

New approaches for enhancing grazing productivity: Meeting the challenges of variable environments¹

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Abstract

Livestock management on rangelands is challenging because rangelands are characterized by inherently low and variable precipitation, a complex native forage base that varies widely in nutritive value and toxicity, and topographic variation encompassed by large pastures. One approach to managing the consequent low and variable forage supply is to exploit the natural abilities of animals. Livestock adapted to low forage supply are those with low relative maintenance requirements. Livestock management systems can be designed to respond to distinct seasonal plant growth patterns by ensuring that peak nutrient demand coincides with the period of nutritious available forage. Herbivores vary substantially in their ability to harvest and digest rangeland forages. Making efficient use of existing forage resources can therefore be accomplished by selecting the species and breed of animal that has the natural ability to eat the available forage. The differences between herbivores in landscape use patterns could also be exploited to create livestock enterprises that best meet the topographic character of a specific ranch. Livestock well adapted to rangeland conditions can be selectively culled and bred for desired characteristics and given opportunities to learn about the grazing resource. The flexible and opportunistic strategies necessary for successful management in variable ecosystems are rooted in a clear understanding of the challenges facing the grazing animal and its natural abilities to meet these challenges. The livestock manager's role is to facilitate and exploit these natural abilities to efficiently convert forage into saleable livestock products.

Key Words: Grazing, Food Preferences, Landscape Ecology, Rangelands

Introduction

Livestock management on the rangelands of western North America is, and will always be, a difficult endeavor because of the variable nature of these ecosystems. Crafting successful livestock production strategies in any ecosystem requires a clear understanding of the challenges facing grazing animals. Challenges of grazing management on rangelands include 1) low forage productivity, 2) variable rainfall, 3) diverse and native vegetation, and 4) variable topography and geography (based on Stafford Smith, 1996). One response to these challenges is to modify the system and change the land to better suit the animal. Rangeland managers have spent decades and dollars fertilizing and irrigating land to improve forage production and limit the repercussions of low and variable rainfall. Plows, mowers, and herbicides have also been employed to convert unpalatable, native vegetation into a more useful forage resource. However, years of economic assessments have clearly shown that these input-based strategies are seldom feasible in the nonequilibrium systems exemplified by western rangelands (Stafford Smith, 1996). In this article, we suggest an alternative approach to meeting the challenges of livestock production on rangelands through the careful selection and modification of the grazing animal and the livestock production system. We will explore several applications suggested by scientists and managers to create "range-adapted livestock."

The Nature of Rangeland Ecosystems

Traditional approaches to grazing management have focused on efficiently harvesting forage biomass and limiting ecological disturbance. These approaches are predicated on the notion that when disturbance occurs, the interacting ecological components (i.e., herbivores, plants, and environmental conditions) will drive the system back to the assemblages of the previous equilibrium or equilibrate to a new, stable community (Tainton et al., 1996). This view of the grazing world is quite viable in ecosystems characterized by high rainfall that is predictably distributed throughout the year. However, most rangelands of western North America do not follow this description. Competent rangeland managers quickly discard the notion that management should be focused on an illusive ecological equilibrium. Western rangelands are best characterized by nonequilibrium properties for which a steady state is seldom achieved and plant and animal populations fluctuate widely in response to variable and erratic environmental conditions, most notably distribution, amount, and intensity of precipitation (Westoby et al., 1989; Tainton et al., 1996). In other words, rangelands are characterized more by variability than by averages and equilibriums. Though rangelands are inconstant and unpredictable, they are also inherently resilient and responsive (Tainton et al., 1996). This paradigm of nonequilibrium dynamics sets the stage for a contemporary approach to grazing management. Successful livestock management in nonequilibrium systems must be opportunistic, flexible, and adaptive to ex-

exploit the spatial and temporal variability in forage production (Westoby et al., 1989; Tainton et al., 1996).

Biological Adaptations To Low Forage Production

Rangelands are characterized by inherently low precipitation, generally ranging from 200 to 700 mm annually (Holechek et al., 1989). Moisture available for plant growth may be further limited by salt-ridden soils, low temperatures and short growing seasons, or hot temperatures and excessive evaporation rates. The result is low forage biomass available for livestock production. Because of low forage production per hectare, large areas of land are required per animal unit of production (Stafford Smith, 1996). Animals well adapted to rangeland ecosystems are those of the appropriate biological type and age that have low absolute intake and energy requirements and, thereby, need to travel fewer hectares to meet their requirements.

One way in which animals can be biologically adapted to environments of low forage availability is to possess relatively low absolute energy requirements for maintenance. Maintenance accounts for 70 to 75% of a cow's yearly energy requirement (Ferrell and Jenkins, 1985; NRC, 1996). Thus, it could be reasoned that animals with lower maintenance requirements could survive on less-abundant or lower-quality forage and partition a greater proportion of energy to gestation or lactation when available energy exceeds maintenance. It is clear that maintenance requirements vary by cattle type (Ferrell and Jenkins, 1985; Taylor et al., 1986; Montaña-Bermudez et al., 1990) and that maintenance variation seems to be greater than variation for growth, gestation, or lactation (Ferrell and Jenkins, 1985). Furthermore, breeds that possess greater milk or growth potential partition a greater proportion of energy intake to maintenance than breeds with less production potential (Ferrell and Jenkins, 1985; Montaña-Bermudez et al., 1990). The specific reason for greater maintenance requirements for cattle types with greater lactation or growth rates is unclear but is correlated to greater energy expenditures of visceral organs, especially the liver and gastrointestinal tract (Ferrell and Jenkins, 1985).

Because low maintenance requirements are associated with lower potential for lactation and growth, it is necessary to examine how efficiently cattle of different biological types convert ingested energy into calf weight to assess the appropriate cattle type for production in environments with low forage production. Montaña-Bermudez and Nielsen (1990) studied the biological efficiency of beef production for three breed-crosses with similar mature size but different lactation potential (Hereford × Angus, Red Poll × Angus, and Milking Shorthorn × Angus with low, medium, and high milk production, respectively). In their study, conversion of metabolizable energy consumed to calf weight weaned or slaughtered (i.e., carcass weight) was highest for the Hereford × Angus cross cattle, that is, the breed cross with the lowest milk production. Jenkins and Ferrell (1994) further studied biological efficiency across nine breeds of cattle fed different levels of dry matter. When DMI was restricted ($< 3,500 \text{ kg DM} \cdot \text{cow}^{-1} \cdot \text{yr}^{-1}$) the smaller breeds with lower growth and lactation

potential (i.e., Red Poll, Angus, and Hereford) weaned more kilograms of calf per kilogram of DMI than larger breeds with greater milk production. However, when examined under conditions of abundant forage availability ($> 4,500 \text{ kg DM} \cdot \text{cow}^{-1} \cdot \text{yr}^{-1}$), larger breeds with greater growth potential (i.e., Limousin, Charolais, Simmental, Braunvieh, Gelbvieh, and Pinzgauer) expressed greater biological efficiency than the smaller British breeds. Thus, smaller cattle breeds with lower maintenance requirements are apparently more biologically efficient and better adapted to environments with limited forage production, such as most rangelands.

Finding the animal best adapted to rangeland environments requires a careful examination of biological type, but animal age should not be overlooked. "Stayability" is the term used by animal breeders and geneticists to describe the number of years a cow remains productive in a herd. There are several reasons why efforts to increase stayability and keep cows in the herd longer make sense in range operations. The low output of saleable products per hectare dictates that production costs be kept low. The development of replacement females in the herd represents a significant cost in cow-calf production systems. If cows can remain productive longer (e.g., 9 to 13 yr), this cost of development can be spread over a greater number of calves weaned from each cow. This economic opportunity has prompted at least two breed associations (Red Angus and Limousin) to begin computing an EPD for stayability.

Increasing cow stayability may also yield benefits of reduced energy requirements as maintenance requirements decrease as much as 3 to 8%/yr (NRC, 1996). It is generally believed that maintenance requirements per unit of body weight decline with age, although several studies have presented data contrary to this view (reviewed in Ferrell and Jenkins, 1985). If energy demands decline with age, lower energy needs of older cows should be a distinct advantage in ecosystems with limited forage resources. Older cows also have the advantage of having greater familiarity with forage (Ferrer Cazcarra and Petit, 1995) and thermal (Beaver and Olsen, 1997) resources than younger cows. As cows age, they may therefore have lower nutrient and energy requirements and more knowledge and experience in meeting these needs. The concept of a "range-adapted" animal would therefore be epitomized by a 13-yr-old cow that has weaned 11 calves with very little supplement or intervention.

Management Responses to Variable Rainfall Patterns

The challenge of low average annual precipitation and low average forage production is formidable, but manageable. However, as every range livestock producer knows, the problem is that "average" years seldom occur. The only constant feature of rangelands is variability. Extreme yearly variation in precipitation, and consequent yearly forage variability, is a seminal feature of rangelands (Stafford Smith, 1996). Management strategies to address a variable forage supply can be either fixed or flexible (Holechek et al., 1989). Fixed stocking strategies are based on the reality that precipitation varies from year to year in an abnormal pattern, creat-

ing a situation in which most years have below average precipitation. Research in southern Idaho exemplifies this property; annual precipitation and forage production in the last 43 yr were below average in 63% of the years (K. Sanders, unpublished data). The mode or median yearly precipitation is a more viable basis for management decisions than the average on rangelands where precipitation is not normally distributed. Meeting animal forage demand while maintaining a fairly stable herd size requires that stocking rates be set at least 10% below the rate that would yield proper use in an average year (Holechek et al., 1989). Flexible stocking practices are generally accomplished by keeping or buying extra animals in years of above-average forage production. Conversely, strategies such as heavy culling or early weaning can be used to reduce the nutritive demand in years of low forage production. The costs associated with retaining, buying, or selling animals limit the economic feasibility of highly flexible approaches (Holechek et al., 1989). Therefore, a combination of fixed and flexible stocking strategies will usually maximize economic returns of most livestock operations.

Exploiting the natural abilities of livestock to lose or gain weight in response to nutrient supply is an alternative strategy that may enhance both fixed and flexible approaches to managing variable forage supplies. In years of low forage supply, reproductive females could be allowed to lose one body condition score for 1 to 2 mo before weaning through midgestation. Application of this strategy depends on the availability and cost of nutrients to gain back body condition during late lactation. Similarly, calves can be sustained at a low growth rate after weaning during low forage quality and quantity periods until green forage returns in the spring. This strategy requires minimal daily nonfeed costs such as labor, interest, and capital investment.

Precipitation patterns on rangelands are not only characterized by extreme temporal variation, they are also marked by immense spatial variation. An underused strategy for dealing with insufficient rainfall is to create large ranches or management units such that a portion of the land base is more likely to receive adequate moisture to provide forage. This concept may become feasible as ranch size increases to maintain economic viability. Livestock producers acquiring land for enterprise growth should strategically seek property that will maximize grazing management options to counter variable rainfall. An emerging approach to increase management flexibility is to create cooperative relationships between ranches (Budd, 1999). In these situations, a group of ranchers join together and manage their ranches as a single unit. This approach offers increased flexibility to create "grass banks" for management options such as controlled burns or drought mitigation. The idea of ranches forming management cooperatives seems contradictory to the image of ranchers as independent, self-reliant individuals. However, management options for meeting challenges such as variable rainfall may be an appealing prospect for even the most independent person.

Forage supply in temperate climates is also characterized by significant within-year variation. Seasonal variation in forage supply is a biological reality for which most ranchers

prepare. One of the greatest capital inputs on range livestock operations in the western United States is the purchase or harvesting of hay or grains to meet deficits in nutrient supply. The reliance on harvested forage can be reduced by matching nutrient demand with forage supply. This can be accomplished by planting forage crops that either initiate growth before native range or remain nutritious in summer or fall when native range becomes dormant (e.g., complementary forages). Seasonal suitability grazing is a time-honored management practice by which animals are moved between range types with different seasonal growth patterns (Holechek et al., 1989). For example, animals may graze on low-elevation, shrub-dominated communities in winter, when shrubs are more nutritious than dormant grasses, then move to midelevation range dominated by cool-season plants that express active growth in spring and fall, and graze during summer months at high elevations while plants are green and growing.

Matching animal demand to the seasonal availability of forage can also be accomplished by managing the cycle of animal requirements. Periods of active forage growth generally last only a few months on rangeland, restricted either by low temperatures or low available precipitation. The reproductive cycle of livestock can be managed so that peak demand coincides with this period of green forage availability (Adams et al., 1996). Calving 45 to 60 d before peak biomass production provides maximum nutrients and energy for lactation, abundant good-quality forage for growing calves, and sufficient grazing time for dams to improve condition before rebreeding. This requires a calving season to begin in late March or April on northern rangeland dominated by cool-season plants and mid- to late May on southern warm-season rangelands. Many producers prefer to calve in late winter (i.e., February or March) because there are several disadvantages to spring calving. Calves born in April are lighter at weaning than calves born in February (May et al., 1999; Grings et al., 2000), which can decrease gross receipts if calves are sold shortly after weaning. Although spring calves have lower weaning weight in fall, this can be partly offset by the fact that smaller calves often receive a higher price at market. In integrated crop-livestock operations, labor demands of late calving can interfere with labor needs in agronomic portions of the enterprise. However, late calving can yield substantial savings in winter feed costs that may offset these difficulties. May et al. (1999) reported feed costs in Wyoming for calving in February averaged \$216/cow, whereas feed costs for June calving averaged \$173/cow. Calving just before peak biomass undoubtedly makes good biological sense; however, issues of economic returns and labor resources must be considered to determine the viability of this practice in each enterprise.

Native and Diverse Vegetation

One of the greatest challenges of livestock production on rangelands is raising animals in an ecologically complex foraging situation composed of many plant species and life forms with forage quality that varies spatially and temporally

(Stafford Smith, 1996; Provenza and Balph, 1990). An herbivore's challenge is to gather enough nutritious forage to evade starvation and produce viable offspring, yet avoid the consumption of lethal doses of poisonous plants. All grazing animals have natural abilities to make reasonable foraging decisions and to face the challenges posed by complex foraging situations (Provenza, 1995). A livestock manager's role is to facilitate and exploit these natural abilities to efficiently convert forage into saleable animal products. We suggest that this feat of animal husbandry can be accomplished with three management practices: 1) selecting a kind and type of animal with natural foraging behaviors that match the available forage; 2) selectively breeding animals to increase the preference for available or target plant species; and, 3) giving animals the opportunity to "learn" about the foraging situation.

Selecting Appropriate Animals

Rangelands are often dominated by plants with limited forage value because of physical plant defenses such as thorns or spines, excessive fiber, or allelochemicals that reduce digestion (i.e., tannins or essential oils) or are toxic when consumed (Provenza and Balph, 1990). Herbivores vary substantially in their ability to cope with these attributes of plants. Making efficient use of the existing forage resources can therefore be accomplished by selecting the species of animal that has a natural ability to eat the available forage. Cattle generally select grass-dominated diets, sheep generally prefer forbes, and goats make better use of shrubs than do cattle or sheep (Holechek et al., 1989). The plant composition of the grazing resource may therefore suggest an appropriate herbivore. This idea of matching herbivore diet preferences to the forage available has also been applied to prescription livestock grazing for weed control (Olsen, 1999). For example, Walker et al. (1994) examined different species' preferences for leafy spurge (*Euphorbia esula*) and found that goats had a greater preference for leafy spurge than did sheep; goats would therefore be the logical species for spurge control.

Selecting an herbivore species compatible with the available forage is more simple in concept than in practice. Converting livestock enterprises from cattle to sheep or goats requires substantial changes in fencing, handling, marketing, and management. Thus, wholesale changes in livestock species are seldom observed. However, variation in forage preferences between breeds within a species might be exploited to more efficiently use the available forage resource. Research with cattle (Herbel and Nelson, 1966; Winder et al., 1996), sheep (Warren et al., 1984), and goats (Warren et al., 1984; Pritz et al., 1997) has revealed that breeds differ in dietary preferences, though differences tend to be small. However, amassing herds of animals that eat even slightly greater proportions of forage that would otherwise be underused may have significant production and ecological implications. Research in animal and range sciences generally focuses on averages and treatment effects. With this research focus we often lose sight of variation between individuals that may be exploited to reach management goals. Studies on

the intake of mesquite (*Prosopis glandulosa*; Baptista, 1995), juniper (*Juniperus pinchotii*; Pritz et al., 1997), and sagebrush (*Artemisia tridentata*; Fraker 1999) clearly show that animals vary significantly in their voluntary intake of specific plants and that patterns of variation are consistent from day to day. In other words, animals that eat an above-average amount of mesquite, juniper, or sagebrush on one day are likely to eat above-average amounts in following days and years. Selecting and retaining animals that naturally eat underused forages is a management practice that could increase the forage supply without irrigating, fertilizing, or acquiring more land.

Breeding Animals with Desired Foraging Characteristics

At least part of the variation in foraging preferences observed between individuals is inherited. This is evidenced by differences in dietary preferences observed between breeds, discussed above. Snowden et al. (2001) recently studied variation in diet selection within a breed by examining sagebrush consumption in more than 400 Rambouillet sheep with known genetic pedigrees. The study estimated that the heritability of percentage of sagebrush in the diet was 25 to 28%. The specific morphological or physiological attributes that are inherited to direct diet selection are not known. However, it is clear that differences in digestive morphology and sensory abilities lead to differences in foraging preferences and that these attributes are substantially inherited (reviewed by Launchbaugh et al., 1999).

Livestock managers have selected animals for desired characteristics and culled undesirable animals since the beginnings of livestock husbandry. Livestock breeds have resulted from selection of production characteristics, behavior, color, size, and resistance to disease, pests, or environmental extremes (Lasley, 1987). More efficient use of rangelands could undoubtedly be made if animals could be selected and bred to efficiently harvest and metabolize rangeland forages. Accomplishing this task is difficult because diet selection is not easily quantified. However, new technologies are emerging, such as near-infrared reflectance spectroscopy (Walker et al., 1998) and laser-induced fluorescence (Anderson et al., 1996) to characterize fecal material, that may improve the success of selecting and breeding for diet attributes to meet the challenges posed by native forages.

Facilitating Animal Learning

Range livestock are gregarious creatures that learn appropriate diet and habitat selection patterns through social interactions. Information about kinds and locations of foods, sources of water, and nature of hazards in the environment are passed from dam to offspring and between members of the flock or herd. Livestock managers striving for efficient livestock production on rangeland are wise to encourage these social interactions. For example, many livestock producers raise their own replacement females because they believe that only animals native to their ranch can effectively

respond to foraging and environmental challenges they will face.

Foraging experiences early in life cause morphological, neurological, and physiological changes in the animal that will yield differences in what the animal will eat later in life (Provenza, 1995). Previous dietary experiences can influence the flavor preferences of animals (Nolte and Provenza, 1992) and their ability to digest (Distel et al., 1994), detoxify (Distel and Provenza, 1991; Robbins et al., 1991), and harvest (Ortega-Reyes and Provenza, 1993) specific plants. These foraging habits can be quite strong and inflexible. For example, goats reared from 1 to 4 mo of age on rangeland dominated by blackbrush (*Coleogyne ramosissima*) ate twice as much blackbrush as did goats unfamiliar with blackbrush (Distel and Provenza, 1991). Even after 1 mo with both groups of goats grazing blackbrush, experienced goats still consumed 27% more blackbrush than did naive goats. These deeply held foraging habits could explain why livestock producers often experience production losses when animals are transported to unfamiliar rangelands.

Spatial Variability

Most of the world's grazing lands are used to produce livestock largely because they are useless for crop cultivation; they are too dry, rocky, or steep. As a result, extreme and variable topographic relief on rangelands is a serious challenge to livestock production. To compound topographic challenges, regions of low forage production are generally managed with large pastures that encompass, rather than segregate, spatial heterogeneity (Stafford Smith; 1996). It is difficult to manage usage patterns in large pastures with great topographic variation. Preferential selection of livestock for areas of level terrain near water sources can lead to range degradation because some habitats, such as riparian ecosystems, become overused whereas others experience little use (Kauffman and Krueger, 1984).

Herbivore species differ in their ability to use steep and rough terrain and in their consequent spatial use of rangelands (reviewed by Bailey, 1999). Horses, for example, generally graze greater distances from water than cattle or sheep (Bell, 1973). Sheep and goats are generally considered more suitable for steep, rugged terrain than cattle (Holechek et al., 1989). Wildlife species, such as bighorn sheep and mule deer, are known for their ability to use extremely steep terrain unusable to livestock (Holechek et al., 1989).

The differences between herbivores in landscape use patterns could be exploited to create livestock enterprises that best meet the topographic character of a specific ranch; however, as discussed earlier, species conversion is seldom a viable option for livestock producers. Thus, much research in western North America has focused on management strategies to improve beef cattle distribution (Walker, 1995). These strategies include fencing, implementing rotational grazing systems, developing water sources, strategically locating salt and supplement, creating patches of high-quality vegetation in underused areas, and providing shade away from riparian areas (Vallentine, 1990; Del Curto et al.,

1999). Livestock selection and breeding programs have also been suggested as strategies to alter distribution patterns of cattle. For example, Brangus cattle have been shown to travel further from water than Hereford or Angus cattle (Herbel and Nelson, 1966; Winder et al., 1996). Thus, breed selection could alter the usable area of a pasture without adding water sources. Breeds also differ in their use of steep and rough terrain, suggesting that some aspects of habitat selection are inherited (reviewed by Bailey, 1999). Social influences and individual learning also affect habitat usage patterns. For example, herbivores have an affinity for the areas in which they were reared (Howery et al., 1996). The location of other members of an herbivore's social group can also affect landscape usage patterns (Bailey, 1999). Several range improvements and livestock management practices are, therefore, feasible after the topographic limitations of a specific grazing area are identified.

Discussion

We propose an approach to range livestock management that focuses on animal adaptation to rangeland environments. The concept is biologically simple. However, there are several management difficulties to implementing this approach. First, the selective breeding of animals with appropriate diet selection or landscape use patterns must be integrated with other selection criteria. For example, sheep could be selected to consume high amounts of sagebrush, but livestock managers must simultaneously consider wool and lamb yield. The production outcome of selecting animals for specific diet attributes is unknown. Second, to select and breed animals with desired traits, technologies must be created and adapted to identify and quantify diet and habitat usage characteristics. Simple techniques to identify diet parameters must be developed, such as those based on fecal or blood analysis. Habitat usage patterns could be readily quantified with automated global positioning systems. Finally, new evaluation procedures need to be created and applied to characteristics relevant to range livestock production. Central performance testing conducted under grazing, rather than confinement, conditions would be necessary to select "range-adapted animals." The potential benefit of overcoming these challenges of identifying and selecting desired animals could yield a new and powerful tool for livestock management in environments characterized by low and variable forage production.

Implications

The challenges of range livestock management are imposed by the low and erratic rainfall and the topographic variation of rangeland ecosystems. A "new" approach to grazing management under these conditions is the careful and strategic application of several "old" tools of livestock management. Animals well adapted to a particular range resource can be selected, based on biological type and age, selectively culled and bred, and given opportunities to learn about the rangeland area. Livestock management schemes should be designed to match animal demands to the temporal and spa-

tial variation in forage supply. The flexible, opportunistic, and adaptive management strategies necessary for livestock production on rangelands can be attained by exploiting the natural foraging and production abilities of livestock.

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Notes

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