SRM Society for Range Management

Upland Bare Ground and Riparian Vegetative Cover Under Strategic Grazing Management, Continuous Stocking, and Multiyear Rest in New Mexico Mid-grass Prairie

By Rick Danvir, Gregg Simonds, Eric Sant, Eric Thacker, Randy Larsen, Tony Svejcar, Douglas Ramsey, Fred Provenza, and Chad Boyd

On the Ground

- We compared land cover attributes on rangeland pastures with strategically managed ranches (SGM), continuously stocked (CS), and rested pastures.
- SGM pastures had less upland bare ground and more riparian vegetative cover than adjoining CS pastures, and SGM pastures had bare ground cover comparable to pastures rested from grazing for three or more years.
- Differences in riparian cover between management types were greatest in years of near-average precipitation and lower in years of high precipitation or drought.
- Remote sensing technology provided a means of quantifying range condition and comparing management effectiveness on large landscapes in a constantly changing environment.

Keywords: complex systems, strategic grazing management, remote sensing, upland bare ground, riparian vegetation.

Rangelands 40(1):1–8
doi 10.1016/j.rala.2017.12.004

Ranchers' livelihoods depend on maintaining animal productivity, ranch profitability, and healthy soils and plants in highly variable environments. Having the knowledge and flexibility to adaptively manage in the face of change can determine whether managers meet these goals. While many ranchers continue to manage with moderate continuous stocking, others have adopted more management-intensive approaches to achieve their ecological and economic goals.[1–3]

We used remote sensing technology in this case study to quantitatively assess whether ranches using strategic grazing management (SGM)[1,3] and rotational grazing had less upland bare ground and more riparian vegetation than neighboring ranches that did not use SGM. SGM ranchers managed with long plant recovery periods, short grazing periods, few herds, and multiple pastures.

Published reviews of the scientific literature have concluded that existing experimental evidence does not support the hypothesis that rotational grazing outperforms moderate continuous stocking in plant or animal productivity.[4] Other reviews suggest that experimental grazing research often fails to consider the influence of external factors on management effectiveness. These factors include spatial scale, the adaptability of managers to changing conditions, and their desire to achieve conservation goals.[4–7]

The need to understand the impacts of management practices on working landscapes has never been greater. Land, water, and wildlife conservation organizations increasingly prescribe more intensive management practices, including rotational grazing, with the goal of increasing resilience.[6] Studying working ranches can help document management effectiveness. "Monitoring outcomes of various practices in a management context can contribute to more rapid development of local knowledge than more traditional forms of experimental research."[2]

Few studies have quantitatively compared management strategies on large working landscapes, as applied by managers adapting and making decisions in a constantly changing environment. Ranch managers continually learn and adapt. Practitioner knowledge, the practices applied, and environmental factors interactively affect economic and ecological outcomes.[1,5,6] It can be difficult to assign cause and effect to specific treatments and outcomes on working lands with certainty.[1,2,7] However, resource managers and researchers working collaboratively may increase their understanding of creative systems, leading to principles-based management practices.[1,7]

To understand the behavior of organisms and environments, scientists attempt to develop principles about processes.[1] Principles of plant and animal behavior help guide our expectations about possible outcomes, but they do not guarantee certainty of those outcomes. An unexpected outcome does not necessarily mean the principles are wrong, but rather reflects the dynamism of biophysical processes and our incomplete knowledge as systems continually change. Through such experiences, we learn about the behavior of organisms and landscapes that we did not previously understand.

Despite the complex nature of biophysical systems, ranchers need ways to assess ecological progress, and grazing management practices must be science-based if they are to be broadly accepted. There is also a need to compare and quantify management effectiveness at large spatial scales.[1,2,5] Comparing differences in land-health metrics between adjacent lands under differing management strategies can provide useful feedback to ranchers as they assess landscape-scale management effectiveness. In this study, the four subject ranch managers wished to know how their ranches responded ecologically to SGM compared with their prior management style of continuous stocking (CS) (pastures grazed growing season-long or year-long). Because most grazed lands adjoining the subject ranches were continuously stocked pastures, we saw an opportunity to compare range cover characteristics on sites of similar ecological potential, but under different management.

The Ranches

The ranches were situated on broad valleys and mesas in eastern New Mexico. Ranches 1 and 2 were large ranches (10,765 and 26,809 ha) at 1,760 to 2,340 m in elevation. Ranches 3 and 4 were smaller (3,029 and 5,161 ha) at 1,330 to 1,540 m elevation. Dominant vegetation was representative of short- or mid-grass prairie, and typical upland species included blue grama (*Bouteloua gracilis*), buffalo grass (*Bouteloua dactyloides*), sideoats grama (*Bouteloua curtipendula*), and western wheatgrass (*Pascopyrum smithii*) with occasional stands of juniper (*Juniperus* spp.) and mesquite (*Prosopis glandulosa*).[8] Riparian vegetation included sedges (*Carex* spp.), rushes (*Juncus* spp.), and willows (*Salix* spp.). Invasive annual brome grasses (*Bromus* spp.) were not found on the subject ranches. Ranches 1 and 2 had <5% juniper or mesquite cover and have done little shrub/tree control. Ranches 3 and 4 had 10% to 15% shrub/tree cover and have practiced chemical or mechanical control.

Annual precipitation occurred primarily in May to September. Mean annual precipitation for the ranches ranged from 38 to 44 cm (15-18 inches, Fig. 1). In 2015, precipitation in Cimarron, New Mexico, (Ranches 1 and 2) was 148% of normal, and in Tucumcari, New Mexico, (Ranches 3 and 4) precipitation was 164% of normal, resulting in above-average growth of cool and warm season grasses (Fig. 1). However, all ranches experienced below-average precipitation between 2001 and 2014. Drought limited forage and stock water availability in the study area until 2015. As a result, several subject ranches were bordered by one or more pastures destocked (rested) for multiple years.

Information regarding ranch management practices was gained from interviews with ranchers, range consultants, and ranch management records. Subject ranch managers all received training in SGM and have practiced it for >10 years. All four ranches were managed with CS prior to adopting SGM. Infrastructure upgrades on subject ranches included development of higher-capacity stock-watering systems and additional interior fences and pastures to allow herd consolidation and higher stocking densities. Small, SGM ranches generally had the greatest pasture and water site densities. Subject ranch managers adjusted their annual stocking rates as needed to maintain livestock condition, based on fall forage inventories. Subject ranch managers

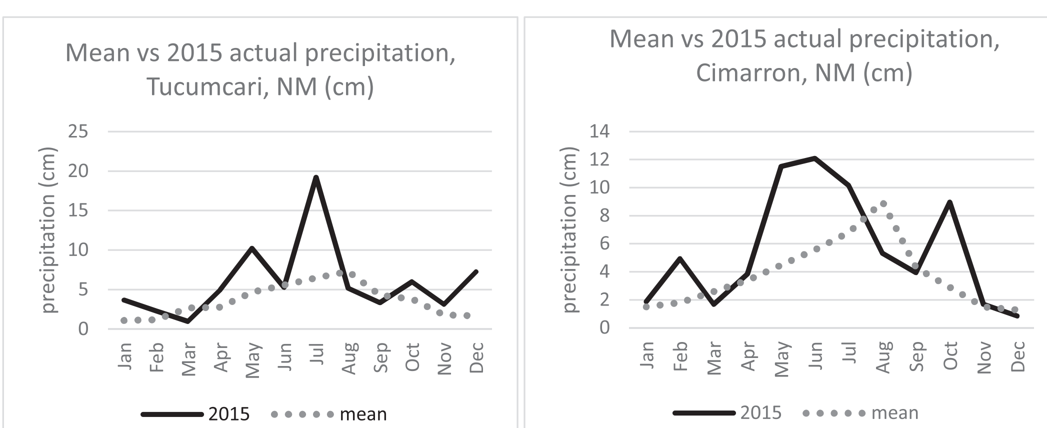

Figure 1. Mean and 2015 precipitation by month for Tucumcari and Cimarron, New Mexico, USA.

Figure 2. High-resolution camera and computer mounted on four-wheeler used for ground-based vertical photographs (GBVP).

implemented periods of plant recovery between grazing periods. Paddocks on the subject ranches received 3 to 12 months of recovery between grazing periods. Subject ranch managers ran 1 to 3 herds each, rotating each herd through 10 to 30 pastures annually. Grazing periods were generally <15 days during the growing season, and pasture season of use was varied through time. Due to these practices, pastures were grazed ≤10% and recovering from grazing for ≥90% of the calendar year. Neighboring ranches primarily used CS and did not use rotational grazing or other SGM practices. Neighboring ranches reduced stocking rates and/or hauled supplemental water and hay in response to drought. Maximum reported stocking rates for subject Ranches 1, 2, and 4 and for the ranches bordering all four subject ranches were 40 to 60 acres/AU (16-24 ha/AU).

All ranches adjoining Ranch 3 were managed with CS. While most remained stocked, some poorly watered pastures were destocked in 2011 to 2015. This enabled us to compare Ranch 3's SGM pastures with both continuously stocked and destocked pastures (rested >3 years). Ranch 3 was stocked at 58 acres/AU (23 ha/AU) when SGM was initiated in 2003, increasing to 32 acres/AU (13 ha/AU) by 2014.

Table 1. Number of ground-based vertical photos (GBVP sample points) and sizes of New Mexico SGM ranches

Ranch	Hectares	Acres	GBVP sample points
Ranch 1	10,765	26,601	117
Ranch 2	26,809	66,246	129
Ranch 3	3,029	7,486	67
Ranch 4	5,161	12,752	75
Totals	45,764	113,085	388

Methods

We used remote-sensing technology to quantitatively assess and compare cover attributes. We conducted interviews, reviewed management records, and obtained fence locations in May 2015, followed by on-site monitoring in September 2015 to obtain high-resolution Ground-Based Vertical Photographs[9] (GBVP; Fig. 2). A total of 388 GBVP were subjectively located to sample the range of ground cover variation occurring on each subject ranch (Table 1). After on-site monitoring was completed, percent ground cover was determined for each GBVP using image classification software following the protocol of Sant et al.[9] The results of that classification were used as training data to estimate percent cover across each subject ranch using Pleiades 0.5-m^2 pixel satellite imagery (http://www.airbusdefenceandspace.com/). Coefficients of determination (R^2) were calculated using linear regression by withholding 20% of the GBVP images from the model to test the prediction of the 0.5-m^2 imagery on the withheld images[9] Coefficients of determination (R^2) for bare ground between GBVP and 0.5-m^2 imagery averaged 0.88 (range 0.82-0.98) for the four subject ranches and their adjoining CS comparison pastures.

Correlating the GBVP with the 0.5-m^2 satellite imagery enabled development of continuous cover maps depicting percent bare ground cover across the entirety of each subject ranch and immediately adjacent lands. Since land cover values in 2015 resulted from management over many years, we chose bare ground as our principle metric for comparing upland range condition. Bare ground is not overly sensitive to yearly environmental fluctuations but shows a legacy effect of grazing over time and is an index of rangeland functionality.[10]

Developing continuous cover maps for each ranch and immediately adjacent lands allowed us to compare bare ground values between SGM-managed ranches and adjoining non-SGM (both CS and rested) lands. This was done by comparing average percent bare ground cover along paired, 100-m-wide strips on either side of the perimeter of each of the subject ranch boundaries (Fig. 3). These adjacent boundary strips were further delineated into 763 soil polygons averaging 4.9 ha (12.0 ac) in size. Each polygon contained a single soil type (SSURGO database[11]) and occurred entirely within a single pasture (Fig. 4). SGM ranch polygons were paired with adjoining non-SGM soil polygons of identical soil type. Since weather and soil types on these paired polygons were the same, differences in cover were attributed to differences in management rather than differing precipitation or soil properties. The average percent bare ground of each polygon within the strips was then calculated from the bare ground continuous cover maps, allowing us to determine and compare average bare ground for each of these paired (SGM vs. non-SGM) strips (Fig. 4).

We restricted these fence line comparisons to only non-cultivated riparian and range sites and soils by omitting sections where the ranch boundary occurred along steep canyon rims or on irrigated or dryland agricultural areas. The 0.5-m^2 pixel Pleaides imagery was used to identify canyon rims and agricultural areas, which were then removed from the analysis. Features along fences, such as trails and roads, can affect cover values. Similarly, soil, vegetation, water, topographic features, and other factors can influence grazing distribution and uniformity. These features are found in both the 106 SGM pastures and in the corresponding non-SGM pastures assessed in this study.

We compared riparian vegetative cover on paired SGM and CS stream reaches on those ranches (Ranches 1 and 2) with streams

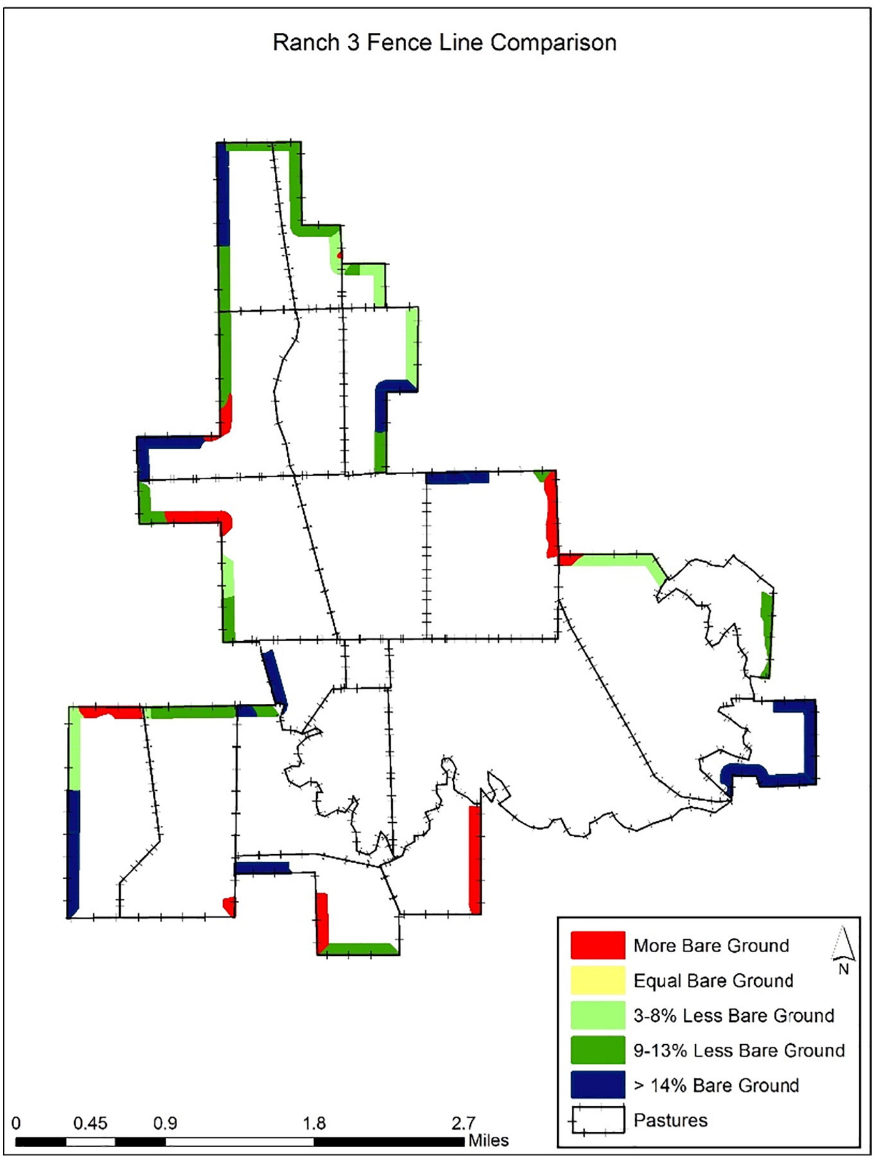

Figure 3. Fence line comparison showing difference in percent bare ground between Ranch 3 SGM pastures and neighboring pastures.

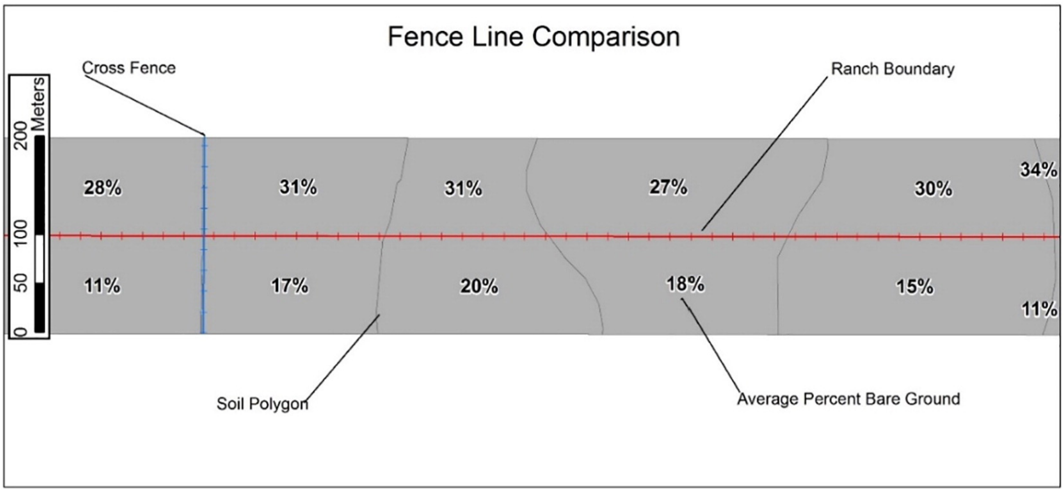

Figure 4. Diagram of 100-m ranch boundary fence line buffers, using soil type and cross-fencing to delineate paired polygons.

crossing their boundaries. Imagery was used to estimate percent riparian cover for SGM and paired CS stream reaches on seven streams for 21 years with available data between 1984 and 2015. We first delineated each stream's potential riparian area (PRA), the area along the drainage capable of supporting a riparian plant community, given adequate soil moisture. PRA was delineated using 2015, 0.5-m^2 Pleiades infrared (CIR) imagery and a combination of self-learning software (Textron Systems Feature Analyst[12]), elevational and topographic layers, and visual interpretation.[13] Greater percent riparian vegetation cover within the PRA suggests greater soil moisture and riparian condition and function. Stream reach lengths were delineated based on soil type, topography, pasture, and ownership boundaries. Each reach occurred within a single pasture, and SGM reaches were paired with adjacent off-ranch CS reaches (Fig. 5). Paired reaches were comparable in terms of soil type, slope, and topography.[11,13] We assessed riparian trend from 1984 to 2015 by using the Pleiades classification as a training data set to develop a model using 2015

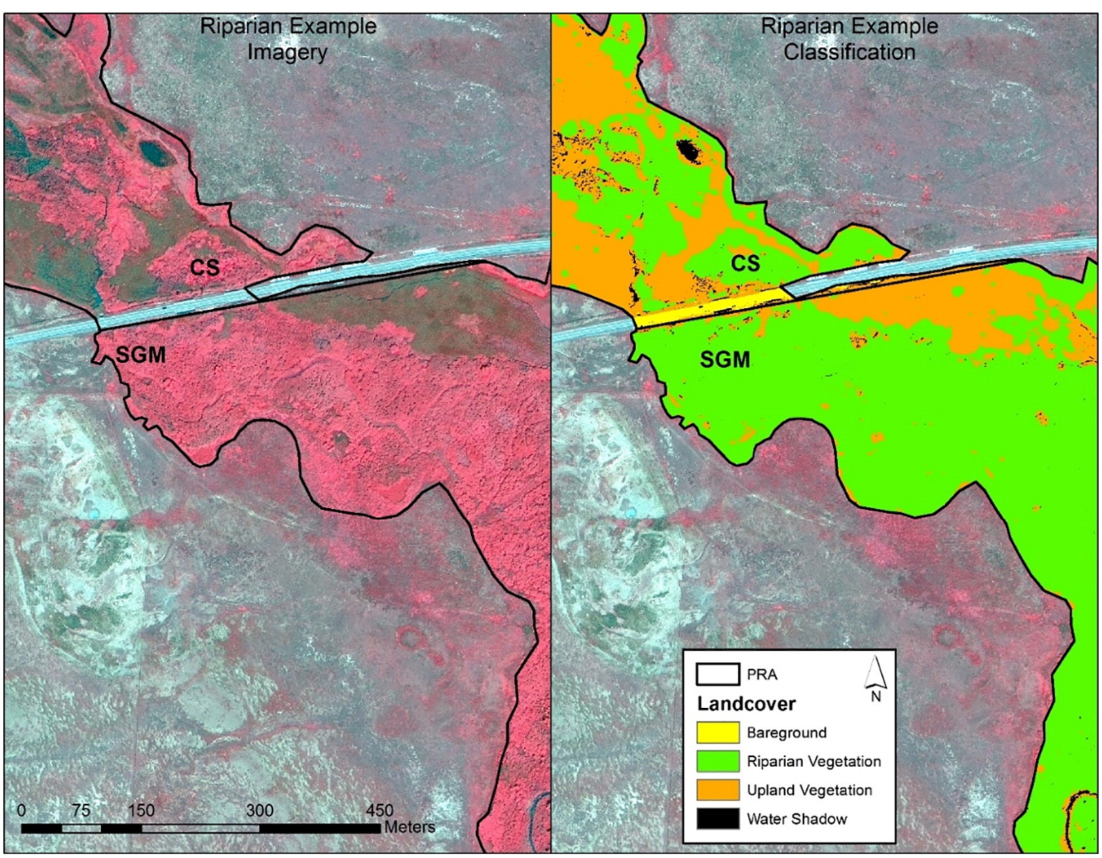

Figure 5. Brighter colors (red) indicate riparian cover within potential riparian area (PRA) of stream reaches on SGM subject ranch (below blue boundary line) and neighboring CS pasture (above blue boundary).

30-m Landsat imagery.[13] The Landsat model agreed well with the Pleiades classification ($R^2 = 0.95$). The model was then applied to each cloud-free year of Landsat imagery going back to 1984.

Statistical analysis for uplands used only 2015 bare ground values. Riparian cover analysis included values from 1984 to 2015. We used a mixed-effects linear regression model and the package lme4[14] R for our statistical analysis.[15] We modeled percent bare ground and percent riparian vegetation of paired polygons along boundary strips and stream reaches as a function of management strategy (SGM, CS, or rested) where ranch, pair, and year (riparian analysis only) were treated as random effects. This accounted for variability due to geographic locations of subject ranches, soil types, and years in means comparisons. We then used Tukey's adjustments to estimate pairwise differences.

Management Results

Upland Management Effects

Estimated 2015 upland bare ground was significantly less in pooled SGM polygons (n = 763, all four ranches combined) than for the paired non-SGM polygons (20% in SGM vs. 23% in non-SGM, $P < 0.001$, D.F. 566, t = 5.17).

Several pastures bordering Ranch 3 had been rested from grazing for 3 or more years. This allowed us to compare bare ground values between Ranch 3's SGM polygons with paired CS polygons and with rested polygons. Bare ground estimates for Ranch 3's SGM polygons was 16% compared with 22% for CS polygons ($P < 0.001$, D.F. 92, t = 4.68). Bare ground estimates for Ranch 3's SGM polygons were also lower than their paired, rested polygons (16% and 20%, respectively), although the difference was not highly statistically significant ($P = 0.072$, D.F. 101, t = 1.82).

Riparian Management Effects

Riparian vegetative cover on individual stream reaches varied widely between 1984 and 2015, ranging from 0% to 98% on CS reaches and 0% to 100% on SGM reaches. Mean riparian vegetation cover on SGM reaches (all years and reaches combined) was 31% compared with 26% on paired CS stream reaches ($P < 0.002$, D.F. 535, t = −3.08). Mean riparian cover varied with precipitation through time under both SGM and CS (Fig. 6A). Riparian vegetation values were similar on paired reaches prior to SGM implementation by the subject ranches in the mid-1980s (Fig. 6A). After 1990, riparian vegetation cover values diverged and remained higher on SGM reaches than on CS reaches, particularly when annual precipitation was near average. SGM and CS values appeared to converge during extremely dry and wet years (Fig. 6A and B). Although SGM reaches consistently maintained higher percent riparian vegetative cover than CS, the percent cover varies markedly with precipitation under both management strategies.

Discussion

SGM ranches had significantly less bare ground and significantly more riparian vegetation than adjacent lands not managed with SGM. Furthermore, we found no significant difference in bare ground between SGM pastures on Ranch 3 and adjoining pastures receiving multiyear rest. Ranch 3 had less bare ground than neighbors despite an 80% increase in stocking rate from 2003 to 2015. Our data are thus consistent with the hypothesis that shortening the grazing and lengthening the recovery periods may lead to improved upland and riparian cover values. Our findings are

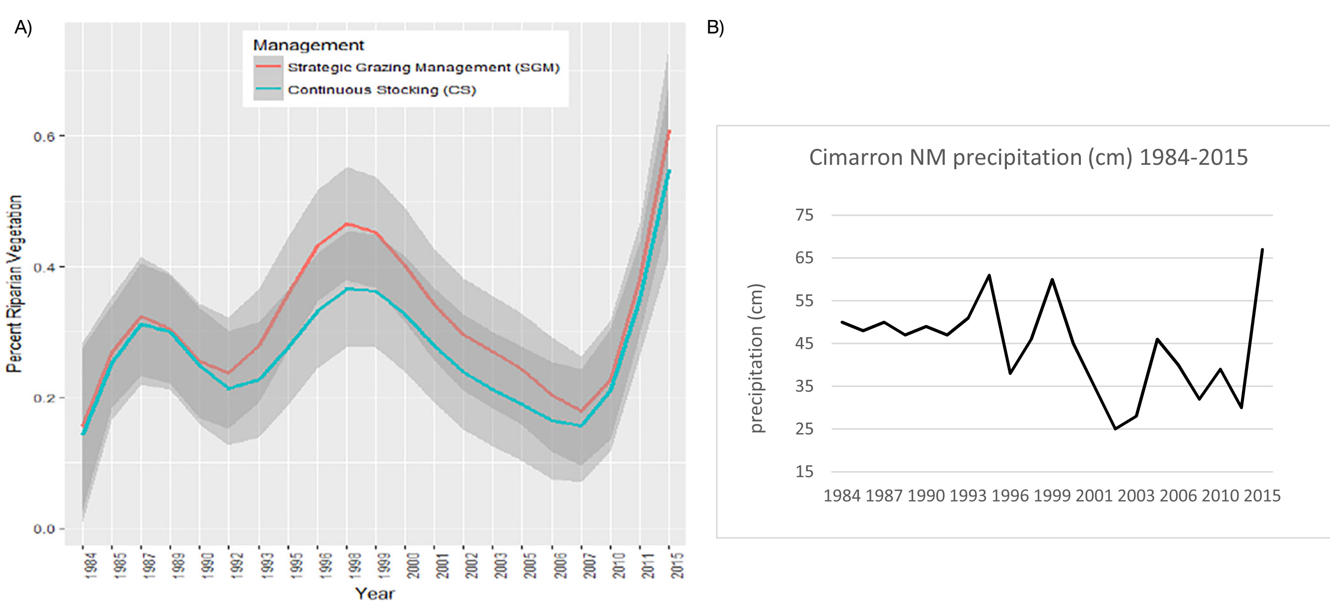

Figure 6. A, Percent riparian vegetation between-year variability (means and confidence intervals) on paired SGM (red) and CS (blue) reaches. While intensively managed reaches consistently maintain higher percent riparian cover than continuously stocked reaches, vegetation varies with precipitation under both management strategies. **B,** Precipitation for same years in nearby Cimarron New Mexico.

also consistent with a century of data on plant physiological processes that describe how reducing frequency and intensity of grazing, along with considering sensitive times in the lifecycle of plants, best enables plants to cope with grazing. As one consultant put it, "We should really call it *Intensive Rest.*"

Applying SGM practices and principles may facilitate learning and adaptive management, increasing "management integrity" but not necessarily affecting ecological function.[2] Adopting practices that improve skills, understanding, and relationships between managers, animals, and land undoubtedly improve management effectiveness. However, applying SGM principles may improve both management integrity and ecological conditions. This is not the first study noting decreased bare ground[16,17] and increased riparian vegetation[13,18] under rotational grazing. Periodic growing season recovery periods are important for both rangeland[16] and riparian management.[13,18] Consider that Ranch 3 pastures, recovering from grazing for >90% of each calendar year, had bare ground values superior to adjacent CS and comparable to adjacent multiyear rested pastures. Certainly, SGM planning and rotational grazing provided managers the flexibility to defer pastures to achieve conservation goals[4,16,19,20] without requiring stocking rate reductions or multiyear rest.

While the differences we observed between SGM and non-SGM management are significant, it is difficult to definitively attribute cause to any specific grazing or other management process or practice within complex systems like working ranches.[1,2] The relative contributions of manifold individual parts or specific SGM practices are difficult to quantify. As Lynam and Stafford Smith pointed out, "The patterns of structures or behavior that emerge from the interaction of the parts are not usually deducible from examining the parts."[21] Still, we believe the assessment method, as well as the observed differences in land cover values, provide useful information to land managers. Our findings suggest understanding and using SGM planning, principles, and practices may better equip managers to improve ground cover characteristics.

Spatial and Temporal Variability

Results from smaller-scale controlled experimental research are not always expandable to larger landscapes due to spatial scale limitations[9,22] and because research tends to be relatively short term (often 2-4 years).[2,7,22] This approach partially overcomes spatial scale and temporal issues by using remote sensing and paired comparisons to assess management effectiveness across large, working landscapes. This large scale, long-term analysis was facilitated by focusing on relatively simple, but impactful measures of ecological status. We focused on percent cover of upland bare ground and riparian cover, which are useful metrics in assessing watershed condition and hydrologic function,[13,16] especially when estimated across large spatial areas.

Our work also illustrates the value of long-term data sets. Precipitation apparently caused riparian vegetative cover on both SGM and CS pastures to fluctuate significantly over time and to converge at high and low precipitation extremes. Comparing riparian cover values between management systems (Fig. 6A) suggests different results at different points in time. The separation between SGM and CS took 5 to 7 years to manifest after SGM began. This was followed by a period (1992-2007) in which riparian cover was consistently greater on SGM stream reaches than CS reaches. Toward the end of the recent drought, the cover values again converged. Three- to five-year studies conducted at the beginning, middle, or end of the time series would each have observed different results.

Quantifying the ecological effects of management decisions provides vital feedback to managers continually adapting and creating within complex creative systems.[1] Providing landscape-scale and long-term feedback can aid both scientists and managers striving to understand and enhance ecological condition and resiliency.

Acknowledgments

This work was supported by the Thornburg Foundation and Western Landowners Alliance. Special thanks to A. Moore, J. Davis-Stafford, J. Thorpe, T. Sidwell, L. Allison, C. White, C. Homer, C. Orchard, and K. Gadzia for additional support.

References

1. Provenza, F., H. Pringle, D. Revell, N. Bray, C. Hines, R. Teague, T. Steffens, and M. Barnes. 2013. Complex creative systems: principles, practices and processes of transformation. *Rangelands* 35:6-13.
2. Briske, D.D., N.F. Sayre, L. Huntsinger, M. Fernandez-Gimenez, B. Budd, and J.D. Derner. 2011. Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. *Rangeland Ecology & Management* 64:325-334.
3. Barnes, M., and A. Hil. 2013. Foreward: Strategic grazing management for complex creative systems. *Rangelands* 35:3-5.
4. Briske, D.D., J.D. Derner, J.R. Brown, S.D. Fuhlendorf, W.R. Teague, K.M. Havstad, R.L. Gillan, A.J. Ash, and W.D. Wilms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology & Management* 61:3-17.
5. Brown, J.R., and M. Kothmann. 2009. Rotational grazing on rangelands: synthesis and recommendations. *Rangelands* 31:37-38.
6. Teague, R., F. Provenza, U. Kreuter, T. Steffens, and M. Barnes. 2013. Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? *Journal of Environmental Management* 128:699-717.
7. Boyd, C., and T. Svejcar. 2009. Managing complex problems in rangeland ecosystems. *Rangeland Ecology & Management* 62:491-499.
8. United States Department of Agriculture Handbook 296, 2006. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050898.pdf.
9. Sant, E.D., G.E. Simonds, D.R. Ramsey, and R.T. Larsen. 2014. Assessment of sagebrush cover using remote sensing at multiple spatial and temporal scales. *Ecological Indicators* 43:297-305.

10. Weber, K.T., C.L. Alados, C.G. Bueno, B. Gokhale, B. Komac, and Y. Pueyo. 2009. Modeling bare ground with classification trees in Northern Spain. *Rangeland Ecology & Management* 62:452-459.
11. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2016. Web Soil Survey. Available at: https://websoilsurvey.nrcs.usda.gov/ 2016.
12. Textron Systems Feature Analyst, version 5.1.20. Available at: https://www.textronsystems.com/what-we-do/geospatial-solutions/feature-analyst.
13. Booth, D.T., S.E. Cox, G.E. Simonds, and E.D. Sant. 2012. Willow cover as a stream-recovery indicator under a conservation grazing plan. *Ecological Indicators* 18:512-519.
14. Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67:1-48.
15. R Core Team, 2016. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.R-project.org/ Accessed October 15, 2016.
16. Teague, W.R., S.L. Dowhower, R.J. Ansley, W.E. Pinchak, and J.A. Waggoner. 2010. Integrated grazing and prescribed fire restoration strategies in a mesquite savanna: I. vegetation responses. *Rangeland Ecology & Management* 63:275-285.
17. Jacobo, E.J., A.M. Rodríguez, N. Bartoloni, and V.A. Deregibus. 2006. Rotational grazing effects on rangeland vegetation at a farm scale. *Rangeland Ecology & Management* 59:249-257.
18. Swenson, S., S. Wyman, and C. Evans. 2015. Practical grazing management to maintain or restore riparian functions and values on rangelands. *Journal of Rangeland Applications* 2:1-28.
19. Krausman, P.R., D.E. Naugle, M.R. Frisina, R. Northrup, V.C. Bleich, W.M. Block, M.C. Wallace, and J.D. Wright. 2009. Livestock grazing, wildlife habitat, and rangeland values. *Rangelands* 31:15-19.
20. Hagen, C.A., D.C. Pavlacky, K. Adachi, F.E. Hornsby, T.J. Rintz, and L.L. McDonald. 2016. Multiscale occupancy modeling provides insights into range-wide conservation needs of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*). *The Condor* 118:597-612.
21. Lynam, T.J.P., and M. Stafford Smith. 2004. Monitoring in a complex world—seeking slow variables, a scaled focus, and speedier learning. *African Journal of Range and Forage Science* 21:69-78.
22. Svejcar, T., and K. Havstad. 2009. Improving field-based experimental research to compliment contemporary management. *Rangelands* 31:26-31.

Authors are Consultant, Western Landowners Alliance, Casper, WY 82609, USA (Danvir, basinwlc@gmail.com); Consultants, Open Range Consulting, Park City, UT 84060, USA (Simonds, Sant); Professor, Range Science, Utah State University, Logan, UT 84322, USA (Thacker); Professor, Plant and Wildlife Sciences, Brigham Young University, Provo, UT 84602, USA (Larsen); Rangeland Ecologist, Oregon State University, Eastern Oregon Agricultural Research Center, Burns, OR 97720, USA (Svejcar); Professor, Range Science, Utah State University, Logan, UT 84322, USA (Ramsey); Professor Emeritus, Range Science, Utah State University, Logan, UT 84322, USA (Provenza); Research Leader, USDA-Agricultural Research Service, Burns, OR 97720, USA (Boyd).