Perspectives on Rangeland Management: Stocking Rates, Seasonal Forecasts, and the Value of Weather Information to New Mexico Ranchers

Research Report 759

Brian H. Hurd, L. Allen Torell, Kirk C. McDaniel

Agricultural Experiment Station • College of Agriculture and Home Economics

ACKNOWLEDGMENTS

We would like to acknowledge the financial support of the National Oceanic and Atmospheric Administration (NOAA), and especially thank Drs. Rodney Weiher and Gary Carter of NOAA for their interest in and support of this research. We would also like to thank Dr. Richard Adams of Oregon State University for his guidance and support throughout the project. Expressed thanks also to Ken Pavelle and Victor Koren of NOAA's Office of Hydrologic Development for their technical assistance and cooperation in preparing data and technical support. Appreciation is also extended to Drs. John Fowler, Chris Allison, and Jerry Holechek of NMSU for discussions and insight on rangeland issues. Finally, we would like to acknowledge the New Mexico State University Agricultural Experiment Station for its continued support of each of our research programs.

INTRODUCTION

Livestock production is the principal economic activity on private and public rangelands throughout the U.S., especially in the western U.S., and soil moisture is a central factor in the economic livelihood of these ranchers and rangeland managers. Restored by summer rain and winter snow, soil moisture is the primary limiting factor to forage growth and productivity, and underpins all the range livestock producer's economic decisions related to grazing, stocking rates, and livestock weight gain; ultimately, it underpins economic productivity. This report addresses the value of soil moisture information in rangeland management and profiles range management throughout the West, highlighting the relationship between ranchers and the federal lands that are critical to the livestock industry. It provides an overview of the rangeland economy, introduces key terminology and concepts, describes the critical importance of precipitation and soil moisture to both rangeland managers and ranchers, and highlights key studies that have examined the value of soil moisture information to ranchers. The intent of this report is several-fold. First, it defines the context and presents a primer on the essential concepts necessary to understand the ranch and range economy. Second, it highlights the challenges ranchers confront in their efforts to maintain an economically and ecologically sustainable rangeland system. And third, it helps define the importance of the climate-sensitive relationship between soil moisture and forage production.

The primary premise is that there may be measurable economic value in developing new forecast variables, such as soil moisture, and in improving upon the accuracy, lead-time, and spatial resolution of new and existing weather forecasts.

We begin by describing the characteristics of livestock grazing and rangeland management across private and public lands of the West. This is followed by a description of the biophysical and economic factors underlying ranch-level decision making and rangeland management. The third section describes how rangeland decisions are scheduled within an uncertain and variable future. Finally, in the fourth section, we examine how improved long-run weather forecasts might contribute measurable value to ranch-level decision making.

THE PUBLIC–PRIVATE NATURE OF RANCHING IN THE WEST

Throughout the West, private ranchlands are near to or scattered within large tracts of public land managed by the U.S. Department of Agriculture's Forest Service (USFS) and U.S. Department of the Interior's Bureau of Land Management (BLM). Of the 770 million acres of rangeland in the U.S., the federal government manages about 43%, or 330 million acres (Jageman, 2007). Together these lands provide the forage—grass and browse—that livestock needs to grow, mature, and eventually supply meat to the nation's tables. Forage from rangeland tends to grow relatively sparsely, constrained by limited water and nutrients. Significant areas of rangeland are required to support the continuous and

[1]Respectively Associate Professor (bhurd@nmsu.edu) and Professor (atorell@nmsu.edu), Department of Agricultural Economics and Agricultural Business, and Professor (kmcdanie@nmsu.edu), Department of Animal and Range Sciences, all of New Mexico State University, Las Cruces, NM 88005.

seasonal grazing requirements for livestock, and to support forage regeneration and regrowth following periods of grazing.

A typical 900- to 1,000-lb steer requires roughly 20 lbs of forage each day—7,300 lbs of forage annually. An acre of arid rangeland in fair to good range condition, with 10–12 inches of precipitation, might be expected to produce approximately 600 lbs of standing forage during the year, of which, rangeland experts suggest, only 25%–50% should be consumed or utilized by livestock in order to leave sufficient vegetation for regeneration and wildlife use. Following the conservative utilization rate of 25% suggested for many arid areas with high precipitation variability (Holechek, 1988; Holechek & Pieper, 1992; Galt et al., 2000) this leaves about 150 lbs of forage per acre per year for grazing. The result is that each steer requires nearly 50 rangeland acres or its equivalent, or roughly a stocking rate of 13 animals per 640-acre section of land.

As a result of such significant land-use requirements, cattle ranching requires a significant partnership with the largest land-owner in the region—the federal government. Under the 1934 Taylor Grazing Act, local ranchers hold grazing permits—renewable every ten years—from the federal government. These permits authorize grazing use under a specified set of conditions, including a specified type, class, and number of animals, the area defined by the allotment, and seasons or durations of grazing. Annual grazing fees are paid by permit holders based on actual use, currently $1.35 (as of March 1, 2007) per animal per month.

Federal grazing resources are managed according to federal statutes and policies, which are promulgated and flow down through several layers, based on scale and aerial extent of the grazing resource. A Resource Management Plan (RMP) is the overarching resource document governing district-wide resources. Within each district, each grazing allotment is governed by an Allotment Management Plan (AMP). AMPs identify and define specific resource management objectives for each allotment that are also consistent with the District RMP. The AMPs describe management objectives for livestock and for all resources affected by livestock grazing, as well as defining the responsibilities of both the permittee and the regulatory agency. Annual operating guidelines are set forth for each allotment by the federal agency based on, for example, an annual assessment of relevant rangeland conditions. These conditions and management prescriptions are then set forth in the Annual Operating Plan, which specifies the obligations both of the rancher and of the federal agency for the current year (Jageman, 2007). Under these annual plans, actual grazing use can be significantly limited by, for example, diminished rangeland conditions brought about by a drought.

KEY CONCEPTS AND TERMS IN RANGELAND MANAGEMENT: STOCKING RATE, GRAZING CAPACITY, AND GRAZING PRESSURE

A typical western rancher is challenged by many decisions, both short- and long-run, that must be made throughout the year. Economic decisions—such as whether to buy or sell livestock, make long-run changes to base herd sizes, or invest in improvements (e.g., stock-watering facilities)—must be made and possibly updated throughout the year in response to, for example, changes in economic markets and weather conditions. The recent prolonged drought that stretched across much of the Southwest and Midwest stressed many ranch operations by reducing permitted stocking rates on public lands. This confronted ranchers with severely limited forage growth and the unfortunate choice of either thinning herd sizes at reduced prices or providing costly supplemental food and water (permitted only on private ranch lands).

Stocking rate is a fundamental recurring question for ranch and rangeland management, because of the significant impact of decisions about stocking rate on financial performance and long-term resource condition (Johnston et al., 2000). The stocking rate, that is, the number of animal-months per unit of land area (or its inverse, the number of acres per animal-month) is, in the short-run, the central factor determining annual livestock production levels and, therefore, economic performance. Strategies for choosing stocking rates are influenced by several factors, as shown in the conceptual model in Figure 1.

The economy of rangelands is principally associated with its potential vegetative productivity—primarily in support of livestock, wildlife grazing, and watershed values. Vegetation productivity is highly correlated with both climate and soils and is affected by the existing vegetation stock (through reproductive potential) as well as by competition from non-grazing types of vegetation. Climatic factors that are typically observed as functional inputs into vegetative growth include solar radiation, temperature, precipitation, and wind speed (especially as a factor determining evapotranspiration rates). Over the course of the normal growing season in Southwestern rangelands, roughly March 1–October 31 (240 days), the dominant climatic factor limiting vegetative growth is soil water availability. As such, soil moisture is a key indicator of vegetative production potential.

As Figure 1 shows, livestock productivity and animal performance are directly related to the quality of, abundance of, and competition for desirable forage species on rangeland. Fundamentally, the stocking decision is an economic decision that balances the rewards from producing healthy saleable livestock against the costs and risks of production and marketing. Once a determi-

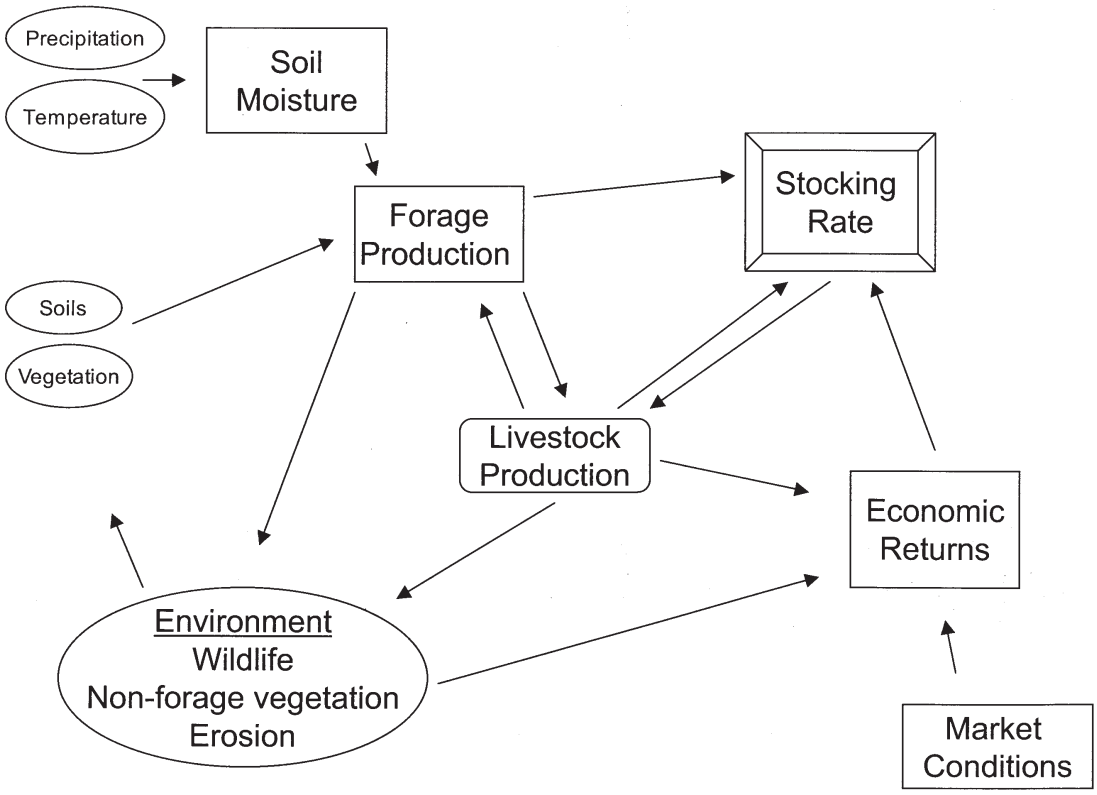

Figure 1. Conceptual Model of Rangeland Livestock Production and the Role of Climate and Weather

nation has been made that the ranch operation, with its capacity for livestock production, is economically viable (i.e., with the expectation that it can be profitably managed), a baseline stocking strategy is developed. This stocking strategy is based on an assessment of expected market conditions and rangeland capacity for sustainable livestock production, often referred to as **grazing capacity** or **carrying capacity**. Defined as the average number of animals a particular range or ranch can sustain over time, grazing capacity is a useful concept for long-run sustainable range management that takes into account both the livestock utilization and the long-run average forage production (Galt et al., 2000).

Grazing pressure is an important concept and measure. It is defined as the ratio of stocking rate to forage produced, and measures grazing intensity (Hart et al., 1988a; Torell et al., 1991; Manley et al., 1997). High grazing pressure (or intensity) is the result of a combination of a high stocking rate and low forage production. Excessively high grazing pressures can have several undesirable consequences. Most immediate of these is a decline in animal performance as a result of heavy forage competition and stress. Adverse effects on animal performance include lower rates of average daily weight gain, lower breeding success, lower birth and weaning weights, lower resistance to pathogens, and reduced body condition (Hart et al. 1988a, Hart et al. 1988b), all of which can negatively affect economic performance.

Not only does high grazing pressure tend to inhibit the regenerative potential of primary forage species; it also will likely stress the ecological balance of the grassland ecosystem and could, for example, enhance the viability of undesirable invasive species. A stocking rate that is relatively high for a given range type and prevailing conditions can be expected to result in heavy forage utilization—defined as the percentage of standing vegetation that is grazed by livestock.

Range types differ in the level of utilization that they can safely and reliably recover from—in other words, their **grazing capacity**. Resiliency of the forage vegetation, and hence level of desired forage utilization, varies by many factors, including vegetation type, climate and climate variability, soil and terrain, slope, aspect, and wildlife pressure. Sustaining productivity over time requires a range-appropriate stocking strategy that leaves

sufficient post-grazing vegetation, usually between 50% and 75%, for the subsequent year's regrowth. The key is to identify a long-run grazing strategy that is both economically and ecologically sustainable. One such strategy that encourages sound stocking rates and appropriate grazing assessment methods is often referred to as **conservation grazing** (Galt et al., 2000; Ash et al., 2000; Torell et al., 1991; Holechek et al., 1999; Mckeon et al., 2000; Khumalo & Holechek, 2005; Johnston et al., 2000; Holeckek & Pieper, 1992).

STOCKING RATE STRATEGIES: BALANCING FORAGE PRODUCTION AND USE

Stocking strategies often vary across ranches and rangeland managers—depending not only on grazing capacity, which varies by, for example, range type and precipitation, but also on experience, knowledge, cultural practices, and beliefs. Fundamentally, all stocking strategies are driven by expected forage production and expected livestock forage utilization. Ultimately, successful rangeland livestock production depends largely on managing stock levels to achieve an appropriate utilization (or harvest rate) of annual forage growth.

The natural economic impulse to increase livestock production and the number of animals grazing is tempered by forage availability. Choosing a stocking rate that is too high or for too long a period relative to the available forage runs the risk of not only diminished livestock productivity (e.g., less weight gain per animal, lower calving success rates, lower birth and weaning weights) but also of reduced vegetative capacity for forage regrowth the following year and, therefore, lowered future stocking rates. Overgrazing can also create openings for undesirable species to invade and become established on the range, which could result in changes in the long-run character and composition of plant communities and could, in addition, adversely affect wildlife and riparian ecosystems. Overgrazing also contributes to soil erosion and sedimentation of surface waters. Rangelands that are overstocked and overgrazed eventually fall in forage productivity, thus limiting future livestock productivity and economic performance, unless the range is given time to rehabilitate (Torell et al., 1991; Holechek & Pieper, 1992; Andales et al., 2006; Galt et al., 2000; McKeon et al., 2000).

Holechek (1988) presents utilization guidelines for moderate grazing levels across a variety of range types and average annual precipitation levels. His prescribed rates range from 25% in highly variable desert range systems to 45% in short-grass prairie systems to as high as 60% in low-variability, moist eastern and southern pine and deciduous forests. Holechek prescribes a relatively conservative stocking rate strategy for desert rangelands in south-central New Mexico, as do Galt et al. (2000) on the basis of observations that "conservatively stocked pastures produced more forage in drought years and required less destocking," and further that "there has also been a substantial improvement in ecological range condition and forage production on the conservatively stocked pastures over time" (Galt et al., 2000, p. 8). Similar utilization rates—of 25%—have been prescribed by range scientists in other arid range regions, such as in Southwestern Queensland, Australia (Ash et al., 2000; McKeon et al., 2000).

In contrast to the constant year-to-year stocking rate strategy described above, there are flexible grazing management strategies that recognize that stocking rates can be affected by several factors and, therefore, may benefit from periodic revision in response to actual or expected changes in rangeland condition and forecasts of weather and economic conditions. Under a flexible grazing strategy, ranchers would typically assess forage condition of a particular range and the economic and productive outlook for the coming year and, if necessary, make adjustments to the baseline operating plan. McKeon et al. (2000) identify two flexible stocking rate strategies along with a constant stocking strategy, and compare these using simulation models of forage and livestock production. The first flexible strategy is to annually adjust stocking rate so as to consume a fixed share of existing pasture growth, whereas the second strategy adjusts to consume a fixed share of expected or future pasture growth. Their analysis indicated that a flexible strategy using a winter forecast of forage would increase live weight gain by 10%, reduce live weight loss by 57%, and reduce the risk of low pasture yield. In considering the value of longer forecast lead times (i.e., forecast changes from spring to winter), they conclude some small advantages exist and that "the development of long-lead forecasts has considerable potential to contribute to better management of climate variability in these grazing lands" (p. 249).

In reference to the former, Galt et al. (2000), suggest that "a good grazing capacity survey not only helps to establish ranch value, but it also provides valuable information on infrastructure (water, fences, roads, corrals); ecological condition of various pastures; land unsuited for grazing due to terrain, distance from water, and other constraints; past range use; range trend; noxious plant problems; and wildlife grazing use" (p. 7).

The dynamic nature of the stocking rate decision is highlighted by Torell et al. (1991), who showed that forage conditions and productivity fluctuate over time and, in fact, reflect the history of stocking rate decisions made in previous seasons. Determining an optimal stocking rate strategy can be quite a complex decision problem that is significantly simplified by recognizing

the importance of periodically monitoring and assessing the condition of the range and using economic and weather forecasts to the greatest advantage.

PRODUCTION VARIABILITY, DECISION TIMING, AND THE VALUE OF SEASONAL FORECASTS

The principal sources of risk for ranchers and rangeland managers are swings and variability in weather and in prices. In managing such risks, it is typical to formulate expectations for the variables that affect decisions or outcomes to the largest degree. For example, the simplest expectation might be to ascribe an average of recent conditions to the coming weather or economic outlook. Most constant stocking rate strategies are based on weather and forage averages that, in the absence of better information, produce reasonably consistent outcomes. A conservative stocking strategy is an example of a constant stocking rate strategy. The conservative stocking rate strategy implicitly recognizes the down-side risk associated with poor weather conditions (i.e., drought) and the financial hit resulting from supplemental feeding efforts and/or herd liquidation (Galt et al., 2000; Johnston et al., 2000; Mjelde et al., 1988).

Information is central to efficient risk management. When information is available that improves upon either the accuracy or the lead-time associated with constructing expectations, improvements to the financial bottom line can reasonably be expected in the long-run. In this case, the central economic question concerns the relative cost of acquiring and applying risk information as compared to the potential value of reduced losses and/or economic gains achieved by changing stocking rate strategies. An additional complication arises in the case of evaluating the efficacies of making updates to conservation stocking rate strategies (Holechek et al., 1999; Galt et al., 2000). Conservative stocking strategies are, by design, aimed at lower forage utilization rates and, hence, lower stocking rates as an implicit risk management strategy. Implicitly, such strategies are less concerned with increasing grazing rates to take advantage of favorable conditions. Under such strategies, therefore, the expected value of improved forecast information is probably to some degree diminished, with value holding only in the most severe forecasts of drought.

Improvements in weather forecasts can take several forms, including improved accuracy and reliability; longer lead times (for example, forecasts for summer precipitation and soil moisture available in winter instead of in spring); and greater spatial resolution of forecasts. Stocking changes are most commonly made in the fall after the summer growing season and again in spring as livestock are returned to summer grazing areas. For greatest relevance to both ranchers and rangeland managers, seasonal climate forecasts should be reasonably accurate, timed to coincide with these seasonal decision schedules, and of sufficient spatial detail to serve users in areas of high geographic variability. There is considerable overlap and cross-dependency among these information pathways for the end user. For example, it would not be particularly useful to improve forecast lead time but sacrifice accuracy and/or spatial resolution. Perceived usefulness and enhanced economic value are both prerequisites for the ultimate adoption of these strategies by ranchers.

In the case of ranchers in the arid rangelands of New Mexico, Arizona, and West Texas, seasonal forecasts with the greatest value would inform ranchers early in the spring planning period how likely and sufficient rainfall will be for the summer growing period. The potential increase in net returns by adding yearling stockers, for example, depends on the degree to which advantageous production years can be estimated and anticipated, and actions taken to harvest the added AUMs of grazing capacity. Hart (1991) notes that taking advantage of flexible profit-maximizing stocking rates requires that early and accurate stocking rate decisions be made. This requires an accurate prediction of how much forage will be available for the year. He notes that in the northern high plains of Wyoming, forage production is primarily determined by precipitation in March, April, and May, and with yearlings typically entering the pasture in May, annual forage production is largely known as the stocking decision is made. This is not the situation for the ranges of the Southwest, where warm season (C4) grasses predominate. For most New Mexico ranches, grass growth does not typically commence until the summer rains of June, July and August. A beneficial spring weather (forage) forecast would project at least 6 months into the future.

The lead time required for a beneficial weather forecast for cow–calf producers will be even longer than what is required for yearling producers, because breeding livestock must be maintained across years. Murugan (2007) found that a grazing strategy similar to that described by Dahl (1963) would be best economically for New Mexico cow–calf producers. By this flexible strategy, the range would be stocked with a core breeding herd whose numbers are set below what would be detrimental to the range during most years. Any excess forage produced in average or above-average years would be utilized by purchased animals. Annual net returns were estimated to be increased by 8% by maintaining a base cow herd and adding a flexible yearling enterprise during favorable production years versus fully stocking with only a cow–calf enterprise.

SUMMARY OF SEASONAL FORECAST VALUES IN RANGE LIVESTOCK PRODUCTION

The potential for seasonal climate forecasts to contribute to livestock and ranch profitability has been investigated in several studies. Jochec et al. (2001) focused on West Texas rangelands and examined the use and value of seasonal climate forecasts. In this study, forage and livestock production was simulated in a biophysical model (PHYGROW, Ranching Systems Group, 1995), which was combined with historical daily weather data to illustrate rangeland productivity for 49 years of simulated data. Grouping simulated outcomes by their deviation from the long-run average—as above average, typical, or below average—the researchers developed forecasts of percentage changes in livestock productivity, which were then paired with depictions of plausible current forage conditions (also generally characterized as above average, typical, and below average).

Jochec et al. (2001) presented simulation findings, illustrating both a forecast with certainty and a forecast with uncertainty, to a focus group of ranchers, who were then asked several questions about the usefulness and value of forecasts of forage and livestock productivity. The researchers concluded that participants were sensitive to weather factors and were more likely to react and change stocking rates in response to forecasts of poor forage conditions than to favorable forecasts. Additionally, if forage is currently scarce, ranchers are more likely to maintain or decrease stocking rates—even if favorable conditions are forecast. Jochec et al. observed that feed and livestock price cycles, in addition to weather, influenced stocking rate decisions. High cattle and feed prices tend to put downward pressure on stocking rates, whereas lower prices tend to have the opposite effect. Ranchers in the focus group reported that they believed current climate forecasts were too uncertain and covered too broad an area to be used reliably. "The forecasts would have to be 70% to 80% accurate and proven for a 4–5 yr period before the focus group would feel comfortable using them. Lead time of forecasts would also be crucial to be able to adjust operations accordingly" (Ibid. p. 1635). Jochec et al. (2001) also estimated the expected value of seasonal forage production forecasts and found that the value varies considerably with changes in either economic or environmental conditions.

Several studies address the issue of forecast value for rangeland grazing production in Australia. Johnston et al. (2000) describe several grazing management strategies and conclude that "perceived unreliability of many improved practices prevents their rapid adoption. High climate variability contributes to this cautious judgment" (Johnston et al. 2000, p. 219). They suggest further that seasonal climate forecasts appear to reduce management risks and, hence, contribute to more sustainable grazing systems, and that attitudes toward their use will change primarily with the feedback from positive experiences with its application.

McKeon et al. (2000) compare the livestock production and rangeland condition resulting from each of five grazing strategies—constant stocking; response to observed conditions in winter; and two different lead-times of a climate-forecast–based strategy, using the forage-livestock production simulation model GRASP (Day et al., 1997) and driven by 108 years of daily weather data. Stocking rate changes were often significant across the strategies. For example, the constant stocking indicated for a 30% utilization was 20 hd/km^2, whereas with the winter forecast the stocking rate dropped to 12 hd/km^2 with poor conditions and rose to 26 hd/km^2 under favorable conditions. One of their key findings was that increasing forecast lead-time—giving forecasts in winter instead of in spring—increased live weight gain by 9% and reduced risk of live weight loss by 57%, though with a slight increase in soil loss.

Ash et al. (2000) expanded on the efforts of McKeon et al. (2000) by focusing more specifically on the type of seasonal forecast. Of particular relevance to Queensland ranchers is the forecast of ENSO conditions, with El Niño conditions being particularly drought-prone. The types of forecasts used in the simulation included spring SOI (southern oscillation index) as dry, average, or wet; SOI presented as five phases (falling, negative, neutral, positive, rising); locally optimized spring SOI; winter Pacific ocean SST (sea surface temperatures); and winter Pacific and Indian ocean SSTs. Their findings confirm the conclusion of McKeon et al. (2000) that there are modest benefits to using seasonal forecast information compared to the constant stocking rate strategy but that improvements are slight when compared to a flexible grazing strategy conditioned only by current winter range conditions. Although the best forecast type varied with the underlying stocking strategy, they found significant production benefits associated with improving forecast lead time from spring to winter. However, the localized forecast appeared to offer no significant advantage over the more general area forecast. This suggests that improved spatial resolution of forecasts is not always a significant improvement in the quality of the information—depending on the geographic variability within the general area and on the location of grazing operations.

Stafford-Smith et al. (2000) consider the value of seasonal forecasting in rangeland livestock production from the whole-farm or enterprise level. In this analysis, the authors link the GRASP model of forage and livestock production (Day et al., 1997) to a herd and property management model, RANGEPACK Herd-Econ (Stafford-Smith & Foran, 1992), in order to assess the overall changes in profitability associated with alternative grazing strategies and seasonal climate forecasts. In addition to the livestock production outcomes of the previous

studies, this effort attempts to realistically simulate, for example, the costs and benefits of buying and selling livestock, and dynamic changes in the resource conditions. Similarly to in the previous studies, 104 years of daily weather data drive the simulations, which compare a constant stocking rate strategy, a flexible, "reaction"-based strategy, and several seasonal forecast strategies. They found that increasing forecast reliability led to more responsive changes in stocking rates, and that longer forecast lead times generated modest increases in cash flow (or, alternatively, could provide equivalent cash flow at much lower risk). In addition, they found that the relative value of seasonal climate forecasts was sensitive to market prices, with the forecasting strategies improving in favor over constant stocking rates as sale prices rose—and even more so when the margins between sale and purchase prices increased. In conclusion they observe that for grazing strategies to successfully employ climate forecasts it is first necessary to have a management system "that is sensitive to pasture conditions and hence using the appropriate stocking rate strategies over time; without such a system no forecast will help" (Ibid, p. 287). Growing economic pressures and concern for environmental stewardship are likely to lead ranchers towards increased adoption of more flexible management and stocking rate strategies that can benefit from improvements in weather forecast accuracy and lead time.

REFERENCES

Andales, A. A., Derner, J. D., Ahuja, L. R., & Hart, R. H. (2006). Strategic and Tactical prediction of forage production in northern mixed-grass prairie. *Rangeland Ecology & Management* 59(6), 576-584.

Ash, A., O'reagain, P., McKeon, G., & Stafford-Smith, M. (2000). Managing Climate Variability in Grazing Enterprises: A Case Study of Dalrymple Shire, North-Eastern Australia. In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems—The Australian Experience* (Eds G. L. Hammer, N. Nicholls, & C. and Mitchell), pp. 253-270. The Netherlands: Kluwer Academic.

Day, K. A., McKeon, G. M., & Carter, J. O. (1997). Evaluating the Risks of Pasture and Land Degradation in Native Pasture in Queensland. Project DAQ124A. Brisbane, Queensland Dept. of Natural Resources. Report to the Rural Industries and Research Development Corporation.

Dahl, B. E. (1963). Soil Moisture as predictive index to forage yield for the sandhills range type. *Journal of Range Management* 16:128-132.

Galt, D., Molinar, F., Navarro, J., Joseph, J., & Holechek, J. (2000). Grazing capacity and stocking rate. *Rangelands* 22(6), 7-11.

Hart, R. H., Samuel, M. J., Test, P. S., & Smith, M. A. (1988a). Cattle, Vegetation, and Economic Responses to Grazing Systems and Grazing Pressure. *Journal of Range Management* 41(4), 282-286.

Hart, R. H., Waggoner, J., Jr., Dunn, T. G., Kaltenbach, C. C. & Adams, L. D. (1988b). Optimal stocking rate for cow-calf enterprises on native and complementary improved pastures. *Journal of Range Management* 41(5):435-441.

Hart, R.H. (1991). Managing range cattle for risk—The STEERISK spreadsheet. *Journal of Range Management* 44:227-231.

Holechek, J. (1988). An approach for setting the stocking rate *Rangelands* 10(1), 10-14.

Holechek, J. L., Gomez, H., Molinar, F., & Galt, D. (1999). Grazing studies: what we've learned. *Rangelands* 21(2), 12-16.

Holechek, J. L. & Pieper, R. D. (1992). Estimation of stocking rate on New Mexico rangelands. *Journal of Soil and Water Conservation* 47(1), 116-119.

Jageman, H. R. (2007). Who Gets to Graze the Range? A Summary of Federal Grazing Permit Requirements and Their Administration. http://www.cnr.uidaho.edu/range456/hot-topics/federal-permit.htm. 2007. University of Idaho. Accessed on 2-1-2007.

Jochec, K. G., Mjelde, J. W., Lee, A. C., & Conner, J. R. (2001). Use of seasonal climate forecasts in rangeland-based livestock operations in West Texas. *Journal of Applied Meteorology* 40(9), 1629-1639.

Johnston, P., McKeon, G., Buxton, R., Cobon, D., Day, K., Hall, W., & Scanlon, J. (2000). Managing Climate Variability in Queensland's Grazing Lands—New Approaches. In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems—The Australian Experience* (Eds G. L. Hammer, N. Nicholls, & C. and Mitchell), pp. 197-226. The Netherlands: Kluwer Academic.

Khumalo, G. & Holechek, J. (2005). Relationships between Chihuahuan desert perennial grass production and precipitation. *Rangeland Ecology & Management* 58(3), 239-246.

Manley, W. A., Hart, R. H., Samuel, M. J., Smith, M. A., Waggoner, J. W., & Manley, J. T. (1997). Vegetation, cattle, and economic responses to grazing strategies and pressures. *Journal of Range Management* 50(6), 638-646.

McKeon, G. M., Ash, A., Hall, W. B., & Smith, M. S. (2000). Simulation of grazing strategies for beef production in north-eastern Queensland. In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems—The Australian Experience* (Eds. G. L. Hammer, N. Nicholls, & C. and Mitchell), pp. 227-252. The Netherlands: Kluwer Academic.

Mjelde, J. W., Sonka, S. T., Dixon, B. L., & Lamb, P. J. (1988). Valuing Forecast Characteristics in a Dynamic Agricultural Production System. *American Journal of Agricultural Economics* 70(3), 674-684.

Murugan, S. (2006). Profit Maximizing Livestock Production and Marketing Strategies to Manage Climate Variability. Unpublished Master's Thesis, New Mexico State University, Las Cruces.

Ranching Systems Group. (1995). PHYGROW—An Object Oriented, Hydrologic Based, Multispecies Forage Production Model. 95-1, (Ranching Systems Group Document, 95-1). College Station: Texas A&M University, Department of Rangeland Ecology and Management.

Stafford-Smith, D. M. & Foran, B. D. (1992). An Approach to Assessing the Economic Risk of Different Drought Management Tactics on a South Australian Pastoral Sheep Station. *Agricultural Systems* 39, 83-105.

Stafford-Smith, M., Buxton, R., McKeon, G. M., & Ash, A. (2000). Seasonal Climate Forecasting and the Management of Rangelands: Do Production Benefits Translate into Enterprise Profits? In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems—The Australian Experience* (Eds G. L. Hammer, N. Nicholls, & C. and Mitchell), pp. 271-290. The Netherlands: Kluwer Academic.

Torell, L. A., Lyon, K. S., & Godfrey, E. B. (1991). Long-Run Versus Short-Run Planning Horizons and the Rangeland Stocking Rate Decision. *American Journal of Agricultural Economics* 73(3), 795-807.

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