possible values, and a manager using adaptive management may manipulate each of these components within and across years, thus creating an endless number of possible grazing strategies. It is important that a manager using rotational stocking has a good understanding of principles related to the four components because different grazing strategies produce very different plant and animal responses. Success stories for rotational stocking come from ranchers who commit to intensive adaptive management, obtain the requisite knowledge and experience, and design and manage grazing strategies to fit their resources and objectives. They represent a relatively small cohort of ranchers.

Different combinations of the four rotational stocking variables produce different intensities and frequencies of defoliation. Although both intensity (I) and frequency (F) of defoliation are continuous variables, I have classified them as high (H), medium (M), and low (L), allowing nine combinations (e.g., HILF, HIMF, HIHF, MILF, MIMF, MIHF, LILF, LIMF, and LIHF). High-intensity, low-frequency (HILF) and short-duration grazing (SDG) are terms commonly used without specific definition with respect to the intensity and frequency of defoliation. It is beyond the scope of this paper to examine all possible rotational stocking strategies for many different kinds of rangeland ecosystems. Therefore, a discussion of the strengths and weaknesses of two contrasting frequencies of grazing (high and low), both with high grazing intensity (e.g., an increasing intensity of defoliation), with respect to the stocking level and kind of environment is presented. These two general categories of rotational grazing, high-intensity, low-frequency (HILF) and high-intensity, high-frequency (HIHF), define the opposite ends of a management continuum with respect to frequency of grazing.

High-intensity low-frequency (HILF), as the name implies, has a high-intensity of defoliation and a low frequency of grazing (e.g., long rest periods of 90 days to >1 year). In systems with a small number of pastures per herd, long rest periods produce relatively long grazing periods, increasing the intensity of grazing. In systems with a larger number of pastures per herd the grazing periods can be shorter, but the increased stocking density increases the grazing intensity. Reducing the system stocking level can produce MILF or LILF, which improves animal performance. HILF grazing is most applicable for vegetation improvement in low precipitation environments.

High-intensity high-frequency (HIHF) employs short rest periods and very short grazing periods, again with a high intensity of defoliation. Rest periods range from 2 weeks to 6 weeks. Grazing periods are 1 day to 7 days, with 1-day

grazing periods being optimal. HIHF grazing focuses on increasing animal production and is best suited to high production environments.

Focusing on these two extreme types of rotational grazing, this discussion illustrates vegetation and livestock production responses across the continuum of grazing frequencies and identifies principles that ranchers can use to plan and manage rotational grazing.

HILF Key Concepts:

- HILF is an effective conservation practice for enhancing plant succession on degraded rangelands (e.g., promoting species composition change and improving rangeland health).
- HILF frequently reduces animal production compared to continuous stocking.

The low frequency of grazing in HILF maximizes range improvement but reduces livestock production compared with continuous stocking at a comparable stocking level. The intensity of forage use during each grazing period depends on the system stocking level, the stocking density, and the length of the grazing periods. To improve animal performance, increase the number of paddocks per herd and shorten the grazing periods while keeping the rest period constant.

Long rest periods produce mature forage, especially with higher precipitation, and increase selective grazing. Many plants initiate and complete their growth cycle during long rest periods without livestock having any opportunity to graze them when forage quality is high. Vegetation at the beginning of a grazing period consists of some high-quality forage and much mature low-quality forage. The result is a high level of diet quality at the beginning of a grazing period followed by declining diet quality and intake as the grazing period progresses. This cycle repeats with each grazing period, causing continual fluctuations in the animal's nutrient intake, reducing animal performance. Reducing system stocking levels improves individual animal gains but reduces total livestock production. Where HILF is desired for rangeland improvement but where livestock production is also a high management priority, strategic supplemental feeding can be used to even out the fluctuations in diet quality and intake. Free-choice supplement feeding allows animals to vary their consumption of supplement based on their nutritional needs. This would be most applicable to stocker operations and can maintain high animal production while promoting rapid range improvement.

Large increases in stocking density can change the spatial distribution of grazing and can cause animals to graze the landscape more uniformly. By increasing the number of paddocks per herd, stocking density can be increased 20 to 50 times, compared with continuous stocking without changing the system stocking level. Ranchers using high stock density have observed significant reductions in area-selective grazing problems. When combined with a low frequency of grazing, this produces significant range improvement. Areas of animal concentration around water and bed grounds recover and become productive, and animals graze more uniformly across the landscape. Significant improvement in grazing distribution can significantly increase grazing capacity.

HILF is more effective for decreasing area-selective grazing than it is species-selective grazing. The high average forage maturity may intensify species-selective grazing. As rangeland improves, the manager may shift management towards shorter rest periods that will maintain rangeland health, but yield better livestock production.

HIHF Key Concepts:

- *HIHF is a practice to maximize livestock production by producing uniform high quality swards and efficient forage utilization.*
- *HIHF is best suited to highly productive pastures of palatable forage species with long continuous growing seasons.*
- *HIHF is not a good grazing strategy for arid or semi-arid rangelands or those with significant species-selective grazing problems.*

Ideally HIHF uses 1-day grazing periods with very high stock densities to produce a uniform harvest of forage across the entire pasture while leaving adequate residual green biomass to support rapid plant recovery during short rest periods. Short rest periods prevent forage from maturing and present animals with a uniform standing crop characterized by predominantly green leaves with very little stem or dead leaf. Frequent defoliation shifts plant growth towards a greater proportion of leaf and lesser proportions of stem and root. Leaves are consumed before they senesce. Frequent uniform grazing produces a dense, compact, leafy sward structure that allows animals to obtain a large bite size with high nutrient concentration. HIHF can reduce selective grazing; however, it is not an effective method to correct significant species-selective grazing problems in arid and semi-arid ecosystems.

Short grazing and rest periods maintain uniformly high levels of diet quality and prevent the wide swings in diet quality and intake that are characteristic with long rest periods in HILF. HIHF is best suited for humid regions with long growing seasons, high nitrogen availability, and plant species that are adapted to respond quickly following frequent intensive defoliation. Applied to rangelands with limited water and/or nutrients or extreme temperatures, HIHF does not provide adequate recovery time and can collapse forage growth. Plants in arid environments are less tolerant of intensive defoliation and require longer recovery periods than are plants in highly productive humid environments.

Successful use of HIHF requires suitable ecosystems and adaptive management. Fixed grazing schedules and stocking

rates are not recommended. Managing HIHF requires knowledge and experience to make frequent (e.g., daily) adjustments in response to changing environmental, biotic, and management factors. Short grazing and rest periods in HIHF increase animal production by maximizing the efficiency of nutrient harvest. HIHF is not an effective range improvement strategy because intensive defoliation and short rest periods do not provide deferment to promote plant succession.

Mixed Grazing Methods

Key Concepts:

- *There is not one "best grazing management" practice.*
- *Grazing strategies are tools that a rancher can use to achieve specific vegetation management and livestock production objectives.*
- *Successful managers understand the condition and potential of their rangelands and design grazing programs that combine grazing methods to achieve their management objectives.*

From the proceeding discussion, you may correctly conclude that there is no ideal grazing method. Each method has advantages and disadvantages. This makes it crucial that managers understand the current condition and productive potential of their rangelands and the plant and livestock responses to different grazing methods. A ranch plan can incorporate all grazing methods, either simultaneously or sequentially. Degraded pastures need grazing strategies to promote range improvement. Healthy rangelands can use grazing strategies to improve livestock production and maintain rangeland health. Grazing strategies can also meet a variety of other purposes, as illustrated by other papers in this issue.

Creative managers combine different grazing methods with flexible management. For example, periods of above-average forage production allow deferment of additional pastures and application of practices such as prescribed burning. On the other hand, during drought, pastures scheduled for deferment can be grazed to maintain livestock production. Decision deferment can be applied within HIHF by skipping pastures during rotation cycles. The number of pastures per herd can be changed either by changing the number of herds or by changing the number of pastures. Pasture size and number can be changed on a daily basis using temporary electric fences. These are just a few of the possibilities for adapting management to meet management objectives under changing conditions.

Summary

Continuous stocking is not an effective method for restoring degraded rangelands. Deferment combined with moderate stocking enhances restoration of deteriorated rangelands. Deferment applied in conjunction with other range improvement practices can produce synergistic responses for rangeland improvement. Deferment is primarily a conservation practice not an animal production practice.

Rotational stocking requires adaptive management in order to be successful. Rotational stocking at light to moderate stocking with frequent long rest periods (e.g., HILF) maximizes range improvement through promoting plant succession but reduces livestock production compared with continuous grazing at a similar stocking level. Rotational stocking during the growing season with HIHF will maximize livestock production, but it is only sustainable on pastures with high water and nitrogen availability where plant species are adapted to frequent close defoliation.

Successful managers identify their management goals, understand their management preferences, know the principles governing plant and animal responses to different grazing methods, and use adaptive management to develop unique grazing plans suited to their ranch. Instead of research designed to identify "the best grazing method," researchers need to identify and quantify grazing processes and principles that will support adaptive grazing management.

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References

1. Voisin, A. 1959. Grass productivity. Washington, DC, USA: Island Press. 353 p.
2. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
3. Gordon, K. 2008. Is rotational better? Beef. Available at: http://beefmagazine.com/pasture-range/grazing-programs/0701-producers-scientists-found-grazing/index.html. Accessed October 2009.
4. Price, F. 2009. RC Factor. *Grassroots*, May–June 2009, Texas Section, Society for Range Management. Available at: http://texas.rangelands.org/. Accessed October 2009.
5. Van Poolen, H. W., and J. R. Lacey. 1979. Herbage response to grazing systems and stocking intensities. *Journal of Range Management* 32:250–253.
6. Dwyer, D. D., J. C. Buckhouse, and W. S. Huey. 1984. Impacts of grazing intensity and specialized grazing systems on the use and value of rangeland: summary and recommendations. *In:* Developing strategies for rangeland management. Boulder, CO, USA: National Research Council, National Academy of Sciences, Westview Press. p. 867–884.
7. Frost, W. E., and E. L. Smith. 1991. Biomass productivity and range condition on range sites in southern Arizona. *Journal of Range Management* 44:64–67.

8. Liang, Y., G. Han, H. Zhou, M. Zhao, H. A. Snyman, D. Shan, and K. M. Havstad. 2009. Grazing intensity on vegetation dynamics of a typical steppe in northern Inner Mongolia. *Rangeland Ecology and Management* 62:328–336.
9. Smith, J. G. 1895. Forage conditions of the Prairie Region. USDA Yearbook of Agriculture—1895. Washington, DC, USA: US Government Printing Office. p. 309–324.
10. Heady, H. F. 1961. Continuous vs. specialized grazing systems: a review and application to California annual type. *Journal of Range Management* 14:182–193.

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Even small amounts of precipitation, in this case fog, can increase the diversity in forage availability and animal distribution in arid landscapes (Wind River, WY, USA). Photo courtesy of Bob Budd.

Benefits of Managed Grazing: A Manager's Perspective

By Bob Budd and Jim Thorpe

Recent discussions of the merits and scientific bases for the comparative benefits of rotational grazing systems have been clouded by a lack of agreement on definitions and by actuality that the experimental results are not expressed in terms that address desired outcomes of many managers, particularly habitat values for wildlife. "Grazing" as an ecological process has been addressed in more than a dozen professional journals of disciplines such as fisheries, wildlife, range science, ecology, conservation biology, forestry, applied ecology, limnology, and others. Some of that body of literature reflects basic relationships between management and ecological processes—such as stocking rates, duration of grazing, season of use, type of forage, species or class of grazer—but many lack relevance to a variety of different management strategies on the ground.

The most common criticism of grazing experiments has been centered on their lack of relevance to the time and space in which managers practice. Small plot experiments are not particularly well suited to investigating or predicting landscape-scale processes, and large-scale experiments are expensive. While it may be "possible" to interpret historic and prehistoric interactions between living organisms at scale, the cost is prohibitive. It is virtually impossible to compare and contrast grazing management methods at spatial or temporal scales, between and among different ecosystems, and especially between different managers. In their recent synthesis paper, Briske et al.[1] raised the issue of the importance of management based on their analysis of literature comparing continuous grazing with rotational grazing systems, and a debate has ensued.

In repeated criticisms of Briske et al. we have found neither an indictment of rotational grazing nor a validation of continuous (season-long) grazing, yet both have been the conclusion of some critical readers. Inasmuch as Briske et al.'s conclusion holds that rotational grazing is not a panacea, few can disagree. However, the alternative interpretation of the same set of experimental results to conclude that rotational grazing is detrimental to a variety of resource attributes is equally invalid.

A wide array of the world's ecosystems evolved with variable levels of grazing, fire, and often the combination of the two, leading to patterns that proponents of both rotational grazing systems and continuous grazing have used as models for design and implementation. Much of the basis for planning and assessing grazing management historically has been based in the demonstrated range of species responses to defoliation. At the community scale, areas burned in one year are grazed selectively in the next, allowing fuel to build in other areas. Historically, many of these fires were individually small but were large in landscape scale, and recent use of "patch burning" to create diversity and wildlife habitat is a means of mimicking natural process. These "chocolate chips" in the cookie are highly valuable in restoring native species like prairie-chickens and quails. Over time, the impacts of grazing were also moved across the landscape in a manner that created a combination of plants, patches, and habitat types occupied by a diversity of wildlife. At the landscape scale, unique areas such as springs and streams might attract higher levels of herbivory across seasons, creating unique habitats for species like the mountain plover (*Charadrius montanus*) or burrowing owl (*Athene cunicularia*). Conversely, areas inaccessible or unattractive to grazers might have little use at all, creating dense nesting cover or winter forage for deer and elk. Domestic sheep operators have long understood the value of windswept ridges and arid areas where water is limiting in summer but where snow and shrubs are a valuable forage combination in winter. And a variety of wildlife species typically range in and out of seasonal habitats that may appear to be of little value in one season or another.

In addition to grazing and fire, other ecological processes must be considered when developing management alternatives. Drought is a common occurrence, as is seasonal flooding. Management that recognizes the limiting nature of drought may allow market options as well, such as combinations of cow–calf and stocker programs, though persistent drought will challenge the abilities of the best managers.[2] Erosion in many areas is an ongoing and unavoidable natural process, which, when brought into the management equation, may actually accelerate recovery of riparian species such as cottonwood (*Populus deltoides*), birch (*Betula* spp.), and willow (*Salix* spp.). In a shorter time scale, keystone species, especially beaver (*Castor* spp.), can have strong

influences on ecosystem response. The mode of vegetation reproduction and regeneration is another process that should be considered in the design of grazing. Cool- and warm-season grasses will respond to management differently, as will bunchgrasses and rhizomatous species. Using seasonal rotation may also help to maintain diversity (species evenness) within the plant community, and in some cases, may be essential to recovery of species that have been preferentially grazed. Understanding the processes that shape plant communities is critical background in designing grazing systems that are both resilient and productive for livestock and wildlife.

As with any management process, the success of all grazing management should be predicated and evaluated on a desired outcome—that is, a result. Without an outcome-based approach, evaluation of management is impossible. However, objectives focused solely on ecological or economic indicators are equally incomplete. In cases where grazing management is oriented primarily toward livestock production, as in irrigated pastures, production goals may be largely one-dimensional in an economic sense, but even these should not ignore ecological and environmental considerations, such as water quality, soil health, plant diversity, and habitat. Conversely, on public lands, production goals may be effectively trumped by other values, such as nesting cover for sage-grouse (*Centrocercus urophasianus*; residual forage), nesting habitat for mountain plovers (bare ground), crucial winter range for mule deer (shrub communities), or riparian and wetland health. In those settings, the focus may be primarily on ecological outcomes, but those outcomes must also recognize economic constraints.

The implementation of most grazing systems can be traced as a response to a handful of stimuli. Overstocking became synonymous with continuous grazing because that was the primary method of use at the time. Early range management textbooks correctly identified the cardinal principles of grazing management as stocking rate, distribution, season of use, and kind and class of animal.[3,4] Rest or deferment was incorporated into grazing as a means to achieve specific management goals (usually plant related), and it took little time for that notion to translate into rest-and-rotation methods. While these rotational approaches were often a response to severe range degradation, results led many other managers to consider the tactic for a variety of reasons. In many ways, this was the genesis of the rangeland profession, an attempt to restore and understand ecological systems—many long ignored and some abused. With greater understanding of plant physiology and plant–animal interactions, "rest" was expanded to include the concept of deferment, and ultimately, recovery periods from bouts of grazing. Most recently, advances in human understanding of animal behavior have led to development of fairly intricate grazing management systems, many of which use grazing animals to control invasive plants, to maintain or establish wildlife habitat, to manage natural and prescribed fire, or for other purposes.

By viewing herbivory (grazing) as a tool to achieve a desired, clearly enunciated result, managed grazing can be used to achieve multiple purposes. While continuous grazing under appropriate stocking rates and proper distribution is really "managed" grazing, rotational grazing may offer a wider range of options to managers, both for plant and animal objectives. Rotational grazing may include opportunities to employ the following to achieve economic goals: 1) temporary higher stock density, 2) deferment or rest, 3) spatial and temporal control, 4) seasonal use variation, and 5) livestock management.

Increased stock density may be important to attain a variety of results. Livestock have been used to eliminate weeds and to harvest less desirable species, a practice that generally requires short durations of intensive grazing followed by long periods of rest. This has led to a new field of practice, often referred to as "targeted grazing," which becomes management at an even finer scale.[5] Targeted grazing may be used to create disturbance or to solve other problems, such as the reduction of fuel in fire-prone locales. Ecological objectives, such as the variability of habitat types required by species like sage-grouse, bobwhite quail, or mountain plover, are often achieved by using varying stock density to maintain or create a heterogeneous vegetation pattern at the landscape scale, although concentrating animals can homogenize plant species and communities. Different numbers of animals may also lead to subtle behavioral changes that may create different management options.[6]

Deferment or rest may be necessary to allow for prescribed or natural fire. In areas where fire is a high-risk endeavor, rotational grazing may be used to simultaneously provide fine fuels, and to reduce fuels (and fire risk) in adjacent pastures. Seasonal deferment of plant use may also contribute to the long-term health and vigor of plants, as well as seed production in areas where that form of reproduction is important. Another form of "deferment" that has shown a high level of ecological benefits in some areas is removal of livestock from riparian areas in the hot summer, following use in late spring. This pattern of use attempts to mimic historic regional patterns by herds of large ungulates that would follow a maturing forage base from basins to mountains. Historically, in the northern portions of the United States, as upland cool-season grasses began to grow, animals would switch their dietary preference, allowing woody species, like willow, to escape defoliation and to eventually flourish in lowlands. When rest or deferment is rotated seasonally among pastures over a course of years, it may be possible to increase diversity (both species composition and structure) of vegetation.

In most western rangelands, especially in some of the more marginal landscapes that include vast expanses of public lands, distribution is difficult, if not impossible, to

manage properly using stocking rate alone. In the 1980s, concern over the condition of riparian areas on public lands became so elevated that numerous reports were issued at the federal level, the most damning a report from the (then) General Accounting Office.[7] Management that controls season of use and duration of grazing directly impacts riparian area recovery and maintenance, often without restricting access to water or vegetation in arid ecosystems. On smaller operations, or in more mesic environments, rotational grazing may allow managers to better utilize seasonal plant species; this strategy has been valuable in restoring tallgrass prairie species in fragmented agricultural landscapes, while controlling introduced species, such as fescue. Many operators in Missouri have found that grazing non-native species in a very aggressive grazing regime allows them the ability to restore native prairie species that are highly productive and resilient.

Rotational grazing may be essential to achieve some economic goals. Every operation is unique, and each will have a different set of parameters that must be met to be successful economically. The ability to concentrate females during the breeding season, to disperse animals during parturition, to manage multiple herds, to take advantage of specific vegetation types (or eliminate undesirable plants), to prepare for prescribed fire (or recover from wildfire), or to address other economic issues may be the most important reasons for some managers to employ a managed grazing strategy. When a strong management system is in place at a reasonable stocking rate, operations may become more resilient to drought and other variables. And, in some economic environments, light stocking simply may not be viable for a variety of reasons. On public lands and on rangelands where elevation, seasonal variation, poisonous plants, or other factors limit use, those limitations may manifest biologically. In other cases, the economic limitations of management may lead to higher stock densities and lower durations of grazing. Every situation is unique and should be evaluated in light of the realities of that particular operation.

Rotational grazing "systems" will not work without a high level of management and monitoring. This may be the most valid criticism leveled at rotational grazing. If a management system is not clearly outlined and understood, or if it is not evaluated regularly, the system is likely to fail to deliver the desired objectives. However, the same can be said for continuous grazing. The process of continuous development of grazing strategies, coupled with honest feedback from monitoring, affords managers a clearer picture of both ecological and economic outcomes. In most situations, managers will find that a combination of management alternatives may be the most beneficial.

So, what are all these alternatives? In general, there are four strategies: 1) continuous, 2) rest-rotation, 3) deferred, and 4) intensive (or twice-over). Keys to success under continuous grazing are correct stocking rates, adequate water, and a reasonably uniform vegetation type, or the use of distribution tools. Rest–rotation systems incorporate rest in some pasture(s) annually, and they usually employ seasonal rotation of pastures. By doing so, these systems will also defer pastures used late in the season. A deferral system does not rest pastures but rotates seasonal use. More intensive systems, including those pioneered under the Holistic Resource Management and other grazing planning guidelines, may use pastures more than once each growing season. Providing plants an adequate recovery period after grazing is essential to this form of management.

It is not uncommon to have multiple strategies employed on a single ranch. One manager has used continuous grazing at appropriate stocking on an upland pasture to manage his purebred cow herd. Commercial cows were managed in a rest–rotation system on public and private lands, and stocker cattle were intensively grazed on irrigated meadows. This allows the manager to match his ecological systems to a diverse mix of agricultural products, thus controlling market risk to some degree.

The recent "debate" over the use of rotational grazing systems seems somewhat misguided, in part because terms like "rotational," "planned," "pulsed," or "managed" grazing are not recipes, but general concepts that must be adapted to each unique situation. It is possible to rotate or manage grazing with any stocking rate or density. It is equally possible to manage grazing to achieve any level of utilization, and rotation can take place within seasons or across seasons. Clearly, light to moderate grazing has been shown to maintain or even slightly increase vegetative production in a variety of ecosystems. Many of those studies seem to support the "take half–leave half" mantra of grassland conservation, but that approach may not address issues of biodiversity at a landscape scale or take into account the responses to defoliation of important species (i.e. black grama [*Bouteloua eriopoda*] in desert grasslands).

The "art" of range management lies in understanding the natural and economic systems in which grazing is a fundamental process and in applying the appropriate tools to achieve explicit goals or objectives. Much of the attraction to rotational grazing systems comes from historic observations and perceptions of herbivore behavior in extensive unfragmented landscapes, where constant motion and different utilization patterns created and maintained highly variable, biologically rich ecosystems. It is interesting to note that many of the animal species of greatest concern actually choose areas that are heavily disturbed, while other species in the same ecosystem will seek out the most undisturbed habitats. For instance, keystone species like prairie dogs (*Cynomys* spp.) may thrive in and contribute to the disturbance of heavily grazed uplands, while beavers both remove and increase vegetation along the streams.

Before choosing a management scheme, it is imperative that managers undergo a thorough evaluation of these

elements: 1) historic patterns of natural processes, including the nature and condition of the resource base; 2) skills, availability, and experience of management; and 3) the economic and ecological objectives and constraints of a grazing operation. In addition, a clearly defined system for evaluation with clear links to management actions is necessary in order to respond to unexpected events. Like the management of any complex system, a clear understanding of the ecology, coupled with measurable, articulated goals is essential to success.

In light of the controversy, and especially in view of the tremendous dialogue created by Briske et al.,[1] we encourage the investigation of these management choices to move forward. While it is true that there has been little empirical research of grazing systems at commercial scales, there is an abundance of data from federal land management agencies, private landowners, and consultants that could be the basis for comprehensive review of the response of rangelands to different management schemes. Some of these data sets go back more than 60 years and would be an excellent point of departure. Given the level of monitoring and analysis on rangelands in the past 40 years, this type of data could be further subdivided by region, vegetative type, soils, or other components. And analysis of the data should include the input of managers as well as researchers. Such an effort would do a great deal to alleviate much of the misunderstanding and miscommunication that appears to be present on either side of the "debate" and would lead to positive reconciliation of the art and science of rangeland management.

References

1. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
2. Thurow, T. L., and C. A. Taylor, Jr. 1999. Viewpoint: the role of drought in range management. *Journal of Range Management* 52:413–419.
3. Sampson, A. W. 1923. Range and pasture management. New York, NY, USA: John Wiley. 421 p.
4. Stoddard, L. A., and A. D. Smith. 1943. Range management. New York, NY, USA: McGraw-Hill. 547 p.
5. Launchbaugh, K., and J. W. Walker. 2006. Targeted grazing: a new paradigm for livestock Management. *In:* K. Launchbaugh [ed.]. Targeted grazing: a natural approach to vegetation management and landscape enhancement. American Sheep Industry Association. Available at: http://www.cnr.uidaho.edu/rx-grazing/handbook/Chapter_1_Targeted_Grazing.pdf. Accessed 2 October 2009.
6. Provenza, F. D. 2003. Foraging behavior: managing to survive in a world of change. Utah State University. Available at: http://www.behave.net/index.html. Accessed 2 October 2009.
7. General Accounting Office. 1988. Public rangelands: some riparian areas restored but widespread improvement will be slow. GAO/RCED-88-105. Gaithersburg, MD, USA: General Accounting Office. 86 p.

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Elk cows and calves grazing following livestock in a rotational grazing system on the Mt. Haggin Wildlife Management Area. Photo courtesy of Mike Frasina.

Livestock Grazing, Wildlife Habitat, and Rangeland Values

By Paul R. Krausman, David E. Naugle, Michael R. Frisina, Rick Northrup, Vernon C. Bleich, William M. Block, Mark C. Wallace, and Jeffrey D. Wright

Livestock managers make and implement grazing management decisions to achieve a variety of objectives including livestock production, sustainable grazing, and wildlife habitat enhancement. Assessed values of grazing lands and ranches are often based on aesthetics and wildlife habitat or recreational values, which can exceed agricultural values, thus providing additional economic bases for effective grazing management. Perhaps more basic is the intention of many producers and managers to pass on the land in as good or better condition than when it was first acquired.

Grazing management plays a large role in the quality and extent of wildlife habitat. Livestock grazing is the most widespread land management practice in the world, affecting 70% of the land surface in the western United States.[1] Chronic overgrazing is detrimental because it reduces primary productivity, impedes plant growth and survival, and alters species composition of the grasses, shrubs, and forbs that provide wildlife with food and cover. Past efforts to increase livestock production have also homogenized the natural variability of grasslands upon which wildlife populations depend.[2]

Some have questioned the value of rotational grazing based largely on vegetation and animal production while also recognizing a lack of conclusive research that might support other benefits, such as wildlife habitat enhancement.[3] Conclusive experimental results showing a direct cause and effect between rotational grazing and enhancements to wildlife production or survival are indeed limited. This is more likely a product of the difficult nature of deriving this type of information with suitable rigor than it is an indication that rotational grazing does not influence certain wildlife values. Researching the effects of different grazing schemes with sufficient sample sizes at geographic scales reflective of a subpopulation's geographic extent can be demanding, particularly considering the overriding role that fluctuating weather events and other short-term factors can play in wildlife abundance.

The emergence of competing land uses that alter western rangelands are a sign of the times—and debates over livestock and wildlife values should be placed within this broader context. Ranchers and conservationists in the West realize that debates over grazing systems and stocking rates are of little consequence if rangelands continue to be lost or fragmented due to subdivision, farming, weed invasion, catastrophic wildfire, and energy development. However, impacts of domestic grazing that diminish land value via reduced range productivity and wildlife habitat quality can also lead to alternative land uses and habitat conversion. Maintaining the multiple values of western rangelands will require a shift from local to landscape conservation to match the scale of land use change that threatens grazing, rural ways of life, and wildlife habitat.

The future of western rangelands is in developing partnerships that help keep sustainable grazing the prevailing land use. Indeed, as rangelands are lost to other land uses, overlapping interests will make conservation partners out of otherwise odd associates—ranchers need open space for grazing and wildlife biologists, managers, and other conservationists want to maintain or enhance the wildlife values on working ranches.

In this paper, we review a representative sampling of scientific literature to document grazing impacts on wildlife and its habitat to better understand the roles of grazing strategies in wildlife habitat conservation. Further, we explore commonalities between grazing and conservation interests and provide a vision for advancing wildlife and habitat management and conservation.

Synthesis of Grazing Impacts

Grazing by domestic livestock can impact wildlife habitat in numerous ways. Composition and structure of a plant community are directly linked to qualities of wildlife habitat. As much as livestock grazing can affect vegetation characteristics, it will affect wildlife habitat structure and productivity. We consider these impacts at annual or short-term and long-term time scales.

Herbaceous vegetation provides hiding cover for a variety of grassland birds, amphibians, reptiles, small and large

mammals, and others. Substantial annual consumption of herbaceous vegetation in native rangeland settings that leaves only remnant cover is detrimental to many wildlife species. Management for grassland songbirds typically requires a mosaic of grassland habitats because species preferences vary widely from tall and dense to short and sparse vegetation.[4] Grazing can be used to diversify grassland habitats to benefit songbirds but overgrazing that leaves little vegetative cover is detrimental to songbird diversity. An abundance of short and sparse vegetation is beneficial to some species (e.g., chestnut-collared longspurs [*Calcarius ornatus*]) but would largely exclude others of management concern (grasshopper sparrow [*Ammodramus savannarum*]). For example, grasshopper sparrows in the southeastern United States had higher clutch sizes (4.5 vs. 3.9 young) and nest success (70% vs. 25%) in ungrazed than in grazed pastures.[5] Moreover, invertebrate biomass was greater in ungrazed than in grazed areas, and vegetation had less litter, more shrubs, and shorter, less-dense vegetation in grazed than in ungrazed pastures. Most unsuccessful nests were depredated, and authors surmised that shorter, less-dense vegetation in grazed areas made it easer for predators to locate nests, whereas taller, denser vegetation in ungrazed areas provided greater concealment.[6]

Grazing of rangelands by domestic livestock, sometimes combined with other influences (e.g., fences, roads, structures), alters the structure and composition of rangelands, with resultant impacts to biodiversity and ecosystem function[7,8] that can alter the environment for predators and prey. For example, insects, an important food for many wildlife species, can be reduced in abundance as a result of reduced herbaceous cover due to domestic livestock grazing.[7]

Reduced productivity and survival of smaller insectivorous wildlife species may lower productivity for various species of carnivores. Alternatively, trophic cascades resulting from the elimination of top predators can have implications beyond the immediate ecosystem occupied by those carnivores. The results could be detrimental impacts to some species that may otherwise not have been preyed upon as a result of mesocarnivore release.[9] Thus, a consequence of the reduction of many carnivores from rangelands in North America has had additional, but indirect, impacts to other species and different ecosystems than those from which carnivores in question were eliminated.

Domestic livestock grazing has also had a long-term impact on many native plant communities and the wildlife species adapted to these settings. Many native rangelands have experienced shifts in plant species composition due to persistent heavy grazing that leaves little ability for desirable perennial plants to reproduce (either by seed or vegetatively), resulting in a loss of favored plant species.[10]

Likewise, grazing lands over large expanses of the West have lost entire native plant communities due to invasion by exotic annual grasses and associated alteration of fire regimes. Invasion of these annual grasses has been facilitated by the absence of native vegetation,[11] another effect of overgrazing that may have occurred over a century ago. The continued spread of exotic annual grasses is likely a function of vacant plant niches and increased fire frequency that further excludes native perennial vegetation. Many species dependent on sagebrush (*Artemisia* spp.) grasslands[12] are thus directly impacted.

In similar fashion, the synergistic effects of planting with exotic crested wheatgrass (*Agropyron cristatum*) followed by grazing reduced small mammal abundance and locally extirpated all but one nesting bird species.[13] Part of the problem could be solved by more aggressive measures to replace crested wheatgrass plantings with native perennial vegetation.

Riparian areas, considered to be among the most productive and critical habitats for wildlife, have a well-documented history of deterioration or destruction as a result of livestock's preference for these areas for grazing, watering, and loafing.[14,15] Corresponding impacts to riparian wildlife are known; for example, livestock grazing in riparian ecosystems of western North America has been linked to decreased bird species diversity and abundance,[16] and may influence bird populations by facilitating nest predation, possibly by increasing nest detection or through changes in predator assemblage.[17] Similar examples are commonly available for fish. Trampling of riparian areas by domestic livestock destroyed redds (i.e., in-stream breeding sites) for the federally endangered bull trout (*Salvelinos confluentus*).[18]

Arthur Sampson, the "father of range management," writes, "The easiest way to overcome the deteriorating effect of premature grazing and overstocking, as well as of trampling, would be, of course, to eliminate grazing entirely. Obviously, however, such a procedure would be impracticable from the standpoint of the stock industry."[19] He then points out the means to solve the problem is in a scientific manner based on needs of the plants. Perhaps Sampson's reflection on this point is not wholly different from the current rotational grazing debate. A number of specific examples exist where rotational grazing has been successfully applied to meet the needs of vegetation and associated conservation objectives. We illustrate three case studies to provide an examination of how grazing management strategies have been used to achieve wildlife conservation objectives.

Case Studies Documenting Benefits of Rotational Grazing

Case Study 1: Grassland Birds in South Dakota

A comparison of three different types of rotational grazing systems at the Fort Pierre grasslands of South Dakota revealed some grazing strategies were more likely to fulfill standing cover requirements (455 kg/0.4047 ha; 1,000 pounds per acre) than others for prairie grouse (*Tympanuchus* spp.).[20] The authors compared deferred rotation, rest–rotation, and winter-only grazing. Pastures that were grazed

only in winter provided for the highest number of sharp-tailed grouse (*Tympanuchus phasianellus*) and prairie-chicken (*Tympanuchus* spp.) nests and broods per 404.7 ha (1,000 acres). Rest–rotation grazing accommodated the second highest density of nests and broods for both of these species. Deferred rotation did not provide blocks of undisturbed cover available in the spring for nesting, which was reflected in the lowest density of nests and subsequent broods. Pastures managed under rest–rotation grazing, which had the highest cattle stocking rate of any system, produced approximately 10 times more nest-broods per 404.7 ha (1,000 acres) than pastures managed in a deferred rotation system. During the 5-year study, grouse followed the grazing rotation seeking the best herbaceous cover for nesting and rearing broods. Grouse preferred rest pastures for nesting that were at times 4.02 km (2.5 miles) from breeding leks. Brood movements were also related to cover height, and although quantitative data were not provided, the implication was that the heaviest cover available was sought by broods, especially during the heat of the day. In 1978, when vegetation conditions were good, movement by females was considerably less than in previous years as birds were never recorded more than 0.4 km (0.25 miles) from nest sites. Waterfowl nest data were also collected in this study, producing similar results among the three grazing systems. A key message from this study is the capacity for a grazing system to produce substantial wildlife while supporting the producer's economic needs.

Case Study 2: Elk in Montana

Planned grazing by cattle on elk winter ranges can be an effective way to enhance forage palatability.[21] In 1984 a rotational grazing system was established to address forage conflicts between elk (*Cervus elaphus*) and livestock on Mount Haggin Wildlife Management Area in Montana.[22] The system rotated rested pastures in a manner that maintained productive cover and forage for elk while enhancing native vegetation condition on all of the managed areas. A 2002 update of the Mount Haggin project revealed considerable riparian and grassland improvements from what had been managed as continuous season-long grazing prior to 1984.[23] This is one of a number of examples in which conflicts over elk on private lands, availability of cover and forage, and adjacent landowner relations were improved using rotational grazing to fulfill a variety of conservation objectives in Montana.[24,25]

Case Study 3: Small Mammals and Riparian Habitats

Grazing exclosures were erected as wildlife habitat enhancement projects along riparian areas in Pennsylvania that had historically been continuously grazed by cattle.[26] Researchers found within a short time frame (1–2 years of rest) that small mammal abundance and diversity (species richness) was approximately twice what they found on continuously grazed riparian areas. They speculated that improved stands of herbaceous vegetation provided enhanced combinations of food and cover, depending on the particular species of small mammal. Although this project did not specifically consider rotational grazing, the relatively quick response of small mammals to improved cover suggests the potential benefits of managing livestock in a manner that results in herbaceous cover improvements in riparian areas. Others similarly found that the grazing system on Mount Haggin Wildlife Management Area in Montana provided habitat for maintaining a substantial prey base of small mammals for hawks and owls.[27] They concluded that a carefully designed grazing system would provide for substantially larger and more diverse small mammal populations than present under continuous season-long grazing.

In each case study the temporary or permanent partitioning of habitats using fenced pastures provided benefits to wildlife. Seasonal deferment and year-long rest provided effective habitat for very different wildlife species. Others have pointed to the value of using pastures as a mechanism for controlling livestock and achieving wildlife habitat objectives.[28] In some situations the pasture being grazed by livestock may provide the habitat component desired by a wild species; for example, young greater sandhill cranes (*Grus canadensis tabidu*) in search of invertebrates preferred the grazed pasture within a rest–rotation system.[29] Other investigators reached similar conclusions and provided a graphic of grazing treatments and their potential benefits to wildlife, including deferment and rest.[30]

Analysis and Recommendations

Our synthesis, although limited by space, clearly documents the overwhelming and negative impacts that poorly managed or inappropriate livestock grazing can have on wildlife populations and their associated habitats. Results are highly variable because ecosystems differ widely in their adaptation to grazing. The severity of impacts is directly related to environmental gradients and grazing regimes, both notoriously difficult to quantify. However, habitat needs of many species are well known and these requirements provide the "biological sideboards" necessary to develop guidance for grazing strategies for maintaining or enhancing wildlife populations. Food, cover, and space are indisputable habitat needs.[31] Domestic livestock grazing can directly affect one or more of these elements. The question of rotational vs. continuous grazing can be reduced to managing livestock in a manner that supports these basic habitat elements while maintaining native plant community integrity—the same plant communities to which native wildlife have adapted.

Continuous grazing at moderate stocking levels can result in long-term deterioration of important plant communities, including upland[32] and riparian areas.[14] Although it may be possible to maintain native rangeland integrity using light stocking levels, we question the economic viability of this approach for most traditional livestock producers.[33] We also

question the ability to maintain quality habitat features even under light stocking for areas where livestock prefer to graze.[14,32]

Grazing is not universally "bad" or "good" for wildlife—rather, it has positive or negative effects depending on current and historic timing and intensity of grazing, soil conditions, precipitation, plant communities, and specific habitat features under consideration. The literature does not provide a comprehensive review of the benefits of continuous vs. rotational grazing to wildlife populations. Replicated experiments to further document wildlife response to different grazing systems should be a focus of research to help guide landowners and public-land managers to practices that are beneficial to wildlife and economically viable to producers. But the appropriate response is not a call for more research; rather, the appropriate response is to ascertain what can be done now in light of uncertainty to sustain wildlife populations that depend on grassland and shrubland habitats.[34]

We propose that the alternative to continuous grazing is to develop grazing strategies that are appropriately stocked and are managed to provide blocks of undisturbed cover at times that allow for plant reproduction and energy storage and wildlife reproduction and survival. We recommend that producers and managers establish grazing management systems that help to achieve long-term native habitat conservation objectives while using grazing treatments that provide for basic cover and food needs of wildlife species. The most practical way to accomplish this may be through carefully planned grazing systems that use pastures as a means to control livestock distribution and timing of grazing. Grazing rotations can achieve short- and long-term conservation objectives. When wildlife habitat needs are considered in the pasture layout, pastures scheduled for rest and deferment can serve as high-quality habitat areas providing food and cover for wildlife as other pastures are being grazed, sometimes intensively, by livestock. Briske et al.[3] similarly acknowledged the long-term benefits of lengthy rest coinciding with plant growth as contributing to the sustainability and recovery of grazed ecosystems. Carefully planned grazing rotations can therefore ensure maintaining native habitats that are also functional for an abundance and diversity of wildlife.

Maintaining rangeland function requires a shift from local to landscape conservation to match the scale of land use change that threatens grazing, rural ways of life, and wildlife populations.[35] Rotational grazing is more likely to help managers achieve wildlife habitat objectives than continuous grazing because, through grazing treatments, key wildlife habitat components can be assured on the landscape from year to year. That is, rotational grazing systems may be more useful than continuous systems for providing necessary habitat elements (food and cover) in specific locations at specific times. Continuous grazing at light stocking rates seems to leave to chance the possibility of achieving specific wildlife objectives in any given area.

References

1. Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8:629–644.
2. Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity and rangelands: ecosystem management based on evolutionary grazing patterns. *BioScience* 51:625–632.
3. Briske, D. D., J. D. Dener, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Williams. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
4. Fuhlendorf, S. D., W. C. Harrell, D. M. Engle, R. G. Hamilton, C. A. Davis, and D. M. Leslie, Jr. 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecological Applications* 16:1706–1716.
5. Davis, S. K. 2005. Nest-site selection patterns and the influence of vegetation on nest survival of mixed-grass prairie passerines. *Condor* 107:605–616.
6. Sutter, B., and G. Ritchison. 2005. Effects of grazing on vegetation structure, prey availability, and reproductive success of grasshopper sparrows. *Journal of Field Ornithology* 76: 345–351.
7. Rambo, J. L., and S. H. Faeth. 1999. Effect of vertebrate grazing on plant and insect community structure. *Conservation Biology* 13:1047–1054.
8. Blaum, N., E. Rossmanith, A. Popp, and F. Jeltsch. 2007. Shrub encroachment affects mammalian carnivore abundance and species richness in semiarid rangelands. *Acta Oecologica* 31:86–92.
9. Berger, K. M., E. M. Gese, and J. Berger. 2008. Indirect effects and traditional trophic cascades: a test involving wolves, coyotes, and pronghorn. *Ecology* 89:818–828.
10. Savory, A. 1988. Holistic resource management. Washington, DC, USA: Island Press. 545 p.
11. Chambers, J. C., B. A. Roundy, R. R. Blank, S. E. Meyer, and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? *Ecological Monographs* 77:117–145.
12. Welch, B. L. 2005. Big sagebrush: a sea fragmented into lakes, ponds and puddles. Fort Collins, CO, USA: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-144. 210 p.
13. Reynolds, T. D., and C. H. Trost. 1980. The response of native vertebrate populations to created wheatgrass planting and grazing by sheep. *Journal of Range Management* 33: 122–125.
14. Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian plant communities and stream-side management implications, a review. *Journal of Range Management* 37:430–437.
15. Chaney, E., W. Elmore, and W. S. Platts. 1990. Livestock grazing on western riparian areas. Eagle, ID, USA: Northwest Resource Information Center, Inc., for US Environmental Protection Agency. 45 p.
16. Mosconi, S. L., and R. L. Hutto. 1982. The effect of grazing on the land birds of a western Montana riparian habitat. *In:* J. M. Peek and P. D. Dalke [eds.]. Proceedings of the Wildlife Livestock Relationships Symposium. Moscow, ID, USA:

University of Idaho, Forestry, Wildlife and Range Experiment Station. p. 221–233.

17. Martin, T. G., and S. McIntyre. 2007. Impacts of livestock grazing and tree clearing on birds of woodland and riparian habitats. *Conservation Biology* 21:504–514.
18. Gregory, J. S., and B. L. Gamett. 2009. Cattle trampling of simulated bull trout redds. *North American Journal of Fisheries Management* 29:361–366.
19. Sampson, A. 1914. Natural revegetation of range lands based upon growth requirements and life history of the vegetation. *Journal of Agricultural Research* 3:93–170.
20. Rice, L. A., and A. V. Carter. 1982. Evaluation of South Dakota grassland management practices as they affect prairie chicken populations, 1974–1978. Pierre, SD, USA: South Dakota Department of Game Fish and Parks. Completion report 84-11. 25 p.
21. Frisina, M. R. 1992. Elk habitat use within a rest–rotation grazing system. *Rangelands* 14:93–96.
22. Grover, K. E., and M. J. Thompson. 1986. Factors influencing spring feed site selection by elk in the Elkhorn Mountains, Montana. *Journal of Wildlife Management* 50:466–470.
23. Frisina, M. R., and R. B. Keigley. 2004. Habitat changes Mount Haggin Wildlife Management Area. *Rangelands* 26: 3–13.
24. Frisina, M. R., and F. G. Morin. 1991. Grazing private and public land to improve the Fleecer elk winter range. *Rangelands* 13:291–294.
25. Alt, K. L., M. R. Frisina, and F. J. King. 1992. Coordinated management of elk and cattle, a perspective: Wall Creek Wildlife Management Area. *Rangelands* 14:12–15.
26. Guiliano, W. M., and S. D. Homyack. 2004. Short-term grazing exclusion effects on riparian small mammal communities. *Journal of Range Management* 57:346–350.
27. Douglass, R. J., and M. R. Frisina. 1993. Mice and management on Mount Haggin Wildlife Management Area. *Rangelands* 15:8–12.
28. Eng, R. L., and R. J. Mackie. 1982. Integrating grazing-range management practices with management of major wildlife species on rangeland in northcentral Montana. *In:* Western Proceedings 62nd Annual Conference of the Western Association of Fish and Wildlife Agencies; 19–22 July 1982; Las Vegas, NV, USA. p. 112–119.
29. Frisina, M. R., and J. E. Canfield. 1987. A plan for inventory and management of greater sandhill cranes on the Mount Haggin Wildlife Management Area, Montana. *Proceedings of the Montana Academy of Science* 47:21–26.
30. Payne, N. F., and F. C. Bryant. 1994. Techniques for wildlife habitat management of uplands. New York, NY, USA: McGraw-Hill. 840 p.
31. Krausman, P. R. 2002. Introduction to wildlife management. The basics. Upper Saddle River, NJ, USA: Prentice Hall. 478 p.
32. Teague, W. R. and S. L. Dowhower. 2003. Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. *Journal of Arid Environments* 53:211–229.
33. Holecheck, J. L., H. Gomez, F. Molinar, and D. Galt. 1999. Grazing studies: what we've learned. *Rangelands* 21: 12–16.
34. Sayre, N. F. 2009. Bad abstractions: response to Sullivan. *Conservation Biology* 23:1050–1052.
35. Williams, C. K., F. S. Guthery, R. D. Applegate, and M. J. Peterson. 2004. The northern bobwhite decline: scaling our management for the twenty-first century. *Wildlife Society Bulletin* 32:861–869.

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Behavioral Factors in Rotational Grazing Systems

By Mark W. Brunson and Elizabeth A. Burritt

Many in the range profession are perplexed by the apparent discrepancy between experimental studies suggesting that rotational grazing carries no advantage over continuous grazing[1] and the observations of ranchers and range managers who have personally seen benefits for livestock production and plant communities by shifting to a rotational system.[2,3] We believe one reason for this seeming contradiction is that research on plant and animal production is typically designed to control for the effects of behavior of grazing animals and their owners. As researchers who have spent many years studying the behavior of range livestock and people, we argue that understanding human and animal behavior as it relates to grazing management can help to bridge the gap between science and practice. In this paper we discuss how livestock behavior factors (such as prior experience and stress) and managers' learning processes can influence the outcomes of grazing management practices, why a standard experimental approach may not detect those influences, and how an improved knowledge of behavior can help both ranchers and researchers achieve their goals with respect to rotational grazing systems.

Behavior and the Scientific Process

Before discussing behavioral factors in grazing management, we would like to explore briefly the behavioral factors in experimental science that may help to explain why research results do not seem to match experience with rotational grazing. There is a long and illustrious history of using experimental methods to study behavior. Many of the greatest breakthroughs in psychology came from carefully controlled experiments with human subjects. Similarly, behavioral researchers use animal models in experiments to understand both human and animal behavior.[4,5] In our own profession, hundreds of experiments have been published examining aspects of livestock behavior with regard to diet and habitat selection, social influences, effects of stress, and how animals learn. In this paper we are guided by the experimental studies of herbivory by Fred Provenza along with collaborators that include Beth Burritt, the second author of this paper.[6,]

Yet when the topic of study is *not* behavior, researchers go to great lengths to filter out its potentially confounding effects. Behavior can vary over time and from individual to individual, whether the individual is an experimental subject or a researcher. Therefore scientific protocols typically spell out very specific steps that must be taken whenever a treatment is administered or a measurement is taken in order to reduce the potential effects of variations in how experimenter and subject behave during the trial.

Researchers conducting animal studies often try to limit variability by using animals similar in age, breed, and sex; they are less likely to consider how prior experiences can profoundly affect their experimental animals. Numerous studies show that experiences early in life affect acceptance and preference for different foods.[7-10] Habitat use and foraging skills also are influenced by prior experience, and these can influence how effectively an experimental animal adapts to its new surroundings.[11,12] Social scientists, especially survey researchers, take an opposite tack: they incorporate enough different individuals into a study that the differences between respondents are averaged out, and a statistically derived picture emerges of a "typical" individual.

While such approaches are valid and have greatly increased our certainty about scientific phenomena, these approaches have pitfalls. In their search for statistical power and rigor, scientists who tightly control or fail to control for behavioral variation may have to create artificial situations that do not match the conditions under which the results will be applied. Just as a researcher's behavior must be consistent, a successful grazing manager's behavior must be adaptive, changing over time as influenced by information and experience. Similarly, livestock engage in behaviors that are shaped by consequences (intentionally or unintentionally) to produce desirable or undesirable outcomes.

Experiments isolate the effects of one or a few factors (e.g., grazing frequency, timing, or intensity) on a particular variable (e.g., forage production). However, a livestock operation is a complex system. It may be difficult to isolate particular factors and to predict how the entire system will respond. To exclude the confounding effects of year-to-year climate variation, grazing systems studies normally compare effects of different systems on similar tracts of land in the

[1] For an overview of this work see BEHAVE: Behavioral Education for Human, Animal, Vegetation & Ecosystem Management (http://www.behave.net) or Provenza.[6]

same year or the same system on the same tract in different years. This differs from the evaluations made by ranchers that report beneficial effects of switching to rotational grazing by comparing effects of different systems on the same tract in successive years. A ranch manager using continuous grazing is most likely to switch to a rotational system when there do not seem to be any other viable alternatives. Successful managers of any sort of enterprise rarely switch from something that is working to something that may or may not work; they switch when they believe that what they have been doing is no longer working. Thus the shift to a rotational system most often occurs when a rancher sees his or her operation on a downward trajectory (real or perceived) or unlikely to survive (or to provide a desired level of economic and non-economic benefits) without radical intervention.

Rancher Behavior and the Nature of Change

In their synthesis of research on rotational versus continuous grazing, Briske et al.[1] acknowledged the behavioral factor when they observed that "long-standing controversy very likely originates from managerial emphasis on the socioeconomic benefits of the ranch enterprise while research scientists focus on ecological processes" (p. 10). We believe they were half right. Certainly ranchers monitor socioeconomic benefits, and a noticeable decline in these benefits may be likely to trigger a significant change in management. But progressive, successful ranchers also focus to a significant extent on ecological processes, although they may interpret them differently than scientists do. This is one reason why they remain successful.

In our work with ranchers and other range managers, we often hear common-sense axioms that describe the nature of management change. Research has shown how and why these axioms actually work. One such truism is that change is a constant—as the Greek philosopher Heraclitus wrote, "You could not step twice into the same river, for other waters are ever flowing on to you." This is one of the most attractive aspects of ranching. No two days are alike. Animals change with the seasons as does the land. But when small changes happen constantly, it is easy to miss important trends. Changes can go unnoticed until they reach crisis proportions. For self-employed ranchers, an economic "crisis" may be noticeable sooner than an ecological one.

A recent study of ranchers' adoption of new practices in Colorado[13,14] identified two types of management change: *corrective change*, an adjustment in an existing practice such as moving a fence, adding a water development, or going to market a week or two earlier; and *substantive change*, adopting a new approach to managing one's land, e.g., moving from feedlot to pasture finishing, or from a cow–calf operation to a stocker operation. Ranchers tend to make corrective changes quite easily; substantive changes are much rarer. Shifting from a continuous to a rotational grazing system is likely to represent a substantive change, in that typically (though not always) it requires changes in a time-tested production calendar, short-term increases in labor, and often a significant investment in infrastructure such as fences and water developments.

A second, even better-known axiom is that change is difficult. We take comfort in the old saying, "If it ain't broke, don't fix it." The tendency for agricultural producers to retreat from change, rather than embrace it, has helped foster the extension profession. If change were easy, one could simply make new information available then stand back to avoid the rush of ranchers clamoring to apply it. Because change is hard, people try to avoid it. Agricultural producers may be especially likely to avoid change because the negative impacts of making a mistake are amplified in an operation that has only a single production cycle per year. Therefore we not only have trained extension professionals who learn to coax cautious clients into improving their practices, but also an entire branch of sociology that seeks to enhance rates of adoption of new technologies and management practices.[15,16,a]

Everett Rogers, the founder of adoption–diffusion research, described five features of innovations that affect the likelihood that they will be adopted. The most important of these is *relative advantage*, a manager's calculation of whether a change in practice is likely to lead to a better condition than before the change. Such a calculation may seem simple. Will my cattle gain more weight? Can I reduce operating costs without sacrificing profits?

But there is more to the equation: How easy is the new practice to learn? Will it take more time? Can I test it on a portion of my land, or do I have to go "whole hog?" Does it fit with my current operation, or must I change other aspects of my business to accommodate it? Can I tell easily whether it's making a difference? The harder it is for a rancher to answer these questions positively, the less likely he or she will be to make a change.

In the short run, a shift to rotational grazing can be more labor-intensive, especially at first before the cattle are trained to move easily from pasture to pasture (see discussion below). Also, a trial comparison of rotational versus continuous grazing is not easy in a practical setting, i.e., the vast majority of producers do not have enough of a land base to implement a rotational system on part of their property while maintaining continuous grazing elsewhere. Even though the basics of rotational grazing are easy to understand, the specific application to one's own property may require trial and error. For example, here is how one rancher described his efforts to use electric fencing in order to move cattle more often:

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[a] The best-known thread of social science on extension and technology transfer is the so-called "adoption-diffusion theory" of Everett Rogers.[15] Other research traditions exist, however. One such publication that is especially relevant to range science and management is Ison and Russell.[16]

The thing that helped us most was that three of us were trying to use it at home and talking back and forth about it. Plenty of failures. I don't have any of the first electric fence posts that I bought. None of them were right. Some of the chargers, the tape, the wire—all that stuff we changed. . . . So [we got there by] trial and error and also neighbors' trial and error.[17]

In our work with the Consortium for Behavioral Education for Human, Animal, Vegetation & Ecosystem Management (BEHAVE)[7-10] we often speak of the "3-year rule," i.e., the notion that any significant innovation takes time to learn—often about 3 years. The rule's name refers to the annual cycle of ranching. As retired Forest Service range manager Floyd Reed explained it, the first year after a change in grazing system is often a "wreck." The second year is not as bad, but there still are kinks to work out. By the third year—if the permittee persists into year 3—things work more smoothly than ever before. For example, a public land permittee who previously used a continuous system must learn when to move cattle, where they are likely to be when it is time to move to the next pasture, and how best to move them to that new pasture when the animals can make many wrong turns. In such cases it is easy to have a "wreck." Word about a wreck travels fast within the local ranching social network. It does not take many bad anecdotes to deter an already hesitant rancher from making a change. Conversely, given the length of time it takes to truly learn how to benefit from a new practice and the relatively slow pace of environmental improvement in semi-arid range environments, it may take a decade or more before real benefits are noticed.

If all this is true, why does anyone change grazing systems? As we noted previously, such a change often comes from a decline in net economic returns. It is broken, and fixing it means substantive change. Some places also have resources to make learning easier. Working in western Colorado, we began to identify a "culture of innovation" that arose because multiple sources of information, including a Range Management School for Ranchers[17] and experts in Holistic Management,[18] were locally available. As more ranchers used those resources, it became progressively easier for others to learn from the successes and wrecks of their neighbors.

This is because people are social animals. Everett Rogers[15,16] pointed out that adoption decisions depend on characteristics of the innovation, as described above, characteristics of the potential adopter (e.g., life stage, financial resources or risk-aversion tendencies), and characteristics of the adopter's social system. In the previous paragraph, we saw how a supportive social system can make it easier to adopt a new practice. On the flip side, ranchers can be reluctant to make a substantive change in management if they believe their fellow ranchers will think less of them for going against the norm.

This is one place where financial and/or technical assistance from a federal agency, such as the Natural Resource Conservation Service's (NRCS) advocacy of prescribed grazing systems,[19] can be important. A study of Utah's most innovative ranchers[20] found that the structure of federal programs can have a significant influence on whether or not a practice is adopted. But that is just one of many potentially influential factors in a social system. The studies in Utah and Colorado found that adoption can also be influenced by ranchers' beliefs about the likely reactions of customers, lessors of public or private forage, and the general public.

Once a rancher does decide to make a change, he or she is likely to follow Napoleon's advice: "Take time to deliberate; but when the time for action arrives, stop thinking and go in." Ranchers tend to be "doers," accustomed to making quick decisions in a crisis. Once a change is made—especially one requiring a substantial investment in both infrastructure (e.g., fences, water developments, etc.) and time—they will work extra hard to make it succeed. This helps to explain why stories abound of successful shifts to rotational grazing even though scientific research does not predict success. A rancher who makes a change in practice has made a large psychological as well as economic investment in that change. With such a strong incentive to succeed, a rancher is prepared to make all sorts of adjustments to assure success. This seat-of-the-pants form of adaptive management is contrary to the scientific process, wherein a protocol cannot be changed once an experiment has begun, even if it is clear that the original approach is not going to work.

For example, many rotational systems call for moving livestock when forage has reached a predetermined level of utilization. Thus, the system calls for adaptive management based on indicators that vary over time. Managers have the option of changing pasture size, stocking rate, stock density, length of time in a pasture, etc., depending on management goals. They can make changes quickly in response to changing conditions or to the impacts of management on plant production, and also to factors unrelated to utilization such as undesirable livestock behaviors. Conversely, most research protocols call for the scientist to rigorously follow the same procedures from start to finish. This is not to say that environmental conditions cannot dictate researchers' decisions—in fact, many studies have used a combination of utilization and standing crop as the decision criteria for moving animals just as ranchers would do—but the range of possible adjustments is narrower because consistency of procedure is vital in science.

Producers may look at other differences between their grazing management and research studies on rotational grazing and decide that the research is not applicable to their operation. For example, many practitioners of rotational grazing use high-density, short-duration grazing with many pastures or grazing cells. Of the 47 studies reviewed by Briske et al., 83% used fewer than eight pastures, whereas

short-duration rotational systems on larger ranches can use several times that many pastures. Second, research studies typically use smaller pastures with fewer animals than most ranching operations; this means that the added benefit of changing distribution is less because distribution in a smaller pasture is likely to be less uneven initially.

Testimonials from fellow ranchers about increased carrying capacity, improved plant diversity and production, and higher economic returns are likely to have more influence on a rancher than research results. Many ranchers have good monitoring records that document rangeland improvement under a rotational system. For a rancher thinking about changing to a rotational system, photos documenting improvement in rangeland condition, monitoring data, and financial records from another ranch may be more compelling than any research study. After all, "Seeing is believing."

Other advantages of rotational grazing not thoroughly studied may include the following: reduced losses due to illness, injury, or theft (because cattle are monitored more often), gentler animals, flexibility to take advantage of unusual rainfall events, ability to stockpile forage for fall and winter grazing, improved relationships with agency personnel, improved wildlife habitat, and increased diet breadth (the variety of plant species eaten by livestock).

Lastly, ranchers who find themselves in financial trouble often make several changes at the same time. If the situation improves, ranchers may attribute most, if not all, of the improvement to changes in grazing management. However, in an attempt to save the ranch, improvement may not be due to the grazing system but simply due to their having become more attentive and creative managers.

Livestock Behavior and Rotational Grazing

Rancher behavior is only half of the behavioral story, however. Like people, cattle are social animals that learn from each other and individual experience. The behavioral tendencies of cattle help to explain why rotational grazing may be less effective in an experimental setting than in a working ranch. A producer who understands livestock behavior can also enhance the likelihood of success when making a change in grazing systems.

Animals, like people, prefer to live with companions rather than strangers. Cattle purchased from a variety of locations and mixed as a single experimental herd show more signs of stress than animals reared together.[21] Mixing unfamiliar animals together may be more stressful in a rotational system than in a continuous system because animals are in closer proximity to one another when grazing.

Cow–calf operations typically retain the same animals from year to year, especially if they keep their own replacement females. Using the same animals year after year may produce better results in a grazing system because animals are familiar with the grazing system, animal handlers, locations of shelter and water, the vegetation, and their herd mates. However, most research studies use yearling heifers or steers to evaluate grazing systems. Using naïve animals each year may affect results. For operations that graze stockers, some producers put an older cow with stockers to teach them the locations of forage, water, and cover on a rangeland; this is not a practice typically used in research.

A potential advantage of rotational grazing not often considered is that animals may learn to increase the number of plant species they eat.[22,iii] In a continuous system, livestock often eat only their preferred forages. But in a rotational system, as forage declines, animals are forced to eat less-preferred species. In the process, they learn to mix their diets to include preferred and less-preferred forages. Positive experiences with less palatable foods have been shown to change dietary preferences for those foods.[23,24,iv] Ranch livestock that do not learn to eat less-preferred species and continue to perform poorly will eventually be culled, thereby creating a "culture" of livestock that eat a wider variety of plant species. Thus, a rotational system may reduce the spread of undesirable species, may increase amount of forage available, and may improve rangeland quality. This benefit may be missed in grazing-system studies, which typically have not attempted to measure the species being consumed beyond very broad categories such as graminoids vs. forbs.

Behavior-Based Management of Grazing Systems

We began this paper by discussing why rigorous scientific research may not be able to explain the benefits of a rotational grazing system when implemented at the scale of a commercial ranch. The real question is not about why science and application are inconsistent, but rather it is about how we can use scientific findings along with reports of real-world success to improve the sustainability of livestock production on rangelands.

Animal scientists and practitioners increasingly agree on the importance of reducing the stress experienced by livestock when handled.[25,v] One way to do so when applying a

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[iii] For example, Canadian researchers found that cattle in a high-intensity, low-frequency rotational system learned to eat Canada thistle to the extent that thistle stems were virtually eliminated from the experimental pasture.[22]

[iv] Work by Villalba et al.[23] showed that experience with foods can dramatically change diet selection. Lambs that are experienced with foods containing tannins, oxalate, and terpenes eat over 800 g per day of those foods even when they have alfalfa and barely free choice. Sheep that are experienced with low-quality forage eat 20% more than inexperienced animals even if they have nutritious alternatives. Cattle can be trained to eat a variety of weeds, decreasing the weeds' abundance. For a rancher's report on this phenomenon, see Banister.[24]

[v] The best-known proponent of low-stress handling is Bud Williams, whose workshops have been attended and lauded by many thousands of stock growers. For a scientist's view of stress in animals and ways to reduce it, see Grandin and Johnson.[25]

new grazing system is to use animals that are already familiar with the landscape, as would be the case for ranchers running a traditional cow–calf operation. This may be impractical for researchers, however. To minimize effects of stress in a rotational grazing experiment, it would be best not to begin a study immediately, but to allow the animals time to become familiar with novel locations and plants, time to learn to respect electric fences, and time to grow comfortable with grazing under more crowded conditions.

Ranchers considering a shift to rotational grazing will be most successful if they think carefully about how it fits with their own behavioral patterns as well as those of others who are significant in their lives. Changes in management should fit one's life stage. For example, a rotational grazing system may be less viable for people who have constraints on their time such as a full-time job in town or an elderly parent needing hours of daily care. It is easier to make a substantive change in management practice when there are sources of support in the community than when there is likely to be opposition, and more importantly when one's family is supportive. A Colorado rancher who changed grazing systems after attending Holistic Management training described it this way:

> *When I thought I was going to come home and build fences, I . . . got my son and daughter and wife to talk about what was important in their life. I mean that seems a long way from building fences and growing grass, but that's really the important part, because you can make all of those mechanical adjustments but if you don't get the deep down stuff of where you're headed in life with the rest of your family, it isn't so great.*[17]

For researchers seeking to unravel the relative benefits of different grazing systems, the challenge is to design a study that mimics as much as possible the behavioral influences on success or failure in a ranching setting. If the experimental requirements for consistency of measurement and treatment preclude adaptive management midway through a grazing trial, perhaps it would be best to try another research approach altogether. For example, much could be learned from longitudinal research that employed a small number of case studies over 3 or more years. While many of our most familiar statistical tests could not be used, it is possible in such research to isolate the factors that are associated with a successful transition from continuous to rotational grazing but are not seen in operations where benefits are not seen. If the case study also entailed making the same kinds of utilization and animal production measures commonly used in experiments, it could be possible to determine whether the perceived benefits of rotational grazing are as real as many ranchers say they are.

There remains disagreement within our profession about whether a rotational grazing system is always, sometimes, or rarely superior to continuous grazing. What seems certain is that some ranchers *have* benefited from rotational grazing, and others will seek help from federal agencies to follow in their footsteps. In those instances, technical assistance programs should consider behavioral factors, for example by encouraging the use of alternative sources of information. Some ranchers do not trust government range conservationists but trust university extension; for others the reverse is true. Management change can be made more successful by promoting opportunities for ranchers to share information with each other, because that is where the trust is greatest and the expertise is most relevant.

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References

1. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
2. Goodloe, S. 2001. Four decades of understanding watershed degradation and our rehabilitation of the Carrizo Valley Ranch. *In:* New Mexico watershed management: restoration, utilization, and protection. Las Cruces, NM, USA: New Mexico Water Resources Research Institute. p. 1–10.
3. Sayre, N. F. 2001. The new ranch handbook. Santa Fe, NM, USA: Quivira Coalition. 101 p.
4. Pavlov, I. P. 1927. Conditioned reflexes. London, United Kingdom: Oxford University Press. 430 p.
5. Skinner, B. F. 1965. The behavior of organisms: an experimental analysis. Boston, MA, USA: Copley. 457 p.
6. Provenza, F. D. 2003. Foraging behavior: managing to survive in a world of change. Logan, UT, USA: Department of Forest, Range and Wildlife Resources, Utah State University. 63 p.
7. Wiedmeier, R. D., F. D. Provenza, and E. A. Burritt. 2002. Exposure to ammoniated wheat straw as suckling calves improves performance of mature beef cows wintered on ammoniated wheat straw. *Journal of Animal Science* 80: 2340–2348.
8. Distel, R. A., and F. D. Provenza. 1991. Experience early in life affects voluntary intake of blackbrush by goats. *Journal of Chemical Ecology* 17:431–450.
9. Mirza, S. N., and F. D. Provenza. 1990. Preference of the mother affects selection and avoidance of foods by lambs differing in age. *Applied Animal Behavior Science* 28:255–263.
10. Green, G. C., R. L. Elwin, B. E. Mottershead, and J. J. Lynch. 1984. Long-term effects of early experience to supplementary feeding in sheep. *Proceedings of the Australian Society of Animal Production* 15:373–375.
11. Howery, L. D., F. D. Provenza, R. E. Banner, and C. B. Scott. 1998. Social and environmental factors influence cattle distribution on rangeland. *Applied Animal Behavioral Science* 55:231–244.

12. Flores, E. R., F. D. Provenza, and D. F. Balph. 1989. The effect of experience on the foraging skill of lambs: importance of plant form. *Applied Animal Behavioral Science* 23:285–291.
13. Kennedy, C. A., and M. W. Brunson. 2006. Creating a culture of innovation in ranching: a study of outreach and cooperation in west central Colorado. *Rangelands* 29(3):35–40.
14. Kennedy, C. A. 2005. Learning and adoption of range management innovations among ranchers in west-central Colorado [thesis]. Logan, UT, USA: Utah State University. 104 p.
15. Rogers, E. M. 2003. Diffusion of innovations. 4th ed. New York, NY, USA: Free Press. 518 p.
16. Ison, R., and D. Russell. 2000. Agricultural extension and rural development: breaking out of knowledge transfer traditions. Cambridge, United Kingdom: Cambridge University Press. 239 p.
17. LeValley, R. B., J. Murray, F. Reed, J. Hawks, and D. Bradford. 2000. Range management schools for ranchers: or how to teach plant phenology, forage utilization, plant physiology, and other esoteric range management concepts to a bunch of cowboys. *Rangelands* 22(4):10–13.
18. Savory, A., and J. Butterfield. 1998. Holistic management: a new framework for decision making. Washington, DC, USA: Island Press. 616 p.
19. USDA Natural Resources Conservation Service. 2006. National range and pasture handbook, December 2006. Fort Worth, TX, USA: USDA NRCS. Chapter 5, Section 1(f), p. 8.
20. Didier, E. A., and M. W. Brunson. 2004. Adoption of range management innovations by Utah ranchers. *Journal of Range Management* 57:330–336.
21. Mounier, I. Veissier, S. Andanson, E. Delvla, and A. Boissy. 2006. Mixing at the beginning of fattening moderates social buffering in beef bulls. *Applied Animal Behavior Science* 96:185–200.
22. DeBruijn, S. L., and E. W. Bork. 2006. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. *Biological Control* 36:305–315.
23. Villalba, J. J., F. D. Provenza, and GouDong. 2004. Experience influences diet mixing by herbivores: implications for plant biochemical diversity. *Oikos* 107:100–109.
24. Banister, R. 1981. Eight principles of range management. *Rangelands* 13:85–86.
25. Grandin, T., and C. Johnson. 2009. Animals make us human: creating the best life for animals. New York, NY, USA: Houghton Mifflin Harcourt. 352 p.

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Concentrating livestock can increase utilization of forage resources, such as Kochia. Photo courtesy of Jim Thorpe.

Improving Field-Based Experimental Research to Compliment Contemporary Management

By Tony Svejcar and Kris Havstad

Improving both communication and collaboration between rangeland managers and researchers are among the objectives of this special issue of *Rangelands*. The impetus for this series of papers was the article by Briske et al.,[1] which questioned the value of rotational grazing relative to continuous grazing for increasing plant and animal production. Although grazing and grazing systems are the focus, we suggest that the general principles contained in our discussion really should apply to a host of landscape-level issues.

If we are to improve communication between managers and researchers (those who develop the science), it would be helpful for each group to understand limitations facing the other, so we are offering a perspective we share as scientists. We can say without reservation that rangeland research is expensive (usually requiring substantial labor inputs), slow, and has to be very targeted. We have the resources to tackle only a small portion of the problems stakeholders bring to our attention. We try to focus on developing general principles because we know we can study only a limited number of plant communities, treatments, and years. In the sections that follow, we try to outline some of the limitations of traditional field research. We strongly believe that science has a major role to play in management decisions, but there are inherent limitations to science that define and constrain its role in informing management.

Spatial scale is one of the more difficult stumbling blocks for integrating science and management. Traditional experimental designs replicate experimental units (things that are measured to evaluate responses to treatments such as plants, plots, pastures, or animals) to account for natural variability so that treatment comparisons can be made. This often requires a relatively small-scale focus. Certainly, there are instances in which principles indentified from research at a small spatial scale have application at larger scales. For example, small-scale plot studies in the early 20th century clearly identified limits to seasonal and early growing season grazing use of individual perennial grasses, such as bluebunch wheatgrass and black grama. We know those identified limits have application to allotment and ranch-scale management decisions for maintaining important forage species. Another example would be small-scale work on plant response to fire. The nature of a fire may change with scale, but the principles of plant response are consistent across scales. Those small-spatial-scale principles, in a sense, scale up quite effectively. However, there are also cases in which research is difficult to scale up. For example, we may know how individual plants respond to grazing, but animal preference and grazing distribution come in to play at larger scales to influence plant community response. We may manage to maintain individual species and still shift community structure. We believe this issue of scale deserves much more attention from researchers.

There are reasons to be optimistic that we can overcome the obstacles to better integration of management and research. There have been and continue to be plenty of success stories. Some of the newer tools have helped us all gain a better appreciation and description of scale issues (global positioning systems and geographic information systems for example) and our analysis capabilities will only continue to improve. We believe that some of the tools for research on a larger scale will open the door for further collaborations between managers and researchers. We hope that the discussion that follows will 1) point out some of the limitations of traditional field-based research and 2) provide suggestions for some of the approaches that might help us move forward.

The Scientific Method

It is constructive to initially discuss some of the approaches used by both researchers and managers. In this and the next section we will outline some of the steps used by each group. These following comments should apply to most natural

resource–oriented disciplines, but our focus is clearly on rangeland.

Science is generally defined as the acquisition of knowledge that allows us to predict outcomes. Modern science is viewed as a system of acquiring knowledge, usually by applying the scientific method. There are four major steps in a traditional approach.

1) *Identify a problem to solve and use experience or published information to make sense of the problem (explain possible outcomes).* We will use the Briske et al.[1] paper as an example of the process. In this case they used prevailing recommendations as the starting point: that is, that there will be benefits to applying rotational grazing above those accrued though the managed use of continuous grazing.
2) *Develop specific testable hypotheses pertaining to possible outcomes.* A hypothesis is simply an assumed proposition that can be tested in a structured and repeatable fashion (i.e., other people can test your hypothesis). This step requires considerable attention because it drives the rest of the process. The bottom line is that a hypothesis must be written in a manner that allows us to accept or reject the hypothesis once we have completed the process. Continuing with the Briske et al.[1] example, the hypothesis could be this: rotational grazing will increase plant and animal productivity compared to continuous grazing. We might write that as two separate hypotheses, one for plants and one for animals, because one could prove true and the other false.
3) *Design experiments that allow us to accept or reject the hypotheses we developed in step 2.* In the Briske et al.[1] example, they summarized studies that have been performed over the years. So the designs were already determined by the scientists conducting the studies. The following general rules apply as we are designing a new study. Statistical designs and analysis procedures must be determined *before* the experiments are performed. For decades much of rangeland research was tightly constrained within experimental designs that conformed to classic analyses of variance statistics. It is much more common today to see experimentation employ newer statistical approaches to designs and analyses that are not constrained in this fashion. An excellent example is the set of nontraditional analyses for stream data collected from a large watershed in Wyoming to infer water quality responses to different management practices.[2] Irrespective of the design and analyses employed, though, statistical procedures are necessary to express some level of confidence that our inferences about treatments are beyond random variation. So replication and random assignment of treatments are big issues.[3,4] One useful approach for minimizing site differences is the delineation of landscape variation based on ecological sites.[5] For example, applying experimental treatments, such as different stocking rates, within similar ecological sites helps limit natural variation. This is an approach researchers have generally used, often without a formal system in place. We must ensure to the greatest degree possible that we are not systematically favoring one treatment over another through site selection.[6]
4) *Analyze the results of experiments using the preselected statistical procedures and either accept or reject the hypotheses.* If we reject a hypothesis, ideally we use the new information in step 1 and repeat the process. In our example, Briske et al.[1] found that 87% of prior studies showed no increase in plant productivity with rotational grazing, and 92% of studies showed no increase in animal production with rotational grazing. So in this case, we suggest the next generation of studies on rotational grazing should focus on issues other than plant or animal productivity. And it happens that society is also asking our profession to focus on a wider range of ecosystem services than plant and animal productivity.

We have provided a brief outline of research based on the scientific method. But to be fair we should point out that not all research is hypothesis-driven, or can be designed in a fashion where a hypothesis can be adequately tested with some acceptable level of confidence. A good deal of the research in the ecological sciences has been more descriptive than experimental and may or may not test a specific hypothesis. For example, the majority of plant community classification research is aimed at describing plant community types rather than testing specific hypotheses. That does not mean a hypothesis could not be developed for some of these studies, but at a minimum, observational studies often open the door for hypothesis-driven research. We should also point out that some beliefs and assumptions do not allow formulation of a testable hypothesis, and so cannot be tested by the scientific method.

Another example of nonhypothesis research used in rangeland management has been the case study approach. This technique has been effectively used on occasion to provide comparisons of different management practices applied at large spatial scales, such as entire ranch levels. We will discuss this approach later in this paper.

Management Defined

Most of the formal definitions of management revolve around business and managing people, with many of the dictionary definitions reading something like, "the art of managing"—not very helpful. A more useful contemporary definition[7] would be this: "the guidance and control of action required to execute a program." There are also steps associated with management.

1) *Planning.* Deciding what needs to happen and when.
2) *Organizing.* Ensuring that resources are available to carry out the plan.

3) *Staffing or skill acquisition.* Analyzing jobs and skill sets required to carry out the plan. If necessary, hiring appropriate individuals or seeking required training.
4) *Leading.* Determining what needs to be done and getting people to do it (or in the case of a one-person operation doing it yourself).
5) *Controlling, monitoring.* Checking progress against plans, which may need modifications based on feedback (sounds like adaptive management).
6) *Motivating.* Stimulating an individual to take action to accomplish a desired goal (could be self-motivation in that one-person operation).

If we use a grazing example, a rangeland manager may have several goals as part of their plan. If private land is involved, then profitability is likely to be a goal along with sustainability and probably meeting some priority conservation objectives. A manager may be responsible for huge acreages and have limited resources to carry out the task. The opportunities for data collection are fairly limited in most cases. Science is useful at several steps in this process including in the design of a management system (planning). Science-based information can help provide a logical starting point. But there are limitations to what we can realistically demand of science. We agree with the following assertion by Provenza: "controlled experiments are not a good tool to investigate various management options, for example, to compare landscape level manipulations such as different grazing systems."[8] However, these points may not be relevant if a manager is responsible for small or relatively uniform land areas, or the outcomes of interest are not at a landscape scale.

Scale

Spatial scale presents one of the more challenging impediments to bridging rangeland science and management in the 21st century. Today we are much more aware that rangeland dynamics are influenced by drivers at multiple scales from plants, patches, pastures, properties, landscapes, watersheds, continents, and, eventually, from the global scale. We define "drivers" as underlying climatic, economic, social, political, or biotic forces that cause change, such as drought, species invasion, management activities, or human population growth. In traditional experimental design, the goal is to account for background variability so we can compare treatments. The level of landscape variability for most rangelands is very high,[9] which forces researchers to use relatively small experimental units. However, an average family ranch in the Great Basin, as an example, may graze cattle on 30,000 acres or more of rangeland. Let's assume a 400-cow operation and rangeland rated at 10 acres per animal unit month (AUM). If there was a 7-month grazing period (April through October), the land requirement would be 400 cows × 10 acres/AUM × 7 months = 28,000 acres. Over that size of land area there may be large elevation gradients, a variety of different plant communities, and a variety of responses to grazing. It would be virtually impossible to use a traditional experimental approach to compare grazing systems at the entire ranch level. That would require finding a similar adjacent ranch on which to apply the other system and even that would not address the need for replication. In the western United States, it is very difficult to find similar ranches; each has its own individual set of resources. These issues are not unique to grazing, but also apply to many other issues including water quality of streams and rivers, habitat for highly mobile wildlife species, landscape expansion of invasive species, and wildfire impacts.

A more reasonable application of science to management might involve decision-making about individual pastures, plant communities, or species of interest. For example, we know from experimental evidence that early-season grazing favors young bitterbrush plants and late-season grazing can have negative impacts. If favoring bitterbrush is an issue for a particular pasture, then management informed by science would result in grazing before bunchgrasses reach the boot stage.[10] There is published evidence that cattle will use riparian areas harder after the uplands dry and ambient temperatures increase.[11] If riparian condition is an issue, pastures containing streams may need to be used early, or for a relatively short period if used late in the season. In the past many rotational grazing systems were set up to vary timing of defoliation from year to year. There are numerous studies showing that defoliation at specific growth stages (typically the boot stage in grasses) can have a negative impact on subsequent forage production.[12] Of course, these are decisions that managers must make based on a host of factors, including experimental science.

Recommendations

Given these concerns, issues, and limitations facing science and its application to management, we provide the following five recommendations to improve the capacity of science to further inform management.

1) *Incorporate relevant spatial scales.* It appears to us that the issue of scale really needs more attention from our profession and indeed from all natural resource–oriented professions. We need a common framework and language, which allows for improved communication and planning. There is currently a good deal of frustration among managers and policy-makers who are increasingly being asked to address issues at larger scales often with inadequate science. In many cases, we within the rangeland management profession have not discussed which problems to address at which scale. For example, reseeding rangeland may be a small-scale decision, but the specific location of a seeding on the landscape may have wildlife benefits. In this hypothetical case, seeding may have implications for reducing bare ground or invasive species at the patch level on many sites, or it could also have implications for wildlife if

conducted at a landscape position deemed to be important deer winter range. We suggest that the article by Bestelmeyer et al.[5] provides a good starting point in spatial scale discussions.

2) *Encourage multisite studies.* Rangelands can be extremely variable and responses to individual treatments will likely vary with site. Without multisite studies, we are often forced to make generalizations that extend beyond the range of the data. An example of a multisite study would be that by Miller et al.[13] Plant community response to western juniper invasion was quantified on 108 sites and responses were grouped into broad categories. This approach allowed managers to predict responses to juniper control based on site characteristics. This study is also a good example of cooperation between managers and researchers; managers provided the land and applied the treatments, and researchers collected and analyzed the data and published the results. However, we recognize that there will always be significant geographical gaps in our areas of study and site-specific applications. The important role of science-based models that can reflect larger principles and broader inferences cannot be underestimated.

3) *Encourage enterprise-level research where possible.* We presented the challenges to this type of work previously (comparing entire ranches, or other large-scale entities). But where opportunities exist, we should encourage this type of large-scale approach. And it may be necessary to select portions of the larger enterprise to compare. An excellent example of the case study approach was the report of Hinton[14] that compared 15 different ranch properties in Queensland, Australia, to draw inferences about different management practices and their profitability. The case study approach could be used more often and more widely in rangeland management with considerable effect. However, the limitations of this approach should be recognized. Often, the case study approach lacks a true control treatment, or an ability to specifically identify the causes, or underlying mechanisms, of an observed response. Case studies also require willing participants for relatively long periods of time. Though the inferences drawn from case studies may not be subjected to statistical rigor, and are often regarded as weak, this approach provides real opportunities to observe in a structured fashion large enterprise-scale application of management practices. Case studies of this nature could be designed to involve interested parties, from landowners to management professionals as well as the scientific community and interested public. It would be extremely important that this type of approach be developed for long time periods to contend with temporal variability in climate (as discussed in the next section). Measurements may not be necessary every year, but rather could be spread over a reasonable time horizon.

4) *Commit to long-term studies.* Rangelands are well known for tremendous year-to-year variation. Rangeland drivers, such as climate, may not be sufficiently well acknowledged by either scientists or managers when using research results to inform management decisions. Increasingly, we are recognizing the role of specific episodes, such as major droughts that occur in quasidecadal time scales, in driving rangeland systems in response to management.[15] Research to evaluate novel management practices would have to be of sufficient duration to explain how the systems in question fare during the type of episode that often shapes a landscape. In addition, changes in grazing systems may have subtle effects that take years to be expressed.

5) *Add controls (nontreated areas) to help evaluate management effects.* Given the variability inherent in rangelands (over both time and space), tremendous value can be added to monitoring efforts by including controls in the design of management projects. In many cases, the control areas can be relatively small and still allow an objective assessment of treatment effects. The side-by-side comparisons of controls and treatment areas can be useful in explaining treatment results to stakeholders and the interested public. In many cases, this is an area where managers may want to engage researchers to help with initial designs and sampling protocols. We cannot overemphasize the strength of a treatment/control comparison compared to simply conducting long-term monitoring. This approach maximizes our ability to learn while applying management.[16]

Concluding Remarks

Rangeland management has long been described as both a science and an art.[17] Certainly, the management of rangeland resources, especially during the last half of the 20th century, can be characterized by practices commonly informed by science. There are a number of management practices in which synthesized bodies of experimentally derived observations have provided science-based rationales for their application and use. The collection of recorded observations from different field experiments in diverse environments has often resulted in reasoned understandings of relevant ecological processes and the structures and/or dynamics of these systems. At its core, rangeland management is a set of practices implemented over time that reflect a manager's understanding of those structures and dynamics. A well-articulated body of scientific evidence can enhance understanding beyond generational knowledge or site-specific experiences. Tension, though, between practitioners of science and art can result if synthesized knowledge is seen as either counter to or unsupportive of anecdotal knowledge or site-based perceptions. We have acknowledged this tension in the past, and understand that what we learn from science is provisional and we will continue to learn.[18] At issue here is the reconciliation of existing scientific evidence

with a perceived understanding accumulated from either personal or generational experiences, or accumulated over time at specific sites.

For more than 400 years Western culture has been closely linked to science and scientific advances from medicine to physics to genetics to engineering to ecology. However, throughout this history we have seen science progress and provide its greatest contributions when it is understood within the general culture and eventually applied by the general population. Rangeland management may be more correctly viewed, then, as the artistic application of science-based principles. The role of science in rangeland management is not to try to evaluate each novel approach of the artist, but to continue to provide the principles that have application to the art. Science has provided basic principles for management tied to the spatial and temporal scales and uses of the 20th-century land manager. The challenge for science today is to provide the principles for the spatial and temporal scales and the uses confronting the 21st-century resource manager. What has changed is the demand for a wider variety of goods and services, and increasing recognition of the linkage among spatial scales. We think that these science-based principles will emerge from a combination of cross-scale, enterprise-level, interdisciplinary, and long-term studies. We have an excellent base of research and management experience, which can lead us to the next generation of grazing hypotheses and management treatments. We suggest that cooperation and interaction between managers and researchers will be critical for future success in this arena.

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References

1. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
2. Ellison, C. A., Q. D. Skinner, and L. S. Hicks. 2009. Assessment of best-management practice effects on rangeland stream water quality using multivariate statistical techniques. *Rangeland Ecology and Management* 62:371–386.
3. Larsen, R. E., W. C. Krueger, M. R. George, M. R. Barrington, J. C. Buckhouse, and D. E. Johnson. 1996. Livestock influences on riparian zones and fish habitat: literature classification. *Journal of Range Management* 51:661–664.
4. Sarr, D. A. 2002. Riparian livestock exclosure research in the western United States: a critique and some recommendations. *Environmental Management* 30:516–526.
5. Bestelmeyer, B. T., A. J. Tugel, G. L. Peacock, Jr., D. G. Robinett, P. L. Shaver, J. R. Brown, J. E. Herrick, H. Sanchez, and K. M. Havstad. 2009. State-and-transition models for heterogeneous landscapes: a strategy for development and application. *Rangeland Ecology and Management* 62: 1–15.
6. Peterson, R. G. 1985. Design and analysis of experiments. New York, NY, USA: Marcel Dekker, Inc. 429 p.
7. Shead, M. 2007. Definition of management. Available at: www.leadership501.com/definition-of-management/21/. Accessed 29 July 2009.
8. Provenza, F. D. 2000. Science, myth, and the management of natural resources. *Rangelands* 22:33–36.
9. Brown, J. R., T. Svejcar, M. Brunson, J. Dobrowolski, E. Fredrickson, U. Krueter, K. Launchbaugh, J. Southworth, and T. Thurow. 2002. Are range sites the appropriate spatial unit for measuring and monitoring rangelands? *Rangelands* 24:7–12.
10. Ganskopp, D., T. Svejcar, F. Taylor, and F. Farsvedt. 2004. Can spring cattle grazing among young bitterbrush stimulate shrub growth? *Journal of Range Management* 57:161–168.
11. Parsons, C. T., P. A. Momont, T. DelCurto, M. McInnis, and M. L. Porath. 2003. Cattle distribution patterns and vegetation use in mountain riparian areas. *Journal of Range Management* 56:334–341.
12. Ganskopp, D. 1988. Defoliation of Thurber needlegrass: herbage and root responses. *Journal of Range Management* 41:472–476.
13. Miller, R. F., T. J. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. *Journal of Range Management* 53:574–585.
14. Hinton, A. W. 1995. Land condition and profit: a study of Dalrymple Shire properties. Queensland, Australia: Department of Primary Industries, Project No. 90R535, National Landcare Program No. 91. 41 p.
15. Stafford Smith, D. M., G. M. McKeon, I. W. Watson, B. K. Henry, G. S. Stone, W. B. Hall, and S. M. Howden. 2007. Learning from episodes of degradation and recovery in variable Australian rangelands. *Proceedings of the National Academy of Sciences of the United States of America* 104:20690–20695.
16. Reever-Morghan, K. J., R. L. Sheley, and T. J. Svejcar. 2006. Successful adaptive management—the integration of research and management. *Rangeland Ecology and Management* 59:216–219.
17. Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range management. 3rd ed. New York, NY, USA: McGraw-Hill. 532 p.
18. Watson, L. W., D. G. Burnside, and A. M. Holm. 1996. Event-driven or continuous; which is the better model for managers? *Rangeland Journal* 18:351–369.

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Viewpoint: New Approaches and Protocols for Grazing Management Research

By Mort Kothmann, Richard Teague, Heriberto Díaz-Solís, and William Grant

Stoddart and Smith[1] defined range management as "...the *science* and *art* of planning and directing range use..." (p. 2). Over the past 100 years, the art and science of grazing management have sometimes taken divergent paths. Early observations that moderate stocking rates improved rangeland health and vegetation composition were followed by research that identified the ecological and physiological mechanisms for vegetation responses to grazing. However, these scientific principles have seen limited application in grazing systems research. Briske et al.[2] concluded, "The ecological relationships of grazing systems have been reasonably well resolved, at the scales investigated, and a continuation of costly grazing experiments adhering to conventional research protocols will yield little additional information." If further research "at the scales investigated" and "adhering to conventional research protocols" is not warranted, does this mean there should be no further grazing management research?

We suggest that more grazing management research is needed, but with new protocols. Heady[3] stated, "The time has arrived to organize the information from research or few-factor analysis with whole-system practical experience so that specialized grazing systems will be even better" (p. 897). We suggest that achieving this laudable goal will require addressing grazing management research not as the comparison of fixed treatments with the "winner" recommended as a best management practice, but as an analysis of a dynamic system that requires continuous management. In this paper, we present modeling as one component of a new research protocol for grazing management research. Although researchers have modeled ecosystem functions for over 40 years, there are few applications focused specifically on grazing management.

Observations on the Relationship between Science and Management

Forester,[4] considered to be the father of systems analysis, addressed the respective roles of both the art and science of management and, although his discipline was business management, his observations are relevant to rangeland management.

> *The art develops through empirical experience but in time ceases to grow because of the disorganized state of its knowledge. When the need and necessary foundations coincide, a science develops to explain, organize, and distill experience into a more compact and usable form. As the science grows, it provides a new basis for further extension of the art...*
>
> *The manager has often found that management science did not deal with his most urgent problems. It has not learned how to take into account the variables that he knows to be important. It is not cast in a language with which he is familiar...*

Currently, few grazing management research studies are being conducted on US rangelands. However, innovative ranch managers are using adaptive management techniques to successfully develop more complex, site-based, grazing management programs on their ranches.[5] Successful ranch managers apply adaptive management principles because what is optimal for one ranch may not be optimal for another ranch. Past grazing management research has not evaluated this adaptive management approach. Research should identify key processes and principles and should structure them in management-oriented decision-support models that allow managers to develop unique grazing management programs that can successfully adapt to ever-changing combinations of physical, biotic, and social resources and needs.

Provenza[6] defined adaptive management as the continuing process of defining visions and goals → setting objectives → implementing practices → monitoring → changing behavior in repeated learning cycles. Adaptive management

is not looking for prescriptions but rather understandable descriptions of the components, mechanisms, and processes that can be used in repeated cycles of adaptive management to develop successful grazing management programs. This view of management does not ask science to be a predictive oracle attempting to guide grazing management. Rather, science is a way to understand the processes of nature and to monitor and assess ecosystem responses to management. Adaptive management is about flexibility in the face of change and uncertainty.

Management implies making decisions, which involves flexibility. Adaptive management involves continuously applying the cycle described by Provenza.[6] Grazing management on rangelands involves various seasons of use, kinds and classes of animals, kinds and condition of vegetation, characteristics of the soils, topography, and climate, levels of management knowledge and skill, and economic and financial resources that are unique to each ranch. This complexity greatly exceeds the ability of traditional field research to test the vast array of possible "grazing systems." According to Forester, researchers should identify the essential components, interrelationships, and processes of successful management programs in order to understand how leading practitioners manage successful programs. It is the role of researchers to formulate and quantify the concepts and principles so that other managers using adaptive management on their ranch can successfully apply the principles, not a best-management practice.

Changing the Research Protocol

Field experiments using traditional analysis of variance (ANOVA) statistical designs compare responses (e.g., plant and animal production) of defined treatments using the null hypothesis (no difference) as the default. If the null hypothesis is rejected, then "winners" and "losers" are declared. True replication is usually scant or absent. In the comparison of management "systems," specific quantitative cause and effect hypotheses are generally absent. Because treatments are fixed, management during the course of the study is constant. This eliminates the possibility of using adaptive management to capitalize on emergent opportunities or problems. Regression equations can be fit to data sets, but they have limited portability to new locations and very limited capability for formulating new management options.

We propose that grazing research of the future should formulate quantitative functions relating plant and animal responses to system components that are structured into simulation models. These models become the default hypotheses tested using field data from research studies or from observations on managed ranches.[7] This approach allows the evaluation of whole managed systems, not just fixed treatments. As the model is tested repeatedly against different data sets, it is either validated or specific components are rejected and then modified to incorporate the new information. Such models embody much information about the components and their functional relationships in managed ecosystems. Simulation models constructed based on functional relationships can be used regionally and can provide the opportunity to explore many management alternatives. Again, promising new management options identified from the simulation experiments will need to be tested with field studies. This iterative approach of using field data to formulate models, applying the models to field problems, modifying the models, and testing them with new field data was described by Walters.[8]

Most ecosystem models constructed over the past 40 years have been complex mechanistic models. Some have been proposed as decision tools (e.g., Simulation of Production and Utilization of Rangelands [SPUR]) for management of grazing lands, although their use by managers has been very limited. The explicit, detailed representation of ecological processes in these models is scientifically interesting, but the complexity of the databases required to parameterize them and the complexity of their output limits their application in management of grazing lands. The proposed use of increasingly detailed mechanistic models as decision-making tools for management of grazing lands has drawn attention to key problems inherent in the more detailed approach. For example, the number of parameters grows exponentially as processes are decomposed into finer grain and lower levels of organization; small errors in the estimation of individual parameters may have large cumulative effects on model performance; and predictions from the detailed model still must be tested by reference to, and experiments conducted at, the higher levels of aggregation in which managers operate. Thus, while detailed mechanistic simulation models are attractive to researchers for their predictive power, they find few applications in management settings.

An effective model that supports decision making should be suitable for use by managers. The manager must be able to parameterize the model using information that is readily available, and the output must be understandable and applicable to management decisions, i.e., it must not require a skilled research scientist to use it. The parameters need to be observable and measureable in a field setting. These models must be flexible, allowing managers to make adjustments based on monitoring data (e.g., adaptive management). We have found that models with parameters based at the management level of organization are more stable and useful for management than the complex mechanistic models. Management itself should be viewed as experimentation at the highly aggregated level of the intact system.[8] This concept has not been widely accepted or used in the modeling community.

Why do we recommend modeling as a "new" research approach for grazing management when there have been so many models built? This is a reasonable question. Modeling requires conceptualization of the system with specification

of the components, structure, and processes at specific levels of organization. It requires quantification of interdependencies of system components. The model becomes a dynamic complex hypothesis of system functions and relationships. Inputs and outputs of the model can be tested against field data. There are many ways to represent the biotic, physical, and social components of grazed systems. Most modeling research has been conducted by scientists who have been trained in reductionist approaches, and they have built mechanistic models that are based on lower levels of system organization. Our approach has been to conceptualize model components at the management level of organization. This greatly reduces the number of model components and functions and provides greater model stability. It is not the purpose of this paper to describe this process, but references are provided that will allow the interested reader to access publications reporting this research.

We have developed and evaluated simple models that represent selected ecological dynamics of grazing-land systems, and these can be parameterized based on information that is readily available. These models support specific management decisions with output that is both understandable and useful to managers. Philosophically, our modeling approach is to develop the simplest model that will represent the key state variables and processes of interest of the system and test them against field data to determine whether additional components are needed for the model. Components that are not needed for the model to adequately represent the system processes are also removed, much like selecting independent variables that need to be included in the model when using the stepwise regression technique.

Two models that we have designed to support adaptive grazing management are presented as examples of different types of management models. Simple Ecological Sustainability Simulator (SESS) is a strategic-level model designed to simulate vegetation and livestock responses to management alternatives over decades. The Grazing Manager (TGM) is an operational-level decision-support model that facilitates planning, monitoring, and analysis of grazing management based on annual forage balance (e.g., forage production and forage demand). These models are not new approaches to grazing management, but they are examples of models designed specifically to support management decisions. We think that the concepts and approaches used to develop them can provide some new insight for the development of a broader suite of management-oriented models.

SESS: A Simple Ecological Sustainability Simulator

We developed, parameterized, and corroborated SESS as a rangeland management model for Texas and northern Mexico.[9–14] It is capable of long-term (20–50-year) simulations of vegetation responses, animal performance, and economic consequences of different ranch grazing-management options. This model represents a "first step" in quantifying ecological processes and integrating them into an adaptive management framework.

SESS was developed based on simple relationships and expertise of range management researchers of north Mexico and south Texas. The idea of large-scale experiments is new. SESS was built from our years of research experience combined with our knowledge of ranching enterprises and the literature. This year Díaz-Solís is starting with this approach in 10 ranches in different ecosystems of Coahuila, Mexico. This, coupled with current on-ranch research, allows assessment of the short- and long-term biological and economic implications of different range management options. Díaz-Solís has used the original SESS model as a decision-making aid among groups of ranchers in northern Mexico for 5 years.

Models have great potential to enhance our knowledge of ecosystem function and to serve natural resource managers as decision-making aids. Model simulations can address issues at the whole-farm or ranch level, and they can be used to assess the effects of different physical properties, input levels, weather sequences, and management actions in a variety of land management units. We have used the SESS rangeland simulation model to examine the consequences of using different grazing management under a wide range of physical conditions, weather sequences, and management options. This is not possible using field experiments alone. This approach allows us to assess the potential of different management practices to achieve economic and ecosystem service goals in these southern Great Plains agro-ecosystems.

The process of developing a quantitative model highlights fuzzy thinking about the system and identifies knowledge gaps and limitations. During the development of SESS, we found that the forage harvestability threshold varied with the productivity of the site (e.g., forage on low-productivity sites had greater availability at lower levels of standing crop than on high-productivity sites). The National Research Council (NRC)[15] presented an equation for adjusting animal forage intake as a function of forage standing crop. Using the NRC equation for adjusting intake as a function of forage standing crop, SESS predicted that livestock husbandry was not feasible in sites with precipitation lower than 400 mm per year because of severely reduced intake. This led us to develop an alternative hypothesis (e.g., harvest efficiency of herbivores as a function of standing crop is higher in less productive sites). This is an example of how the development and use of models can identify faulty relationships in current science and can suggest alternative hypotheses. Developing more robust and widely applicable functions for grazing management processes is a valid role for traditional science.

Continued use of SESS over a period of years for a variety of different sites and management programs will identify

existing components and processes that should be modified or new variables that should be included to provide more robust predictions. An iterative process consisting of prediction with the model, collection of field data, and adjustment of model structure and parameters will lead to a more robust model that can serve as a general decision support tool to improve decision making of land managers and policy makers.[8]

The Grazing Manager (TGM): An Operational-Level Grazing Management Model

Scientists and managers agree that stocking rate is the most critical grazing management variable. However, the inability of managers to adequately monitor and project annual forage production and availability and to relate forage values to animal production and carrying capacity on their ranch has been a major management limitation. Traditional grazing studies provide average stocking rate recommendations, but the manager must then determine when and how much to adjust stocking rates based on variations in forage production. Research has not provided quantitative decision tools to assist managers with these important decisions. TGM is a simulation model for annual forage balance (e.g., supply relative to demand) that was designed as a decision aid for managers to use to plan, monitor, and evaluate grazing on their ranch in an adaptive management context. TGM was designed to capture the basic elements of the "intuitive" management approach used by many successful grazing managers and to convert it to a quantitative dynamic forage balance model, thus making the decision-making process explicit. It facilitates quantitative analysis and evaluation of grazing management proposed by the manager (e.g., inputs to the model) and validates results by field monitoring on the ranch. TGM has completed five cycles of development.[16–20] In each stage of the development process, we have conducted extensive field testing on many ranches.

TGM Design

TGM was designed as a general model that can be used in many different forage/grazing systems. The following general criteria guided model development.

1. TGM should begin with the simplest model of the forage-balance system that can be conceived. Additional variables should be added only when the model is not adequate to explain observed responses. We eliminated or aggregated variables whenever possible. In short, we kept the model simple and understandable by a manager.
2. TGM should not be site specific, i.e., key model inputs should be entered by the local user. The model should contain the structure for simulation and analysis of input data but should not include site-specific parameters.
3. TGM operates on a daily time step and at the same level of organization as the management decisions it supports (e.g., pastures and herds).
4. TGM variables should be aggregated to use the minimum number of variables possible to address the desired decision analysis. Variable selection is extremely important to making the model both responsive and useable. Explicit representation of detailed components was avoided when an aggregated variable would suffice.
5. All TGM model inputs should be readily available to the manager at reasonable cost of time, labor, and expertise. Keeping the resolution of the model at the management level and selecting aggregated variables facilitate this criterion.
6. TGM should provide useful management information but should not make management recommendations. The manager makes all decisions using analysis that TGM provides.
7. Because management goals and objectives are highly variable, management assumptions should not be made within the model. Our approach was to gather basic inventory and planning data from the manager, to quantitatively analyze the data, to provide a framework for frequent monitoring and updating of plans, and to provide a procedure for on-site validation of the data entered by the manager. This information allows a manager to make better grazing-management decisions.
8. TGM model analyses and reports provide a simple method for the on-site manager to validate the management data they enter against actual system performance monitored in the field.
9. TGM can develop and store annual records of pasture productivity, herd inventory, grazing plans, seasonal forage growth rates, prescribed burns, hay production, and pasture utilization.
10. TGM can be used with grazing methods ranging from continuous stocking to daily rotations.
11. TGM is designed to facilitate and reinforce application of the adaptive management cycle.

TGM software has been evaluated and used on ranches across Texas and in nearly all western states. It can be downloaded free of charge at http://www.thegrazingmanager.com/drupal/.

Future Research Needs Related to Scale

Field research, faced with significant limitations of resources, has not dealt adequately with the effects of scale, of either space or time. Field research and experience gained by ranchers from commercial ranch operations have identified some broad principles; however, this information base is incomplete. Simulation models are needed to address these effects. However, such models will be frivolous unless model output is corroborated with evidence from commercial ranches and/or field experiments.

Spatial distribution of grazing on rangelands is affected by vegetation composition, stock density, pasture size and

shape, topography, location of water, and various other factors. Thus, results of scientific grazing experiments conducted with few animals within small areas often contradict the common sense of experienced ranchers. Development of models that simulate the responses of many individual animals grazing within real landscapes is possible with recent increases in the computing speed of personal computers. Such models provide exciting possibilities for identifying and integrating quantitative "local rules" of grazing obtained from grazing experiments with the general, qualitative "landscape rules" of grazing known by ranch managers. Ranchers whose experience has given them a keen eye for recognizing such patterns can evaluate the grazing patterns produced on simulated landscapes.

Summary

Managers need information to understand functional processes and principles, not prescriptive practices. New approaches for grazing management research must be holistic, straightforward, adaptive, and interactive. Research must be holistic in the sense of recognizing that grazing management is understandable only in relation to the whole ranch enterprise. This is a straightforward procedure if investigations focus on relevant processes at appropriate spatial and temporal scales. It is adaptive and interactive in the sense of viewing grazing management itself as a series of ranch-scale experiments that actively involve ranchers in research design and evaluation. A defining characteristic of such approaches will be the quantitative testing, first via simulation and then in the field, testing specific hypotheses integrated at the whole-ranch scale.

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References

1. Stoddart, L. A., and A. D. Smith. 1943. Range management. New York, NY, USA: McGraw-Hill Book Company, Inc. 547 p.
2. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 61:3–17.
3. Heady, H. F. 1984. Concepts and principles underlying grazing systems. *In:* Developing strategies for rangeland management. Boulder, CO, USA: National Research Council, National Academy of Sciences, West View Press. 2022 p.
4. Forester, J. W. 1961. Industrial dynamics. Cambridge, MA, USA: The M.I.T. Press. 464 p.
5. Howell, J. 2008. For the love of land: global case studies of grazing in nature's image. Charleston, SC, USA: BookSurge Publishing. 496 p.
6. Provenza, F. D. 2008. What does it mean to be locally adapted and who cares anyway? *Journal of Animal Science* 86: E271–E284.
7. Kothmann, M. M., and G. M. Smith. 1983. Evaluating management alternatives with a beef production systems model. *Journal of Range Management* 36(6):733–740.
8. Walters, C. 1986. Adaptive management of renewable resources. New York, NY, USA: MacMillan. 374 p.
9. Díaz-Solís, H., M. M. Kothmann, W. T. Hamilton, and W. E. Grant. 2003. A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazinglands. *Agricultural Systems* 76:655–680. Available at: http://dx.doi.org/10.1016/S0308-521X(01)00115-9.
10. Díaz-Solís, H., M. M. Kothmann, W. E. Grant, and R. De Luna-Villarreal. 2006. Application of a simple ecological sustainability simulator (SESS) as a management tool in the semi-arid rangelands of northeastern Mexico. *Agricultural Systems* 88:514–527. Available at: http://dx.doi.org/10.1016/j.agsy.2005.07.008.
11. Díaz-Solís, H., W. E. Grant, M. M. Kothmann, W. R. Teague, and J. A. Díaz-García. 2009. Adaptive management of stocking rates to reduce effects of drought on cow-calf production systems in semi-arid rangelands. *Agricultural Systems* 100:43–50. Available at: http://dx.doi.org/10.1016/j.agsy.2008.12.007.
12. Dube, S. 2005. A model for adaptive livestock management on semi-arid rangelands in Texas [dissertation]. College Station, TX, USA: Texas A&M University. 125 p.
13. Teague, W. R., W. E. Grant, U. P. Kreuter, H. Díaz-Solís, S. Dube, M. M. Kothmann, W. E. Pinchak, and R. J. Ansley. 2008. An ecological economic simulation model for assessing fire and grazing management effects on mesquite rangelands in Texas. *Ecological Economics* 64:612–625. Available at: http://dx.doi.org/10.1016/j.ecolecon.2007.04.010.
14. Teague, W. R., W. E. Grant, H. Díaz-Solís, U. P. Kreuter, and M. M. Kothmann. 2009. Economic implications of maintaining rangeland ecosystem health in a semi-arid savanna. *Ecological Economics* 68(5):1417–1429. Available at: http://dx.doi.org/10.1016/j.ecolecon.2008.10.014.
15. National Research Council. 2000. Nutrient requirements of beef cattle. Seventh revised edition: update 2000. The National Academy of Sciences. Available at: http//:www.nap.edu/openbook/0309069343/html/R11.html. Accessed October 2009.
16. Casco, J. 1987. Stocking rate decision aid [dissertation]. College Station, TX, USA: Texas A&M University. 226 p.
17. Kothmann, M. M., and R. T. Hinnant. 1990. Grazing management stock adjustments templates. College Station, TX, USA: Texas Agriculture Experiment Station-TAEX, CBZ. 119 p.
18. Kothmann, M. M., and R. T. Hinnant. 1994. The grazing manager version 1 and grazing management stock adjustment templates version 2 [computer program]. College Station, TX, USA: Texas Agricultural Experiment Station MP 1760, Computer Software Documentation Series.
19. Kothmann, M. M., and R. T. Hinnant. 1999. The grazing manager for Windows 95, 98, NT [computer program]. College Station, TX, USA: Department of Rangeland Ecology and Management, Texas Agricultural Experiment Station.

20. Agren, Inc. 2007. The Grazing Manager software. Available at: http://www.thegrazingmanager.com/drupal/. Accessed October 2009.

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Livestock access to forage in rough or rocky terrain can be enhanced with smaller management units associated with rotational grazing systems. Photo courtesy of Tony Svejcar.

Rotational Grazing on Rangelands: Synthesis and Recommendations

By Joel Brown and Mort Kothmann

The role of rotational grazing as a management tool on rangelands continues to be controversial. It is unlikely that the papers in this special issue have convinced anyone advocating an extreme pro or con position to change his or her mind. Our intention with this special issue was not to resolve the controversy in one way or another (not that we could!). We did not intend to refute (or even rebut) the findings of the recent paper by Briske et al.[1] Developing an argument against their findings would require either 1) examining the same literature and coming to a different conclusion or 2) finding peer-reviewed scientific literature that they had overlooked. Although possible, it is not probable that either of these approaches would yield much in the way of useful results.

Likewise, we did not intend to merely confirm the findings of Briske et al.[1] by inviting a new set of authors to re-interpret the same literature for a different audience. The resolution of this issue requires a much more critical and inquisitive (as well as persistent) approach. Even if there is a lack of experimental evidence supporting the widespread application of rotational grazing as a means to enhance plant or animal production, quite a lot of anecdotal evidence and some eloquent arguments provide a substantial amount of support for the promotion and adoption of some form of rotational grazing to achieve other rangeland management objectives. Thus, our challenge is to figure out how to develop testable hypotheses, perform critical experiments, and transfer the relevant information among a variety of decision makers.

First and foremost among hypotheses that need to be tested is the use of grazing systems for the improved management of livestock. While there remains little evidence that grazing-management decisions beyond proper stocking rate, season of use, distribution, and kind and/or class of animal can substantially affect plant or animal production, there is abundant evidence that rotational grazing in some form can dramatically improve the management and profitability of livestock operations (see the article in this issue by Brunson and Burritt). The challenge here is to avoid the temptation to simply compare already accepted attributes of existing systems (e.g., forage production, species composition, and animal gain) with a host of unknown externalities (e.g., management history, soils, climate, managerial expertise, and inputs) and arrive at the questionable conclusion that one approach is "better" than another (see the article in this issue by Svejcar and Havstad). Added to the relatively straightforward livestock operation questions are the larger issues of financial performance in the multi-year time frame that encompasses wide swings in markets and weather and the integration of these attributes in a decision-support framework (see the article in this issue by Kothmann et al.).

Another very important set of hypotheses that will require rigorous testing is the use of rotational grazing (and grazing management in general) to achieve conservation objectives (see the article in this issue by Budd and Thorpe). Although the relationships among livestock grazing (e.g., stocking rate, season of use, etc.), community-scale plant and soil attributes (e.g., structure, species composition, infiltration, etc.), and fine-scale conservation attributes (e.g., habitat, erosion, runoff, etc.) are relatively well known and quantified, the real environmental issues of the immediate future revolve around how we can organize multi-landowner, multi-site activities to achieve meaningful and measureable conservation objectives at landscape and regional scales (see the article in this issue by Krausmann et al.).

Rangeland researchers, advisors, and practitioners can all be justifiably proud of the progress that we have made in defining, transferring, and implementing the basic principles of good management at the paddock and ranch scale. Our new challenge is to systematically organize these and emerging principles of management in order to simultaneously encompass additional (and similarly important) objectives. Clearly, grazing management and rotational grazing are very complex activities, both in terms of their implementation and in terms of their analysis (see the article in this issue by Kothmann). The experimental designs, metrics, and analytical techniques used in the past are unlikely to offer much insight into these more complex questions. With an

acknowledgement of our history, current status, and the future demands of grazing management as our guides, we offer these recommendations for improved grazing management research, information transfer, and assessment.

- There is very little to be gained from the continued application of traditional methodologies to evaluate grazing systems. As we said earlier, the relationships between livestock grazing and soil and/or plant attributes at the community scale are well known and predictable. Unless there are new hypotheses or attributes that are clearly beyond our current powers of inference, these experimental approaches are not a wise use of public resources, and their continued application should be questioned. Similarly, an approach that relies on passionate testimonials without meaningful data lacks credibility and will contribute very little to the profession. The emphasis on science-based decision making at all levels of policy development and technical assistance demands that the ethical use of public funds in any form be based on credible, peer-reviewed evidence.
- Research into grazing management in general, and rotational grazing systems in particular, must integrate managerial expertise into well-designed experiments. The endless array of options and adaptive management responses that must be made in order to successfully manage a rangeland-based livestock production system can easily confound a casual observer. By the same token, an experimental approach that externalizes managerial skill is likely to overlook the most important driving variable. Researchers will have to design experiments that quantify managerial inputs as well as environmental variables with an eye toward integrating those inputs into useable decision support. The case-study methodology seems to lend itself well to this type of approach. However, few practicing rangeland scientists have these skills. Clearly, this area of research represents significant opportunities for bringing new scientists and new skills into the profession.
- Although plant performance is relatively predictable across scales, grazing animals behave differently in large, heterogeneous management units than they do in small homogenous units. And those behaviors, if sufficiently well understood, may offer opportunities to predictably enhance animal performance. Clearly, investigations of animal behavior at paddocks and property scales offer some exciting opportunities for research, but experimental approaches must be geared toward developing predictive models that can be integrated into management or the field will be dominated by intellectual curiosities and will offer little to managers beyond interesting discussion.
- While the vast majority of research has focused on animal performance (i.e., gain and reproductive success), the expenditure of public resources demands at least some shift in emphasis toward the potential environmental benefits of livestock grazing on both public and private lands. Experimental design, analysis, and interpretation must be credible at scales at which the responses of interest (e.g., water quality and wildlife populations) emerge, rather than at the most convenient scale to perform research. Gaining credibility with policy makers will also require expanding and integrating new disciplines to better interpret results and to better communicate in a variety of disciplines and with a variety of users.
- Finally, any successful rangeland management research is dependent upon information transfer via a host of activities in order to make an impact. If grazing-management research shifts to a more integrative approach (across space and time), including practitioners and advisors will be not only necessary, but critical. This more inclusive approach should create new pathways for the flow of information in all directions. However, increased opportunities also mean increased attention and resources devoted to interactions among researchers, advisors, and practitioners. Failure to account for this necessity and to devote resources to these important interactions will doom even valuable information to remain in file cabinets or journal papers, rather than being applied to improve land management. Successful interaction among even highly motivated professionals takes time and money. Policy makers and funding organizations must allocate resources accordingly if they expect results.

The implementation of these recommendations would make grazing management research look vastly different than it does in its current format. New skills, new players, new emphases, and new users could have a dramatic effect on our profession and the way we are perceived. Such radical departures over a short time also have the potential to result in a loss of focus. The adoption of these new approaches must be done at the highest level of scientific rigor regardless of the discipline. The basis for improved management will remain, as it always has been, sound scientific evidence.

References

1. Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology & Management* 61:3–17.

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