

Benefits of Multi-Paddock Grazing Management on Rangelands: Limitations of Experimental Grazing Research and Knowledge Gaps

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The benefits of multi-paddock rotational grazing on commercial livestock enterprises have been evident for many years in many countries. Despite these observations and the results of numerous studies of planned grazing deferment before the mid-1980s that show benefit to species composition, most recent rangelands grazing studies suggest that rotational grazing benefits neither vegetation nor animal production relative to continuous grazing. Detailed comparisons of research methods and practical experiences of successful practitioners of multi-paddock grazing systems identify a number of areas that explain why such different perceptions have arisen. Consistent with producer experience, published data from small paddock trials on both temporal and spatial aspects of grazing management indicates the potential for significantly higher production under multi-paddock rotational grazing relative to continuous grazing and conservative stocking.

While research findings often suggest multi-paddock grazing management is not superior to continuous grazing, researchers have not managed trials to answer practical questions such as: how good is this management option, where is it successful, and what does it take to make it work as well as possible? In contrast, successful ranchers manage strategically to achieve the best possible profitability and ecosystem health. They use basic knowledge of plant physiology and ecology generated by research within an adaptive, goal-oriented management approach to successfully implement planned grazing management.

Published research and experience from ranchers have indicated that the following management factors are the keys to achieving desired goals: (1) Planned grazing and financial planning to reduce costs, improve work efficiency and enhance profitability and environmental goals; (2) Adjusting animal numbers or having a buffer area available so that animal numbers match forage availability in wet and dry years; (3) Grazing grasses and forbs moderately and for short periods during the growing season to allow adequate recovery; (4) Timing grazing to mitigate detrimental effects of defoliation at critical points in the life cycle of preferred species inter- and intra-annually; (5) Where significant regrowth is likely, grazing the area again before the forage has matured too much; (6) Using fire to smudge patch-grazing imprints and manage livestock distribution; and (7) Using multiple livestock species. In all these areas, management is the key to success.

Many researchers have failed to sufficiently account for these management factors, either in their treatment applications or in the evaluation of their results. To define the potential impact, researchers must quantify the management strategies for best achieving whole-ranch business and ecosystem results under different grazing management. Conducting research on ranches that have been successfully managed with planned multi-paddock grazing for many years, together with systems-level simulation modeling, offer complementary approaches to traditional small-paddock field research. These methods are particularly applicable where logistics preclude field experimentation, or when assessing impact over decadal time frames. This chapter discusses these points, suggests areas of research that may explain differences in perception among land managers and researchers, and provides information to achieve the full potential of planned multi-paddock grazing management.

INTRODUCTION

Many ranchers who have practiced multi-paddock grazing management for decades are very satisfied with the economic results and improvement to the ecosystem, as well as the change in management lifestyle and social environment of their ranch businesses. Such ranchers regularly win conservation awards from the ranching industry and natural resource professional organizations. In contrast, many grazing researchers have concluded that multi-paddock grazing offers no significant benefit over continuous grazing (Holechek et al. 1999, 2000; Briske et al. 2008), but their studies have been largely small-scale trials focussed on the technical questions of ecological impacts and livestock production conducted in a relatively limited scope of fairly resilient landscapes. In addition, research plots are designed to reduce or eliminate variability, while ranch managers must manage in the environment with all the inherent variability of the landscape. The relevance of such research to a commercial ranch operation is questionable because many studies do not address critical information needed by ranch managers to achieve desired outcomes.

Ranchers have a vested interest in managing for the best result in terms of production, profitability and sustaining natural resources. Achieving management goals requires integrating knowledge from numerous biological, management and economic disciplines and correctly adjusting management actions to changing conditions. Research scientists, in contrast, almost invariably work only within the narrow confines of a single discipline, be that soils, plants, or herbivores. Consequently, research on grazing systems has not considered the multi-disciplinary and broadly integrative ramifications of treatments. Generally multi-paddock research treatments have been applied to assess esoteric goals that may be academically interesting but are of little benefit to ranch managers.

Questions relevant to managers are: (1) what are the advantages of this management option; (2) where is it likely to be successful; (3) how does it need to be managed to make it work as well as possible; and (4) what are the biological interactions and principles that can provide guidance for adjustments to changing conditions or unanticipated outcomes? Ultimately, every situation is unique in time and space, and while we can understand principles and processes, it is the answers to these site-specific questions that enable managers to assess the benefits of adopting various practices as they pertain to the biological, financial and social aspects of their business to achieve desired environmental, economic and social goals (Provenza 2000).

In this chapter, we first discuss the relationship between ecological science and applied management science. We then provide an ecological and physiological framework that underpins management decisions to achieve desired outcomes. We explain concepts critical for implementing successful planned grazing, then discuss how they can be used to manage for desired outcomes, and finally we provide a list of guidelines for planning successful grazing management programs. We use these guidelines as a framework to examine and explain the differences between much of the scientific literature and management experience and suggest

areas of research to provide information for managers to achieve the full potential of planned multi-paddock grazing management.

THE RELATIONSHIP BETWEEN ECOLOGICAL AND APPLIED MANAGEMENT SCIENCES

Basic ecological and applied management sciences have different but complementary functions (Provenza 1991). The aim of ecological research is to understand principles and processes as they pertain to the interrelationships among organisms and their environments, and not to examine how ecological information can be used effectively by managers. Applied management sciences bridge the gap between ecological information and the achievement of desired management goals by integrating knowledge from diverse disciplines. They evaluate management consequences within a research-based theoretical framework of ecological processes and how they affect ecological, economic and social factors important to management.

The rangeland discipline is distinguished from ecological disciplines in that we work in a management framework. If we fail to address management-related issues important to land managers, we have abrogated our responsibilities and minimized our impact. We are an essential bridge between ecologists and managers of rangeland, but to be relevant to managers, reductionist studies of processes must, at the very least, be rooted in potential for application to managing landscapes within a systems framework. Knowledge of ecological processes can help managers be more effective in implementing strategies that enhance positive responses, reduce or mitigate negative responses, and benefit the financial efficiency and human relationships of a ranch business.

ECOLOGICAL AND PHYSIOLOGICAL BACKGROUND

Fire and grazing by large ungulates are considered integral to the persistence of grassland ecosystems and species diversity, and their importance for rejuvenating landscapes will only become more important as the costs of fossil fuels rise (Provenza 2008). Natural rangeland communities are constantly responding to the effects of the most recent disturbance, in most cases never achieving a steady-state or climax stage. The absence of these disturbances in grassland ecosystems results in a decline in species diversity and deterioration of physical structure (Vogl 1974; Rice and Parenti 1978; Pickett and White 1985; Hulbert 1969, 1988). Grazing by large ungulates has been an integral part of prairie ecosystems from the late Mesozoic, and ecosystems have a high inherent sustainability as a direct result of this long co-evolutionary history (Frank and McNaughton 2002). This is remarkable as they support more herbivore biomass and sustain considerably higher levels of herbivory than any other terrestrial habitat. Nomadic pastoral systems that mimic these grazing patterns also seem to have less detrimental effects on vegetation (Danckwerts et al. 1993).

One key stabilizing element of native grazing ecosystems is that they are characterized by high spatial and temporal variation in forage supply, due to vegetation response to ever changing topography, edaphic effects, and climate. Second, they are dominated by large, migratory ungulate herbivores that are constantly

on the move, and although herbivores often graze intensely at any particular site, such grazing never lasts long and defoliated plants are afforded time and usually suitable conditions to regrow (McNaughton et al. 1989). Herbivores move for a variety of reasons including need for nutrients, satiating on nutrient and secondary compounds, fire, predators, movements by a herder, and rotations in a grazing system (Provenza 2003b; Provenza et al. 2003; Bailey and Provenza 2008). Grazers are important regulators of ecosystem processes (Frank and Groffman 1998). Through their impacts, herbivores link their health with that of soils, plants and ultimately people (Provenza 2008). Grazers can increase forage nutrient concentrations and aboveground plant production (Frank and McNaughton 2002). Grazers also enhance mineral availability for soil microbial and rhizospheric processes that ultimately feed back positively to plant nutrition and photosynthesis (Hamilton and Frank 2001), in addition to increasing nutrient cycling within patches of their urine and excrement (Holland et al. 1992). Frank and Groffman (1998) found that grazer control of carbon and nitrogen processes was as important as landscape effects of topography, catenal position and different soils. By increasing resource availability locally, they can also influence diminish the adverse impacts of secondary compounds in plants (Bryant et al. 1983; Coley et al 1985). However, the positive feedbacks from grazers on the ecosystem are contingent on suitable climatic conditions. During drought these feedbacks are diminished (Wallace et al. 1984; Coughenour et al. 1985; Louda et al. 1990).

Grazing management systems were developed in an attempt to manage grazers and grazing lands in a manner that maintains or improves ecosystem structure and function while achieving social and economic goals (Heitschmidt and Taylor 1991). In stark contrast to native grazing ecosystems, however, the replacement of free-ranging wild herbivores with livestock has generally resulted in overgrazing and degradation of rangelands (Provenza, 2003b). Generally, extensive or poorly managed rotational grazing of domestic animals by humans does not emulate the movements of wild ungulates, and managed herds during dry seasons can be held at stocking rates higher than the land can support. Maintenance of artificially high animal numbers with supplementary feed during less productive periods promotes degradation (Oesterheld et al. 1992; Milchunas and Lauenroth 1993). The more sedentary and concentrated animal use of the vegetation under human management removes the key revitalizing element of periodic deferment and natural response to climate variation. Indeed, in the recent past we have largely restrained the movements of domestic animals and in the process inadvertently trained herbivores to become sedentary, largely with the use of fences in continuous and conventional rotational grazing systems, and with the suppression of fire and large predators (Provenza 2003a).

While the foregoing discussion emphasizes grazer effects on landscapes, defoliation by grazers also significantly affects individual plants morphologically and physiologically. This in turn affects their vigor and productivity, as well as recruitment and survival through the indirect effects on competitive relationships among plants (Briske 1991). The detrimental effects of defoliation are increased with greater intensity or frequency of defoliation (Briske 1991) and can lead to mortality of plants, particularly if environmental

conditions deteriorate. Seedlings and juveniles of palatable species are particularly vulnerable. McIvor (2007) found lower survival rates of plants grazed at > 60% utilization as opposed to <60% utilization under continuously grazed management, drought exacerbated these differences. In an early and classic study, Crider (1955) found that a single defoliation removing 50% or more of the shoot volume retarded root growth in 7 of 8 perennial species examined. This observation, among others, prompted the often used term “take half - leave half” as an aphorism for grazing management that emphasizes stocking rate. However, Hormay (1956) observed that preferred plants in preferred sites are utilized closely and repeatedly even when the entire management unit is lightly or moderately stocked on average.

Preferred plants have probably always been severely grazed when encountered, but much of the time the intermittent nature of the severe grazing described in the second paragraph of this section prevented this condition being chronic (McNaughton et al. 1989). The elements of timing, when and for how long, and adequate recovery distinguish severe grazing from overgrazing, and cannot be overemphasized in any discussion of grazing management. Overgrazing occurs on individual plants (Roshier and Nicol 1998) as a result of multiple, severe defoliations without sufficient physiological recovery between defoliations. It is site, stock density, and time-specific, and diet selection of grazing animals can put palatable and actively growing plants in preferred areas at a disadvantage (Earl and Jones 1996). Stocking rate only affects the proportion of plants likely to be used heavily. Therefore, while conservative stocking is an important first step in sustainable management, it must be applied in conjunction with other management practices like short grazing periods at high stock density (O’Connor 1992) and periodic deferment to mitigate the effects of selective grazing (O’Reagain et al. 2003). Increasing differences in palatability and abundance among different plants in a pasture, decreasing stock density, or increasing the graze period will tend to increase the likelihood of overgrazing the more palatable plants (Earl and Jones 1996).

Vegetation dynamics on a landscape emerge from interactions among plant autecology, community processes, climate, and disturbance, as modified by grazing animal preferences and distribution in response to plant species, topographic and ecological site diversity (Walker 1988). Ash and Stafford-Smith (1996) provide an excellent explanation of how selective use of plants and landscape components can cause a gradually widening area of degradation under continuous grazing, even at light to moderate stocking rates.

Earlier, Hormay (1956) asserted that close and frequent cropping (overgrazing) in preferred areas could not be prevented by regulating only stocking rate, and said that stocking rate determined only the size of the overgrazed areas, and therefore, the spatial scale of degradation if allowed to continue over an extended period of time. He explained that for a given kind of livestock, there are only four factors that can be manipulated to influence desired management goals on rangelands: stocking rate, season of grazing, livestock distribution, and frequency of grazing. These factors are generally acknowledged by many range managers and scientists alike (e.g. Heitschmidt and Walker 1996; Briske et al. 2008). These four

management factors have been further reduced to frequency of defoliation, the intensity of defoliation, and regrowth opportunity (Reed et al. 1999), but should also include spatial distribution (Barnes et al. 2008).

For communities to move from one stable state --assemblage of species occupying a site-- to another, some external force is required (Walker 1988; Westoby et al. 1989; Danckwerts et al. 1993). Management of grazing to enhance soil moisture and seed production can “condition” the resource to take fuller advantage of episodic events like drought, fire, and unusually wet periods, particularly if the event is of a marginal magnitude, so that a community might move or be prevented from moving from one state to another more readily (Watson et al. 1996; Gerrish 2004). In any management situation the key issue is to be aware of what stable state or states have the greatest chance of fulfilling management objectives, and what combination of events and management is required to cause or prevent movement from one state to another (Westoby et al. 1989; Danckwerts et al. 1993).

THE REAL IMPACT OF CONTINUOUS GRAZING

Continuous grazing in large paddocks is usually associated with patch grazing and resource deterioration in localized areas. Grazing under enclosed conditions does not occur uniformly over time or over a landscape (Willms et al. 1988; O’Connor 1992; Ash and Stafford-Smith, 1996; Bailey et al. 1996; Gerrish 2004; Witten et al. 2005). Livestock grazing large paddocks exhibit spatial patterns of repetitive use, heavily using preferred patches and avoiding or lightly using others. The process of patch-selective grazing results in the effective stocking rate on heavily used patches being much higher than that intended for the area as a whole. The resulting heterogeneity in landscapes may be desirable or undesirable depending on desired outcomes and scale of disturbance. Any positive feedbacks on the ecosystem from grazers noted in the previous section are contingent on suitable climatic conditions, and are weakly expressed during low-rainfall years (Wallace et al. 1984; Coughenour et al. 1985; Louda et al. 1990). If threshold amounts of biomass and litter are not maintained, a degradation spiral is initiated (Thurow 1991; Ash and Stafford-Smith, 1996), with heavily used patches as foci (Fuls 1992; O’Connor 1992; Teague et al. 2004).

Consequently, even at light stocking levels the heavily grazed patches and preferred species are subject to excessive grazing pressure. Root biomass (or density) and rooting depth decline as: (1) a greater proportion of leaf material is removed (Crider 1955; Cook et al. 1958; Singh and Mall 1976; Hodgkinson and Baas Becking 1977; Stroud et al. 1985), especially during the growing season (Ganskopp 1988; Engel et al. 1998); (2) the interval between defoliation events declines (Harradine and Whalley 1981; Motazedian and Sharrow 1987; Danckwerts and Nel 1989); or (3) a function of long-term grazing impacts (Weaver 1950; Tomanek and Albertson 1957; Schuster 1964; Blydenstein 1966). This reduces plant vigor and causes desirable plants to die in overgrazed patches during droughts enabling less desirable species or invading weeds to occupy the vacated space and expand into surrounding vegetation.

A continuously grazed paddock must be large enough to supply enough forage for an entire year or climatic grazing season. Paddock size is driven up by herd size big enough for efficient ranch operation and by the cost and logistics of water supply and fencing. Paddock size will also be influenced by declining forage production per hectare with decreasing average rainfall in semi-arid environments. Landscape heterogeneity increases with the size of a grazing unit (Senft et al. 1985; Stuth, 1991; Bailey et al. 1996), resulting in heavier impact on preferred areas and a greater proportion of the paddock receiving light utilization or total neglect. Selection is affected a little by small-scale heterogeneity at the feeding station level but is profoundly affected by large-scale heterogeneity at the landscape level (WallisDeVries and Schippers 1994; Barnes 2002). Both the spatial arrangement of grazing patches and the scale of patchiness are major determinants of selectivity during grazing (WallisDeVries et al. 1999). In addition, patterns of herbivory on the landscape are controlled by the spatial distributions of topography, water, cover, minerals and inter- and intra-specific social interactions (Coughenour 1991). Spatial and temporal variability in primary production localizes and intensifies herbivore impacts (Illius and O'Connor 1999). Historically, herbivores were encouraged to move across landscapes, sometimes in ways that were predictable, such as seasonal movements related to topography and elevation, and sometimes in ways that were not predictable, due to precipitation, fires, and hunting by predators, including humans. These factors compound over time to create long-term impacts on the environment and on primary and secondary production (Coughenour 1991; Fuls 1992; Kellner and Bosch 1992).

Patch selective over-grazing and resource deterioration in localized areas have a number of profound consequences for the interpretation of experimental results and for managing rangeland for sustainable goals. Usually experimental paddocks have been less than 25 ha and often less than 5 ha each (Norton 1998), which is considerably smaller than those of commercial ranches in the same environment. Small herds of livestock continuously grazing in such small experimental paddocks have no problem exploring and accessing the entire paddock one or more times each day. Relatively small research paddocks grazed continuously to compare with rotational grazing do not mimic the continuous grazing of large paddocks. They reduce the manifestation of a critical element of continuous grazing, namely uneven utilization and patches of extreme use over the landscape, as they ignore the documented patterns of selection and resulting effects that occur in large paddocks (Norton 1998; Teague and Dowhower 2003). The conclusions of such research have been extrapolated to all pastoral situations, regardless of paddock size. Small-scale experiments are carried out as though paddock size doesn't matter, and when the paddocks are only 20 ha or less, it doesn't. Unless the issues of scale and spatial heterogeneity are included as treatments, experiments at a only small scales do not represent what happens at the scales of commercial ranches. Great care must be taken in offering advice without due consideration of the effects of extrapolating results from small-scale experiments to larger scales.

It is incorrect to assume that at low stocking rates, grazing pressure will be low across a landscape. This occurs only for a short time after a fire has burned a management area. As time progresses after a fire, the pattern of area- and patch-selective grazing resumes, so that the pattern-removal effect of fire disappears completely after several years (Archibald et al. 2005). On average, grazing pressure might be low but it is heavy on some areas and very low or zero on other areas. The misconception that low stocking rates result in no overgrazing contradicts much of the published research relating to the process of uneven utilization in landscapes (Ash and Stafford-Smith, 1996). All that can be truthfully said is that all other things being equal, at lower stocking rates grazing pressure will be lower *on average*. With low stocking rates, a relatively small proportion of the primary productivity is harvested by grazing animals, while the majority senesces and decomposes without being ingested by herbivores. If the damaging effects of area and patch selection are minimised, by limiting the number or severity of defoliations (e.g. Derner et al, 1994) through short graze periods and providing *adequate* recovery after grazing, conservation and production goals will be achieved.

The published evidence illustrates unequivocally that patch-selective overgrazing happens under continuous grazing on ranches even if small plot research does not confirm this or underestimates it, as outlined above in this chapter. The implementation of planned grazing management allows recovery of heavily grazed patches and the regulation of grazing intensity and frequency.

MANAGING FOR DESIRED OUTCOMES

Successful grazing managers must optimize several ecological goals to attain sustainable production goals (Heitschmidt and Taylor 1991; Briske et al. 2008). These include: (1) Planned grazing and financial planning to reduce costs, improve work efficiency, enhance profitability, and achieve environmental goals; (2) Providing sufficient growing season deferment to maintain or improve range condition; (3) Grazing grasses and forbs moderately during the growing season for a short period to allow adequate recovery; (4) Timing grazing to mitigate detrimental effects of defoliation at critical points in the life cycle of preferred species inter- and intra-annually; (5) Where significant regrowth is likely, grazing the area again before the forage has matured too much; (6) Flexible stocking to match forage availability and animal numbers in wet and dry years or having a buffer areas that can be grazed; (7) Using fire and other tools to manage livestock distribution and increase the total plants harvested; and (8) Using multiple livestock species. These goals cannot be accomplished with continuous, season-long grazing in environments that receive enough moisture to have growing periods of more than a few days.

The means of achieving these goals are discussed below. Because this discussion is focused on biological and ecological relationships, we deal primarily with factors 2-6, which are influenced by factors 7 and 8.

Importance of planned recovery periods

Maintenance or improvement of plant species composition and productivity is of paramount importance to achieving sustainable use. Since even at low stocking rates, patch and area overgrazing occurs, management must provide adequate periods of recovery to maintain or improve the range resource. Rangeland improves if the benefits of recovery exceed the damage of grazing, and degradation occurs if the benefits of recovery are less than the damage caused by grazing (Merrill 1954; Thurow et al. 1988; Tainton et al. 1999; Müller et al. 2006).

Significant range improvement in the form of increased proportion of desired species and increased plant vigor has been demonstrated in many parts of the world following growing season deferment. This allows adequate recovery periods at similar or higher stocking rates compared to season-long grazing or regimens that provide shorter recovery periods (Smith 1895; Sampson 1913; Rogler 1951; Scott 1953; Matthews 1954; Merrill 1954; Hormay 1956; Hormay and Evanko 1958; Hormay and Talbot 1961; Hormay 1970; Reardon and Merrill, 1976; Booysen and Tainton 1978; Taylor et al. 1980; Thurow et al. 1988; Taylor et al. 1993; Tainton et al. 1999; Snyman 1998; Teague et al. 2004; Müller et al. 2006).

Ranch-scale research indicates that plant vigor, ecological condition, and carrying capacity benefit from grazing systems at appropriate stocking rates with only one grazing period during the growing season and the application of full growing-season deferment to each pasture once every 3 to 4 years (Danckwerts 1984; Tainton et al. 1999; Müller et al. 2007). Even when treatments incorporating a growing season rest were more heavily stocked than a continuously grazed treatment there were benefits to species composition in the rested treatment (Thurow et al. 1988).

A theoretical analysis by Müller et al. (2007) indicated destocking in times of drought and restocking post-drought was not always adequate to maintain long-term forage productivity in an area with 177 mm of mean annual rainfall; it is the variability in rainfall, not the mean that makes all the difference. This study, which was corroborated with 40 years of data from a 30,000 ha ranch, showed that rest periods during the normal growing season were indispensable to maintaining productivity of semi-arid rangeland.

It is important to stress that periods of deferment will allow recovery only if adequate growing conditions are experienced during the period of deferment. Maintaining or increasing more productive and preferred species depends on the availability of water and nutrient resources (Lee and Bazzaz 1980; Wallace et al. 1984; Coughenour et al. 1985; Polley and Detling 1989), and a positive response to rest is possible only if sufficient resources are available (Louda et al. 1990). In addition to the respite from grazing afforded by rotational grazing, favorable long-term climatic conditions are necessary for the recovery of more productive and palatable grasses. For this reason more arid rangelands require longer recovery periods (Heitschmidt and Taylor 1991), often a year or more (Bradford 1998; Howell 2006).

Defoliation events during the growing period can have remarkable negative effects on plant vigor and total stored carbohydrates compared to comparable levels of grazing at other times of the year in certain mid

and tall grass species (Mullahey et al. 1990; Mullahey et al. 1991; Reece et al. 1996; Cullan et al. 1999). Multiple defoliations during this period had a more serious effect than single defoliations of the same intensity. Effects also varied with growing season precipitation. Effects of excessive defoliation or defoliation during this critical period may also be manifest in the following year (Hendrickson et al. 2000). These results indicate that if a goal of management is to increase the frequency of these species, a recovery period of at least 2 months following a mid-summer graze period in at least a significant proportion of years would be advantageous, while multiple defoliation events during this time of year would decrease the frequency of these species in an environment receiving around 260 mm of growing season precipitation (Reece et al. 1996). From this discussion, it is evident that continuous growing season grazing or long graze periods would make management for these taller species extremely difficult at best.

The question of what constitutes adequate recovery for species in semi-arid rangeland environments is one of the most important that can be answered in the field of range science, yet it has not been investigated as a principal subject of inquiry. Certainly, it varies with inter- and intra-annual variations in climate, as well as with the intensity and frequency of defoliation of those target species in the preceding graze period. Trlica et al. (1977) found that herbage yields of some species required more than 26 months of recovery following severe defoliation. Dowling et al. (1996) asserted that recovery periods need to be timed to give an advantage to the desired species. They found that deferment of grazing for 3 months during the summer of a mesic environment increased the proportion of palatable perennial grasses compared to a continuously grazed treatment. The timing of the graze period affects the recovery period needed to benefit the desired species, as the length of the remaining growing season and likelihood of precipitation in the intervening planned recovery period will determine if sufficient regrowth occurs. The species of concern will also have a bearing, as growth rates and such critical physiological characteristics as when the apical meristem is elevated will be affected by temperatures and day length.

Some reasonable “rules of thumb” can be developed by evaluating some of the scientific literature and common practices in the rangeland and agronomic fields. The considerable body of work that has been done in Texas at the Sonora experiment station (e.g. Merrill 1954; Thurow et al. 1988; Reardon and Merrill 1976) indicates that in that environment with a variable precipitation averaging 438 mm, 4 months seems usually to be adequate, but 50 days is too short to maintain higher producing warm-season mid-grasses. Yet, in several studies with similar or even drier climates (e.g. Derner and Hart 2007; Hart et al. 1988), a similar recovery period was used but no differences in performance of animals or vegetation between treatments were observed. They correctly assert that rest and deferment during periods of minimal plant growth and low soil moisture or temperature extremes limit the potential for positive vegetation responses. Therefore, recommendations asserting no benefits of periodic recovery in these circumstances must be suspect.

In many areas where cool season, irrigated, perennial grasses are harvested for forage, one or at most two cuttings are harvested in a year, with perhaps some dormant-season grazing of aftermath. Where perennial

warm-season grasses are irrigated with relatively long growing seasons, a common interim between cuttings is about 30 days. Therefore, it might be reasonable to assume that at least 30 days of optimum growing conditions are necessary for adequate recovery from a similar level of defoliation. Torrell et al. (2008) found that for central New Mexico native rangeland, natural rainfall provided only about 30 days in a growing season with soil moisture above 30%. Given the discussion in the previous paragraphs, in many of the arid to semi-arid environments characteristic of western North America, in all but the most favorable years it seems reasonable to assume that plants require most of a growing season to adequately recover from a defoliation. If there are both desirable cool- and warm-season plants in the community, one short, early growing season graze period followed by deferment for the remainder of the cool part of the year when these species are growing should normally benefit that component of the sward. Another graze period, later in the season to use warm-season species, followed by recovery until the dormant season, would likely benefit palatable warm-season species. Grazing management programs that provide less recovery than that would not be expected to show reliable, measurable benefits in most years.

In summary, by providing periodic, adequate growing season deferment, multi-paddock grazing management can minimize the detrimental effects of patch and area-selective overgrazing while adequate deferment can be applied in pauci-paddock systems but multi-paddock systems enable more refined management as discussed below.

Importance of a short grazing period

There are important benefits to both plants and animals by having short grazing periods. The nutritional regime offered to livestock in a rangeland situation is often highly variable, and animals cannot necessarily meet their nutritional needs for high-demand functions like conception, late pregnancy and lactation. This can be turned into a benefit using rotational grazing in which the manager plans his stock movements to place animals in paddocks with the best chance of meeting those higher nutritional requirements. Multi-paddock management can positively or negatively influence both forage productivity and quality. However, management needs to be different in wet and dry areas because there are different factors to take into account due to climatic differences.

One of the purposes of subdividing a management unit into paddocks is to better control the length of time and place where livestock eat plants. This commonly results in shorter graze periods and more even distribution of the animals when considered over the course of a year or grazing season (Barnes et al. 2008), but much more concentrated distribution when considered over shorter periods of time, for example, within a given day or for the length of a graze period. This has the advantages of: (1) decreasing plant selectivity, so that preferred species are not placed at a strong competitive disadvantage with their neighbors; (2) if grazing periods are short, more of the forage consumed consists of “first bites” from the plants on offer (Derner et al, 1994), and one defoliation event not only favors nutritional selectivity but also favors production from

residual photosynthetic material; and (3) intake distribution can be spread over a larger part of the total landscape.

Enhancing plant composition and productivity

In more humid and sub-tropical rangeland, forage matures quickly. The taller grass species lignify as they mature and periods of growth are longer than in more xeric areas. In higher rainfall regions, rotational grazing can be used to maintain plants in a vegetative phase of growth that results in higher forage growth rates and presents the animals with higher quality forage. A long rest period or a low grazing pressure allows plant tissues to mature and forage quality to decrease compared to more frequent grazing intervals. Multi-paddock grazing systems management must specifically address the goals of animal productivity and vegetation stability or improvement. As grazing intensity increases to an optimal level, primary production increases above that of ungrazed vegetation, followed by a decrease at greater grazing intensities, provided adequate moisture and nutrients are available for plants to regrow (McNaughton 1979). Evidence supports the grazing optimization hypothesis at both the plant and community level (Belsky 1986; Milchunas and Lauenroth 1993), and several potential mechanisms within plants have been hypothesized and tested (McNaughton 1983). Critically, plants respond along continua of water and nutrient availability, and they produce best when they have the resources necessary to regrow following defoliation. Management-intensive grazing can enhance the likelihood of these conditions occurring (Gerrish, 2004).

Under season-long continuous grazing, herbivory can be too intensive and frequent in preferred grazing areas for the occurrence of compensatory growth. Multi-paddock grazing management can regulate the frequency of defoliation of preferred plants and preferred areas in systems where regrowth during a graze period is likely, and afford adequate recovery before regrazing if grazing periods are short enough (Derner et al, 1994). The grazing pattern required to increase primary production mimics migratory herbivores because there is a period of intensive grazing, often early in the season when resources for regrowth typically are available, followed by a long period of little or no grazing (Frank and McNaughton 1993). An absolute increase in plant growth occurs under intensive grazing systems only if plants are not subject to chronic defoliation and have the time and resources to recover following defoliation. Continuous grazing does not allow for recovery on heavily grazed patches (Teague and Dowhower, 2003).

Plants growing in xeric environments with erratic precipitation and areas dominated by temperate C₃ grasses face a much greater challenge from herbivory compared to plants growing in more mesic environments. Under these circumstances, flexibility in the duration and timing of grazing is critical. These environments do not have a well-defined rainy season; growth rates are relatively low, of very short duration, and sporadic through the growing season. Forage quality does not decline as precipitously with maturity. The benefits of shorter graze periods may be relatively small compared to the advantage of longer recovery periods. In these environments the provision of planned recovery periods, as outlined in the previous section,

are vital for maintaining or improving range condition, and rotational grazing has a significant role to play in reversing or avoiding the damage caused by patch and area-selective overgrazing that occurs with continuous grazing (Fuls 1992; Snyman 1998; Tainton et al. 1999; Teague et al. 2004; Barnes et al. 2008).

Enhancing animal nutrition

Plant health and animal nutrition are linked. To maximise animal performance in more mesic areas, leaf biomass must not be too low or too high, so relative growth rate (RGR) and digestibility are both kept high (Voisin 1959; Booysen 1966; Booysen and Tainton 1978). At low leaf biomass, and high leaf biomass as plants reach the reproductive phase, RGR is low. Maximum RGR occurs at intermediate levels of biomass when plants are vegetative and kept in a leafy condition. Forage digestibility is high at low biomass and decreases as biomass increases. Therefore, managing for intermediate levels of biomass increases forage RGR and ensures high levels of forage digestibility. This principle was applied in the rangeland rotational grazing management systems of Booysen (1969) and Tainton et al. (1999).

Under continuous grazing, the whole area has a low mean RGR because both heavily grazed patches and avoided patches have low RGR. Grazing systems with a number of pastures can be managed for much of the area to exhibit high RGR. Rotational grazing in productive environments where water and nutrients are adequate for regrowth, such as tallgrass prairie, can maintain plants in a vegetative state for a longer time and reduce the probability of plants reaching a reproductive stage (Burke et al. 1998). The importance of length of grazing period and length of rest are well illustrated by a rotational grazing study in southern African rangeland of Zimbabwe where graze periods of 5, 10, or 20 days, combined with recovery periods of 15, 30, 35, 60, 70 and 140 days (Denny and Barnes 1977; Barnes and Denny 1991 cited by Norton 2003). Animal performance declined linearly from ~70 to ~50 kg/head/season with increasing length of grazing period and from ~70 to ~40 kg/head/season as the recovery period increased from 15 to 140 days. The more positive results were obtained by grazing moderately for a short period and regrazing before the maturing grasses had decreased in digestibility. At both high and low stocking rates, livestock production increased as grazing periods became shorter and utilization was correspondingly less severe. Length of the grazing period appeared to have more effect than length of the rest period. In a similar study in South Africa, a trend toward higher forage production at moderate utilization under short grazing periods occurred consistently as the grazing period was reduced from 20 to 10 to 2 days (Tainton *et al.* 1977; Morris and Tainton 1991). The response to shorter grazing periods was greater than the response to longer rest periods, which varied from 20 to 60 days in their 24-year study (Norton 2003).

One of the primary reasons for a short graze period, often overlooked in grazing studies, is to allow an adequate opportunity for animals to select a high quality diet from a mixed sward or landscape with a diversity of topographic, edaphic, and vegetational features. Allowing this selectivity can promote diversity of vegetation structure at different temporal and spatial scales matching or exceeding that in continuously

grazed situations (Derner et al, 1994). Because of their diet preferences, as animals graze a paddock they will progressively deplete the palatable plants that contain higher quality levels to meet their dietary requirements. This would, in effect, increase the proportion of low-quality forage available to them as the graze period progresses. In the first few days of a fairly long graze period, the animals will harvest the highest quality components of the plant community. As time goes on, they will be forced each day to take a higher proportion of the lower quality forage. Consuming the lower quality forage will lower performance. Practiced consistently over time, “eat the best and leave the rest” degrades soils and plants as well as animal performance and landscapes (Provenza 2003a; b).

One misunderstanding of many scientists and land managers unfamiliar with sound grazing management guidelines is that the purpose of “intensive grazing management systems” is always to reduce the selectivity that can be expressed by livestock and increase the uniformity of grazing (e.g. Briske et al. 2008), creating a “mowed lawn” effect. While animal distribution can be remarkably influenced by planned grazing management, animals still express selectivity in their diet selection and, therefore, exhibit patchy grazing to a greater or lesser degree (Hunt et al. 2007). In a continuously grazed situation, with a given stocking rate and some opportunity for regrowth, the animals will not be forced to reduce selectivity to the same extent, because they will continuously re-graze higher quality regrowth. This causes overgrazing of the preferred plants and degradation in grazed patches. In a planned grazing situation where herbage allowance is sufficient the animals will still be able to meet their requirements. As animals better learn which plants to mix in their diets a greater proportion of the total available vegetation would meet their requirements if consumed in the right temporal framework, so there is often a period of time when performance lags behind that of continuously grazed animals (Provenza, 2003a). Therefore, grazing periods should be kept short enough so that the animals can maintain sufficient diet quality to meet performance goals.

Heitschmidt and Taylor (1991) argue that converting a 1000 ha paddock into a 4-paddock rotation will depress livestock production. They base this thesis on the premise that a rise in grazing pressure (forage demand relative to forage available) causes greater competition for the smaller forage resource in a rotation paddock, and therefore less opportunity for dietary selection and a decline in value of nutritional intake. The flaw in this reasoning is to assume that all forage in a paddock of 1000 ha is equally available to the livestock, and that utilization is spatially even (Norton 2003). On the contrary, patterns of use always emerge with heavy grazing in patches and many areas overlooked. These patterns tend to be reinforced through time via a network of established tracks and behavioral expressions of territoriality. The forage consumed in a large paddock continuously grazed is not necessarily of higher nutritional value than forage consumed in a rotation paddock stocked at higher density. From another perspective, the subdivision of a 1000 ha paddock into four 250 ha paddocks will almost certainly place livestock in parts of the landscape that were previously neglected, and grazing those locations creates a *de facto* increase in forage available over that encountered prior to subdivision. A rotation will also ensure a definite period of recovery for all grazed plants, which is

precluded under a continuous grazing regime. By using grazing management to better control where and when livestock graze the manager can achieve modest ecological impacts by shortening the grazing period. At the same time he can favor animal production by improving distribution and increasing exposure to forage resources over the landscape, and by preventing exposure to heavily used areas with depleted forage. The degree of such control over timing of occupancy of any part of the ranch, and the potential for production benefits, is a function of the number of paddocks at the manager's disposal for an individual rotation cycle.

Herbivore learning and diet mixing

Grazing management influences what animals learn: continuous grazing at low stock densities encourages selective foraging, whereas management-intensive and short-duration grazing at high stock densities encourages animals to learn to mix their diets. The relationship between learning and diet mixing in grazing management plays a critical role. Herbivores learn to optimize intake of foods in a manner consistent with their previous experiences with the mix of foods offered (Provenza et al. 2003). When they learn to eat only a small subset of the more “palatable” foods that provide adequate nutrition, animals are unlikely to learn about the possible benefits of mixing different foods, especially those high in secondary compounds (Provenza, 2003b), nor over generations will they become locally adapted to the areas where they must make their livings (Provenza 2008). Over time, such selective foraging on pastures and rangelands will change the mix of plants on offer, further reducing opportunities to learn. However, herbivores encouraged to learn to eat all plants on a landscape are more likely to learn to eat mixtures of foods that enhance health and nutrition, while mitigating toxicity, assuming appropriate choices are available. Experience and the availability of alternatives both influence food choice (Villalba et al. 2004) and animals can learn to eat unfamiliar food (Shaw et al. 2006). This requires careful management during the familiarization and adaptation periods and ongoing monitoring to achieve the objective of getting the animals to consume a greater variety of plants in the landscape.

When a transition is made from continuous grazing at low stocking rates to multi-paddock management involving short-duration grazing at high stock densities there is an immediate negative effect on animal performance until the animals learn to mix their diets and expand the species they consume, and this can last for up to 3 years in mature animals (Provenza 2003a). Such management, which if implemented with high utilization is known as high intensity, low frequency rotational grazing (HILF; Heitschmidt and Taylor 1991), has been shown in experiments to improve plant communities but have negative impact on animal nutrition and performance (Kothmann 1980; 1984). However, with perseverance such negative results can be overcome, as illustrated by Ray Banister who manages 7,200 acres of hardscrabble rangeland in eastern Montana (Provenza 2003a). His management style evolved over 40 years from reliance on rotational grazing that involved relatively short periods of grazing and rest to boom-bust management that consists of intensive periods of grazing followed by a 2-year period of rest. Banister’s boom-bust grazing management stresses

soils, plants and herbivores with infrequent intensive grazing pressure, and then allows them to recover. Occasional disturbance, followed by rest, creates and maintains a diversity of micro and macro habitats. Heavy use of all plant species keeps undesirable plants in check. Abundant plant cover in the uplands and riparian areas mitigates soil erosion, which leads to clean water and great habitat for fish, waterfowl, and terrestrial species of wildlife.

The change to boom-bust grazing challenged the cattle on his ranch because they were no longer allowed to eat only the most palatable plants as they had under rotational grazing. Instead, they were forced to eat all of the plants. Under the new management procedures, Banister monitors the least palatable plant species, shrubs like sagebrush and snowberry and various weeds, as indicators of when to move the cattle to a new pasture. Cattle are allowed to move only after their use of the unpalatable species reaches high levels. In so doing, Banister reduces the competitive advantage unpalatable plants have over more palatable species. Heavily grazed plants are at a disadvantage when competing with ungrazed plants for moisture and nutrients. It took Banister's cows 3 years to adapt to the boom-bust style of management. During that time, the weaning weights of calves plunged from robust animals well over 230 kg to scrawny individuals that weighed closer to 160 kg, and then rebounded back to over 230 kg.

Under boom-bust management, adapted cattle begin to eat formerly unpalatable species like snowberry and sagebrush as soon as they enter a new pasture. The cows evidently have learned how to mix their diets in ways that better enable them to eat both the palatable and the unpalatable species. Once the older cows made the transition to a new way of behaving, the young calves were able to learn from their mothers how to thrive under boom-bust management. The calves that Banister keeps as replacements never have to make the harsh transition. They were trained by their mothers that all plants are food at Banister's place. Such learned patterns of foraging behavior are transferred culturally from one generation to the next (Provenza 2003a; 2008). We do not advocate this form of management but it illustrates well how animals can learn and modify their behavior.

Flexibility for variable weather

Management is not difficult when forage quality is reasonably good all the time, and when resources for plant growth are abundant and predictable. What makes rangelands different, and managerially difficult, is that management skills must be applied to compensate for poor seasons, poor quality forage, and droughts, all with a high degree of uncertainty. In South Africa, protocols were developed for managing both pauci- and multi-paddock grazing systems in climatically variable semi-arid rangeland to get the best animal performance and improve the vegetation while avoiding the negative resource consequences to range resources from continuous grazing (Fig. 1; Venter and Drewes 1969, cited by Tainton et al. 1999). The approach regulates the level of defoliation and provides growing season recovery after each grazing period,

as well as a drought buffer. Animal performance is maintained by keeping highly digestible, leafy forage in front of livestock, and not grazing too heavily (rotational but not HILF grazing).

This approach is flexible enough to work in wet or dry seasons. In years of average or above-average rainfall, animals are rotated through the non-rested areas to achieve moderate to low defoliation and experience recovery until the forage is ready to graze again. The moderate level of defoliation keeps both the forage quality and plant growth rate high. In dry years, the same principles of moderate defoliation and recovery before regrazing are applied. However, as growth is slower in dry years, more paddocks are grazed before the first grazed paddock is ready to be grazed again. In very dry years, this can be achieved only by grazing the area that was planned to be rested. Thus, the rested area serves as a forage buffer during drought. If consecutive dry years are experienced then animal numbers can be reduced or other pastures can be rented.

In more arid areas of southern Africa, rotational resting of a third to a fourth of the grazing area during the growing season provides a forage buffer (Danckwerts 1984; Tainton et al. 1999; Müller et al. 2007), which stabilizes animal numbers and cash flow from year to year. A low-intensity system with 3 to 4 paddocks per herd provides a rotational rest every 3 to 4 years. For greater production, a more intensive, multi-paddock system (> 12 or 16 paddocks per herd) can be implemented with rotational grazing conducted in the paddocks not being rested each year as discussed by Müller et al. (2007) and Beukes et al. (2002).

In the USA, where it is relatively easy to change livestock numbers, successful managers can regulate stocking rate as an alternative. They either reduce the number of animals grazed on contract for other enterprises or keep no more than half the livestock biomass as breeding stock so they can adjust stocking rate quickly before large numbers of people have to sell and markets drop, and minimize the loss of valuable genetics. Both options are less costly and damaging to the range resource.

In any rotational grazing management program, forage within a paddock will be depleted at a more rapid and noticeable rate per unit of time than in a similarly stocked continuously grazed system. If forage becomes depleted or is more abundant at, for instance, the end of the rainy season, then experience indicates that it would provide a much earlier warning to a manager that a stocking rate adjustment may be needed. These more timely responses in the form of stocking rate adjustments and changes in the grazing schedule are a risk management aspect of properly planned and managed grazing that is difficult to quantify scientifically, but is extremely important regardless.

Importance of fire

In less arid rangelands, fire is important for both continuous and rotational grazing management, as it alleviates the effects of repeated selective grazing of the same areas year after year. Nutritious regrowth following a burn attracts herbivores, and the ensuing heavily grazed patches are maintained by their continued attractiveness to grazers. When a new area is burned, the new regrowth attracts grazers. As a consequence, grazing pressure is spread over the whole burned area for a period, reducing the pressure on the

previously heavily grazed patches. In time the selective grazing of patches and species resumes, so that the patch-masking effect of fire disappears completely after about 3-4 years (Archibald et al. 2005).

In systems with frequent fires, however, these intensively utilized patches do not persist and the landscape can become dominated by tall, fast-growing grasses intolerant of grazing but highly flammable. Managing with fire can, therefore, also reduce the herbivore impact on intensively grazed patches that naturally develop in the landscape by spreading grazing over a larger area for a short period, reducing the grazing pressure on previously heavily grazed areas (Archibald et al. 2005). In addition, patch burning is a relatively new management technique being implemented where a portion of a pasture is treated to increase pasture heterogeneity (Fuhlendorf and Engle 2004). By burning different patches in subsequent years, grazing pressure is reduced on preferred areas while the animals concentrate on the recently burned patches. This natural rotation driven by animal behavior offers some rest and recovery while also providing structural heterogeneity that can improve wildlife habitat. By controlling distribution and providing adequate recovery for heavily utilized areas on the landscape, the need for fire in this context may be less pressing.

Accommodating extensive and intensive management philosophies

Not all managers are comfortable with managing very intensively using pauci- or multi-paddock systems. Risk-averse behavior, resistance to change, and differences in capabilities of managers, as well as the financial constraints associated with infrastructure development in drier regions, dictate that different levels of complexity need to be developed to provide a choice of management strategies to obtain satisfactory productivity and sustain or improve the range resource.

Keeping risk at an acceptable level is most important for rangeland management. Stocking rate should match forage availability in both wet and dry years by allowing for adequate plant residual biomass to enable rapid regrowth following grazing, and by having buffer areas available. Keeping areas of the ranch dedicated as buffers to accept stock during a shift in stocking rate enhances managerial flexibility and is a short-term strategy preferable to marketing animals. Rotational resting and rotational grazing should ensure improved forage plant composition and productive potential so the effects of drought are decreased and there is speedy recovery after drought (Teague et al. 2004). Conversely, grazing management strategies that facilitate patch degradation increase pressure on desirable plants already weakened by heavy use (Norton 1998) and slow recovery post drought.

At the low-intensity end, pauci-paddock systems allow sufficient growing season deferment at relatively low stocking rates. Systems such as the Merrill 4-paddock 3-herd system for ranges grazed year-long have given excellent results with less intensive management (Heitschmidt and Taylor 1991; Taylor et al. 1993) as have the 3 or 4 paddocks per herd systems mentioned above incorporating growing season rest with or without rotational grazing (Danckwerts 1984; Tainton et al. 1999; Müller et al. 2007).

Those aiming for maximum sustainable yield generally use the more intensive multi-paddock systems with > 16 to 30 paddocks per herd and usually stock at heavier rates (Norton 1998). This increases operational risk significantly as maximum sustainable yield is likely to be at a critical point, the location of which is not exactly known and variable between seasons given the unpredictable nature of nature. A slightly higher stocking rate or weather change can drive the forage base to unacceptably low levels so it is a problem determining how conservative management should be, a problem encountered when managing all natural resource stocks (Walters 1986). However, producers who manage systems with 30 paddocks or more often find that there is forage to spare and actually less risk, which is due to a combination of better grazing distribution, quite short grazing periods and long rest periods that increase heterogeneity of landscapes. Some producers have found that the multi-paddock system reduces stress and frees up time, which is partly due to the greater facility for better planning of forage resources. The management activities and management decisions may be more intensive, but overall the intensive rotation incurs lower ecological risk.

The case of high stock density grazing

The most management-intensive form of rotational grazing involves using small paddocks to achieve high stock density with relatively short grazing periods to prevent heavy use. A large number of paddocks per herd are preferable, usually 30 or more, and grazing periods are 7-10 days or even less, so rest periods are automatically long. Having a large number of paddocks per herd gives a manager a lot more flexibility to achieve plant and animal production goals using the guidelines discussed above. We discuss below the implications of using relatively few (4 to 8) compared to a larger number (16 to 50 or more) of paddocks per herd. It is very important to remember that no matter how many paddocks are involved or how sophisticated the management, if the stocking rate is too high for the amount of forage available there will be negative consequences for animal performance, natural resources and profits.

The need for recovery is a function of the severity of defoliation; the more severe the loss of leaf, the more recovery time is required to restore herbage yield, for all the reasons explained above. For simple rotations involving 4-8 paddocks, relatively long grazing periods occur, and paddocks on a commercial operation are large enough for patch grazing to develop to a damaging degree. In such circumstances, the length of the rest period becomes critical for protection of target species. As paddock numbers increase, length of graze period shortens considerably, more of the forage harvested is consumed with one bite from plants on offer, species selectivity declines, severity of grazing becomes less of an issue, and recovery times take care of themselves. As O'Connor (1992) demonstrated, at high stock density species identity has a minor role to play in determining whether any plant is grazed or not.

In multi-paddock systems operating only 2 to 3 paddocks in a deferred rotation, there is little risk to grazing one paddock at a time apart from the fact that periods of occupation are long. If feed supply runs short, the rancher can move the animals a few weeks earlier than planned without causing any negative

repercussions. The grazing and rest periods are long enough, and the paddocks large enough, to accommodate a built-in buffer of reserve forage accessible under higher (but not too high) grazing pressure even if patch selection is not reduced. On the other hand, with only 4-12 paddocks in the rotation, managerial flexibility is considerably reduced. Small errors in judgment can cause negative consequences for plant utilization or animal performance. There is only a small built-in forage buffer to accommodate an increase in rate of rotation, and dropping a paddock out of a rotation cycle is scarcely an option. Most of the research trials of rotational grazing have been done in this range of 4-12 paddocks, a relatively inflexible and ecologically risky strategy with little latitude for avoiding undesirable effects of climatic uncertainty.

At the other end of the scale, in multi-paddock grazing with, for example, 30 paddocks, the system is also less risky to manage. A paddock is being grazed for only 12 days of the year (maybe 2 grazing periods of 6 days each on average) and rested for at least 350 days a year. If two paddocks contain insufficient feed, or present a toxic plant problem, you can skip them in a rotation cycle and the rest period for the grazed paddocks in the cycle drops from 25 weeks to 23 weeks, not enough to really depreciate the benefit of a long rest period. Meanwhile, grazing period and stocking density in the grazed paddocks may remain unchanged. Even if the manager decides to reduce a 6-day grazing period to 5 days grazing in all 30 paddocks, the rest period is still about 4 months, which should be adequate for recovery after only 5 days of grazing. This is still only 12 days of grazing per paddock per year.

Rotations involving 20, 30 or even 50 paddocks are not uncommon on commercial ranches. With an increasing number of paddocks, the manager's anxiety should decrease. The risk aspect can be considered from the point of view that if the ranch can be managed so that the same number of stock are taking their annual feed requirements from more of the landscape than was used before, and from more of the plants that grow on the ranch than were grazed before, then the consequence has to be more benign ecological impact and more productive pasture. If there appears to be excess forage on the ranch as a result of this strategy, then stock numbers can be judiciously increased to harvest the surplus, but on the proviso that if conditions deteriorate, some stock must be removed from the ranch or shunted into buffer paddocks.

The impact of high-density grazing under intensive rotational grazing is ecologically benign due to the combination of low selectivity, a small percentage of preferred species experiencing repeat defoliations, and the inherent long rest periods. Because the grazing impact becomes more benign as the number of paddocks in the rotation increases, the need for a long recovery period declines. A factor reducing the need for a long recovery time is the botanical character of palatable species. They persist in grazed vegetation because they invest in fast-growing photosynthetic tissue rather than high-energy-demanding secondary compounds and physical discouragements to herbivory (Bryant et al. 1983; Coley et al. 1985). If selectivity is being reduced and all species in the pasture are experiencing some level of defoliation, the palatable species are at a competitive advantage to out-perform their neighbors in regrowth.

For the doubters who believe that intensive multi-paddock management is damaging to the natural resource base, Norton (1998) listed 9 examples of grazing trials (from Canada, USA, Zimbabwe, Australia and New Zealand) in studies that ran for 5-35 years. These trials reported no adverse ecological effects of either continuous or rotational grazing treatments even though experimental stocking rates were maintained at 40% to 200% above those recommended for commercial properties in the area. He asserted that when using small paddocks, forage availability is not limited by grazing animal distribution. This supports the belief that it is beneficial to use a high number of smaller paddocks.

Increased stocking rates do have negative effects on soil properties (increased bulk density, disruption of biotic crust, reduced aggregate stability and aggregate size distribution) and are positively correlated with the distribution and frequency of animal trampling (Warren et al. 1986; Gerrish 2004). However, Thurow (1991) reported that surface hydrology attributes, such as infiltration and sediment production, are related almost entirely to the amount and distribution of plant cover and are largely unresponsive to rotational grazing, except when stocking rates and cover removal exceed recommended levels, or precipitation events follow too closely on heavy grazing events. The same study indicated that managing for grassland dominated by high seral plants improves hydrological function. High stocking rates in this study showed strongly reduced infiltration rates due to physical effects on the soil and changes in the vegetation towards dominance by lower seral plants. At a heavy stocking rate, infiltration was much higher in an intensively run, multi-paddock rotational grazing system than in a continuously grazed treatment *at the same stocking rate*. This improved hydrologic function may be associated with the improvement noted between trampling events seen by Warren et al, 1986. Similarly, Pluhar et al. (1987) found that infiltration increased and sediment production declined as vegetation standing crop and cover increased. They found no differences in infiltration and sediment yield among a rotationally grazed treatment at a heavy stocking rate and the moderately stocked, deferred rotation and continuously grazed treatments.

A misconception among many opponents of planned multi-paddock grazing is that they think it necessarily decreases the diversity of plant species and the heterogeneity of landscapes. Depending on the circumstances, just the opposite can occur. Smaller paddocks can improve distribution of animals across a landscape. This can increase or decrease diversity, depending on how well animals were distributed before. As discussed, forage demand compared to forage available determines the proportion of plants that will likely be consumed by the animals while they are in a paddock. Then, depending on the manager's goals for structural and species diversity, the greater control and flexibility of animal placement and movement allows them to come back and regrazed plants sooner, or allows more regrowth and more structural similarity within a paddock. Small paddocks will allow a "checker board" effect where some paddocks can be closely grazed and neighboring rested paddocks could have tall, untouched growth, creating heterogeneity across the landscape. Thus the manager can decide exactly how best to juxtapose these components to achieve specific plant, livestock or wildlife goals. Likewise, depending on placement of fences and diversity of topography,

aspect, soils, and plant communities within paddocks, grazing can be more or less uniform within a paddock for a given graze period.

LIMITATIONS OF RESEARCH ON MULTI-Paddock GRAZING

The results of much experimental research are inconsistent with the demonstrated effectiveness on commercial properties in many countries of planned multi-paddock grazing management. The potential for significantly higher production under planned multi-paddock grazing management, consistent with producer experience, can be justified with published research data, using scientific arguments focusing on the temporal and spatial aspects of grazing management and their physiological effects on plant and animal production and complementary relationships. Many grazing system research projects have been conducted with no ecological or production goals and have often ignored relevant ecological research or practical knowledge when choosing and implementing treatments. This lack of treatment goals or consideration of their possible efficacy allows limited opportunity for understanding mechanisms behind observed results. Consequently, the relevance of much small-scale research on grazing systems is of questionable value to commercial ranch managers.

We offer the following reasons to explain these differences in perception: (1) The manner in which researchers have managed multi-paddock grazing treatments has been sub-optimal for providing the best possible vegetation or animal production results; (2) The notion that rotational grazing can control frequency of defoliation within a grazing period is flawed *at the scale of rotations employed in research trials* (Norton 1998); (3) Grazing systems comparisons in small-paddock trials fail to address the problem that continuous grazing in large paddocks causes patch grazing and localized pasture degradation and underuse elsewhere, resulting in low growth rate relative to moderately and more uniformly grazed vegetation; and (4) The omissions in grazing research of a spatial dimension and consideration of the effect of grazing management on animal activities have created a communication gap between scientists and commercial producers, for whom landscape features and herd behavior are a prominent aspect of their production system.

Research experiments are structured to minimize variability when testing hypotheses to promote understanding of ecological processes. Yet, in nature individuality and variability are the rule, not the exception to the rule. Thus, an effectively designed grazing experiment may not necessarily represent the most flexible and hence effective way to manage a ranch enterprise for production or conservation goals. Grazing treatments may be intentionally severe to induce ecological contrasts, and they are usually applied more rigidly than the adaptive management practiced by many grazing managers. Effective management must be adaptive to changing conditions and environments, and timely monitoring information is crucial to this process (Danckwerts et al. 1993). Consequently, research results may be inapplicable or misleading if not placed within an adaptive management framework managing for sustainable use at the landscape scale.

Researchers have rarely taken into account how the manner of conducting experiments has contributed to the results obtained. Any experiment is merely an inflection in time and space of biophysical processes that link soils, plants, herbivores and people. If the same treatments were applied while managing for the best ecological, social and economic outcomes, how would the results differ? For example, as mentioned previously, there was confounding in many experiments between continuous grazing at moderate stocking rates and much heavier (often double) stocking rates with intensive rotational grazing treatments (Briske et al. 2008). The vast majority of grazing studies cited above compared responses to continuous season-long grazing at recommended stocking rates that optimize livestock gains per head or per unit land area (e.g., Bement 1969) with responses to the short-duration grazing at a higher stocking rate, often 1.5 to 2 times greater. Stocking rate, in any given circumstance, has greater effects on animal and vegetation responses than grazing system (Van Poollen and Lacey 1979; Heitschmidt and Taylor 1991; Manley et al. 1997; Gillen et al. 1998; McCollum et al. 1999).

This confounding with different stocking rates between systems being compared is further exacerbated by the variable weather in semi-arid grazing ecosystems. Accepted good management during droughts commonly includes reducing stock numbers early to reduce damage to the vegetation, animal condition and profitability. These patterns at best mimic natural systems in which the number of animals decreases during a drought and then gradually increases as a drought diminishes. Experiments have very rarely done so. If they did, the higher stocking rate treatments might not incur detrimental effects and would be consistent with accepted good management practices. The currently perceived “correct” management of an experiment is often not the best way to manage in a production ranch setting. It is very important to take these differences into account when giving management advice. Whether managers use continuous, pauci- or multi-camp systems they need to know how to manage their ranches to get the best results and avoid the problems associated with each system. To do this they need to know the benefits of each management system if it were managed to give the best result. Most experiments comparing continuous with rotational grazing systems set the rotations, rather than manage them for best animal or plant responses within the constraints of the system.

As outlined above, the small spatial and temporal scales at which most experimental grazing systems research is conducted has produced contrasting viewpoints between research scientists and successful grazing managers. These scale effects are largely ignored when extrapolating experimental results to large-scale ranch operations. The short time frames of most studies, and the lack of awareness of adaptation troughs for soils, plants, herbivores and people, ignore realities of systems as they transition to different modes of use (Provenza 2003a). The majority of experimental paddocks have been considerably smaller (usually < 25 ha and often < 5 ha) than pasture sizes of commercial ranches (500 to 5,000 ha or more; Norton 1998). This juxtaposition of scales has had profound consequences for the translation of experimental results to the management of grazed ecosystems. Small research paddocks that are grazed continuously do not always mimic the continuous grazing of large paddocks because they preclude evaluation of uneven

landscape utilization (Norton 1998; Teague and Dowhower 2003; Teague et al. 2004). Smaller experimental paddocks usually result in a more uniform distribution of grazing pressure (Barnes et al. 2008), which restricts ability to evaluate how grazing animals use landscapes. There should be greater awareness of the problems in extrapolating results from small scale experiments to grazed ecosystems at larger scales. For example, the work of Gammon and Roberts (1978) and O'Reagain and Turner (1992) reported that defoliation is not always controlled more effectively in intensive than in continuous grazing systems, and that forage quality and quantity are not consistently and substantially increased in intensive systems compared to continuous grazing. However, these interpretations may have been different if pasture size had been hundreds or thousands of hectares rather than a few hectares. Similarly, work reported by Derner and Hart (2007) and Hart et al. (1988) suggested there were no differences in performance of animals or vegetation between continuous grazing and a treatment including deferment. It is probable that in this circumstance, as in other small-scale experiments (24 ha), the continuously grazed paddocks would have received a more uniform defoliation than would occur in the larger paddocks encountered on commercial ranches that also varied in biophysical characteristics. Thus the patch and area-selective grazing that causes deterioration under continuous grazing would have been underestimated.

Grazing system research generally has not acknowledged other research on the effects of grazing at a large scale (see Coughenour et al. 1985; Fuls 1992; O'Connor 1992; Bailey et al. 1996; Teague et al. 2004; Archibald et al. 2005), which demonstrates the often detrimental effects of patch and area-selective grazing in the landscape. Teague et al. (2004) found that in large pastures, 1500-2000 ha in size, resting provided by rotational grazing reduced deterioration and facilitated improvement of shortgrass and midgrass patches associated with patch and area-selective grazing. A phenomenon such as enhanced productivity based on individual plant and community response to defoliation, that is not detected at a small scale, is often likely to emerge at a larger scale (Levin 1993; Bissonette 1997; Turner et al. 2001), particularly if there are interactions between grazers and plants that affect productivity at larger scales as has been shown by Frank and Groffman (1998).

Failure to consider the rate and scale of ecosystems response to changes in management activities may further minimize the value of translating experimental research to management situations. Such effects are unlikely to be detected in small-scale experiments conducted over 2 to 3 years. It is very difficult to determine treatment differences in rangeland ecosystems because of the slow or erratic response times that may be triggered by reactions to stochastic events such as climatic fluctuations that interact with management actions (Danckwerts et al. 1993), but these effects are critical to determining what is sustainable and what is not. Watson et al. (1996) and Walker (1988) emphasize that, even though climate is the most important driver in rangeland ecosystems, management is still critical to sustainable management. Watson et al. (1996) further state that emphasizing climatic or other event-driven or episodic drivers may de-emphasize the importance of management that can better take advantage of these events within a relatively stable plant

community. Management directed towards soil moisture, seed production, etc., can “condition” the resource to take fuller advantage of these episodic events when they occur, particularly if the event is of a marginal magnitude (Gerrish 2004). One interesting question that comes from the discussion of Watson et al. (1996) whether such conditioning can move a plant community from one stable state to another when some advantageous circumstance occurs (e.g. a particularly wet spring following a drought or wildfire). Time in the order of decades may be needed to evaluate these types of changes on rangelands (Burke et al. 1998).

Advocates of rotational grazing have long contended that timing of grazing and recovery periods according to plant growth rates is of central importance to their success (Savory 1983; McCosker 1994), and that many failures may have been due to not slowing down the rate of rotation during slow or no growth to provide for a non-grazing interval long enough for complete recovery (Savory with Butterfield 1999). The benefits of rotational grazing in many studies may have been reduced or lost due to calendar-based, multiple-cycle rotations (e.g., Kirby et al. 1986; Burboa-Cabrera et al. 2003; Derner and Hart 2007; Hart et al. 1988; Hart et al. 1993). Recommendations asserting no benefits from periodic recovery in these circumstances must be suspect because the benefits are dependent on timing relative to conditions adequate for plant growth (Mullahey et al. 1990; Mullahey et al. 1991; Reese et al. 1996; Cullan et al. 1999). Many grazing studies have used insufficient recovery periods (e.g., 2 months during dormancy) even when the rotation was flexible (e.g., Bryant et al. 1989; Walker et al. 1989).

Another significant factor that can influence research results is the time the different elements in a system take to change from previous pre-experimental management. A shift from continuous grazing at low stocking rates to intensively managed rotational grazing at the same or higher stocking rates will affect many ecosystem variables, including soils, vegetation, livestock and associated herbivores at different temporal and spatial scales, and it may take several years after making consistent, substantial, correct management changes for the system to adapt to these new conditions (Provenza 2003a; 2008), and decades for changes to be measurable at the landscape level. However, they may respond relatively rapidly in preferred grazing areas or those receiving run-on or sub-surface moisture (e.g. Teague et al. 2004). Therefore, some means of stratified measurement of vegetation responses for grazing research studies and of stratified monitoring to obtain timely monitoring information to facilitate management decisions as advocated by Danckwerts et al. (1993) would be desirable. Developing protocols that are time efficient and repeatable is ripe for scientific investigation, as currently being pursued by people such as Gregg Simonds (personal communication). Animals accustomed to low-density continuous stocking can be trained to increase harvest speed and efficiency, but this takes time and a few never adjust (Provenza 2003a; 2008). Research experiments that operate for short periods following treatment imposition may capture the period of system adaptation and underestimate the potential of long-term intensive grazing systems. When well managed, long-term intensive grazing programs improve after the adaptation phase (Merrill 1954; Provenza 2003a). These factors have largely been ignored in research projects, or there have been constraints to taking them into account.

FUTURE RESEARCH

Attempts to study grazing systems are complicated by many issues, not the least of which is having adequate resources. With limited land and funds, researchers have been forced to conduct experiments on small areas of land. The necessity for comparable land attributes between replicates only exacerbates this problem. As changes occur relatively slowly in rangeland ecosystems it is unreasonable to expect meaningful results from research conducted over less than 10-year periods, for reasons outlined by Burke et al. (1998). Indeed, given the dynamics of landscapes, it is reasonable to ask if soils, plants and herbivores ever reach any sort of equilibrium (Provenza 2003b; 2008). While certain questions can be answered from small-scale, short-time-frame operations, the applicability of such research should not be overextended. These limitations may be overcome by monitoring biological processes related to soils, plants and herbivores on ranches managed successfully for many years, often decades, and using systems-level simulation modeling. Comparing the experiences of successful and unsuccessful managers will provide insights unlikely to emerge on research stations.

There are a number of advantages to monitoring ranches with and without track records of successful multi-paddock grazing management. A case study by Jacobo et al. (2006) compared adjacent ranches that used either continuous or rotational grazing, and similarly, Earl and Jones (1996) studied producer-managed rotational grazing at the ranch scale. The strength of this approach is that researchers could evaluate the entire ranch enterprises within the constraints of respective grazing regimes, including the capacity to adaptively manage for the best possible outcomes. This approach simultaneously evaluates ecological and managerial responses. A number of ranches world-wide have been successfully managed at different levels of sophistication using pauci- and multi-paddock systems. Some have operated successfully for nearly three decades. The importance of data gathered from such management over these long periods of time should not be ignored.

The belief that intensive grazing systems involving many paddocks per herd (>20) will necessarily increase profits has largely not been substantiated, even though an ecological economic evaluation of a ranch in South Africa does not refute this claim (Beukes et al 2002). However, successful ranch businesses that employ such management, for example the Richard's Ranch in Jack County Texas, have demonstrated superior profitability and return on capital investment. The Richard's Ranch has demonstrated superior performance and economic results when evaluated in the US National Cattlemen's Beef Association-Standardized Performance Analysis program (Bever pers. Comm.¹). This particular ranch has also won conservation awards from the Society of Range Management, Texas Parks and Wildlife Department, and the

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National Cattleman's Beef Association. It is important that research examines and documents this topic as well as the impact of such management on the natural resources.

Systems-level simulation modeling can complement both small paddock and ranch-based research as the influence of treatments can be explored without the space, variability, time or cost limitations of traditional small-scale or ranch-based research. Simulation modeling would also develop a sound theoretical base for understanding of processes and linking biophysical processes with observed results, essential elements that have so far been lacking. Developing understanding from large data sets requires theory, and theory often requires models to test understanding (Woodward 2005). Modelling of grazing systems has included such topics as ecological economics (Beukes et al. 2002), stock number management strategies (Hahn et al. 1999; Diaz-Solis et al. 2003), spatial issues (Witten et al. 2005; Müller et al. 2006) and achieving a better understanding of field experiments (Teague and Foy 2004).

ALTERNATIVE RESEARCH HYPOTHESES AND PARADIGMS

The original paradigm of rangeland management was based on the widespread observation that degradation of the range resource was largely due to excessive numbers of livestock. In this paradigm the solution was to reduce stocking rates while allowing season-long continuous grazing to continue. Subsequently, another paradigm was developed following the experience of pioneer rancher conservationists and scientists, who had achieved significant range improvement using growing season deferment to allow recovery periods (Smith 1895; Sampson 1913; Scott 1953; Matthews 1954; Merrill 1954; Hormay 1956; Hormay and Evanko 1958; Hormay and Talbot 1961; Hormay 1970; Müller et al. 2006; Booyesen and Tainton 1978; Tainton et al. 1999). A number of earlier researchers confirmed the success of using growing season deferment, often in conjunction with rotational grazing (Rogler, 1951; Merrill, 1954; Reardon and Merrill, 1976; Smith and Owensby, 1978; Daines 1980; Danckwerts et al. 1993; Taylor et al. 1993; Kirkman and Moore 1995).

A third, more radical paradigm was developed in the early 1970s based on earlier writings (Voisin 1959; Acocks 1966) which inspired people such as Savory and colleagues (Savory 1978, 1983; Savory and Parsons 1980; Savory and Butterfield 1999) and Gerrish and colleagues (Gerrish 2004) to explore the merits of multi-paddock, high-density rotational grazing in rangeland ecosystems using grazing periods that were unconventionally short and stocking rates that were considered irresponsibly high. Since then, many ranchers have substantially increased stocking rates while simultaneously improving range vegetation composition using these methods (Goodloe 1969; Tainton et al. 1977; Cumming 1989; McCosker 1994; Earl and Jones 1996; Stinner et al. 1997; Norton 1998, 2003; Sayre 2000; Berton 2001; Gordon 2002). Many in the rangeland science discipline have totally rejected this alternative paradigm, even in the face of much anecdotal evidence (Holechek et al. 1999, 2000; Galt et al. 2000; Briske et al. 2008).

It is most difficult in science, as in other fields, to shake off accepted views (Dubin 1978). Many scientists feel threatened professionally when an innovative and nontraditional way of thinking is introduced.

That is especially true if: (1) a new way of thinking involves a major shift in the scientific paradigm; (2) acceptance of the new theory implies that currently used practices are inadequate or inappropriate; or (3) the new theory threatens the assumptions of the established paradigm. Obsolescence of knowledge threatens the professional integrity of proponents of that knowledge, or the assumptions of the new paradigm appear so contradictory to the assumptions of the accepted paradigm that it is rejected outright. An example from the medical profession is the systematic and long-term intransigence of the established medical profession to prevent legal acceptance of the chiropractic profession, which is now widely accepted and operates with full legal authority (Lisa 1986).

Traditionally, disciplines operate on the tenets of a single major paradigm (Kuhn 1970), which produces valuable but incomplete understanding. All paradigms are a narrow view of the multifaceted nature of most fields of study (Burrell and Morgan 1979; Frost 1980; Provenza 2000). Different paradigms are grounded in fundamentally different assumptions and produce markedly different ways of approaching and building a theoretical base for any discipline (Gioia and Pitre 1990). Considering and comparing more than one paradigm can generate more complete knowledge than is possible with any single paradigm. A broader approach that accounts for differing paradigmatic assumptions yields a more comprehensive understanding of the processes of nature, and their constantly changing manifestations.

It is important to remember when assessing any hypothesis that a single refutation is sufficient to illustrate that the hypothesis being tested should probably be revised to accommodate what has been learned by such a refutation (Kuhn 1970). The numerous instances from research studies outlined in this document and evidence from scores of ranchers around the world provide solid reasons to modify the hypothesis expressed by Briske et al. (2008) that there is no reason to favor multi-paddock rotational grazing over continuous grazing and conservative stocking. Because hypotheses cannot be proved, only rejected, the role of science is to test alternative hypotheses or paradigms and specifically try to refute them. Consequently, we need to expand our methods of enquiry to include ranch-based research and simulation models to develop and test theories, and constantly check conclusions for any inconsistencies between them and evidence from other sources.

To do so, we must focus not only on comparisons of grazing systems, but on the relationships between biophysical processes and management. While it is certainly possible to understand the processes of nature, and much is known about soils, plants and herbivores, the variation inherent in the manifestation of processes in time and space precludes direct comparisons of grazing systems *per se* in experimental analyses. All the physical and biological variables in the various processes are in constant flux, as influenced by history, necessity and chance, and therefore their manifestations become unique in time and space (Provenza 2000). Managers must work with physical and biological processes to manage landscapes. Optimally, this involves knowledge of processes combined with flexibility to respond to ever-changing environments, and that can't be studied with classical grazing studies. Flexibility in the face of unending change is what plants, herbivores

and people are about, and that involves ongoing interactions among genes, environments and chance (Lewontin 2000).

CONCLUSIONS

A large body of evidence from controlled experimentation before the mid-1980s has shown effects of defoliation by grazing animals on plants and the benefits of adequate recovery following defoliation. The benefits of multi-paddock rotational grazing on commercial livestock enterprises have been evident for many years in many countries. However, despite these observations and the benefit to species composition found in numerous studies of planned grazing deferment, most recent rangelands grazing studies suggest that rotational grazing improves neither vegetation nor animal production relative to continuous grazing. Detailed comparisons of research methods and practical experience of successful practitioners of multi-paddock grazing management have identified a number of areas that explain why such different perceptions have arisen. The uneven distribution of livestock in continuously grazed large paddocks leads to localised pasture degradation, which has not been accommodated in the design of most research studies comparing continuous grazing to rotational grazing. This oversight also assumes spatial homogeneity of forage availability and utilization, which is refuted by a large body of observations at larger scales.

This failure to take into account plant and animal processes at appropriate temporal and spatial scales has resulted in incorrect interpretations for rangeland management. Research at a small scale diminishes the degree of selective use and impact that animals have over the landscape. This has resulted in many researchers interpreting the herbivore as an amorphous, diffuse defoliator, that plucks forage in random fashion or like a harvesting machine blanketing the pasture, and even when defoliating selectively does so in a spatially uniform way as implied by Briske et al. (2008). In fact the herbivore is an animal with a point-sampling defoliation apparatus, that moves in forward motion and normally walks long distances, that responds to visual and tactile cues and reacts to its surroundings in various ways, that engages in activities other than defoliation, that is a social creature influenced by history, necessity and chance, that has biological limits to bite size and energy expenditure, and that develops patterns of behavior in response to its environment and companions. Grazing ungulates have an entirely different impact on the landscape than that implied by Briske et al. (2008), as is well documented by work at the landscape scale we have outlined earlier in this chapter. This points to an entirely different and more meaningful way of designing and interpreting grazing trials.

Another reason for mixed results is that researchers have often applied treatments that did not adequately consider physiological effects, complementary relationships among soils, plants, animal behavior, preferences and selectivity, and ecological processes like water and mineral cycles. As a result, they often do not address nor provide valid answers to practical questions such as: how good is this management option; where is it successful; and what does it take to make it work as well as possible? Consequently,

interpretation of grazing trials by some researchers has incorrectly concluded that planned grazing benefits neither vegetation nor animal production relative to continuous grazing. As we have indicated in this document, unless experiments have been conducted in a manner that aims at achieving the best plant and animal responses, the results will probably be misleading in defining the potential of an experimental treatment. Similarly, when reviewing the literature to draw general conclusions (Holechek et al. 1999, 2000, 2004; Briske et al. 2008), each experiment needs to be examined to see how it was conducted and if the objective was such that the study results could be extrapolated to practical ranch situations. If it was not conducted in a manner that current understanding would define as the potential of the treatment, then the interpretation of the experiment will be spurious and misleading. In addition, if such reviews use only references that support a particular viewpoint and do not relate to what a manager needs to know, understanding of the subject will be clouded and not enhanced. Thus it is essential to address and test alternative hypotheses with equal vigor using comparable management goals.

In contrast to the conclusions of many researchers, numerous commercial livestock enterprises in many countries have used a basic knowledge of plant and animal physiology and ecology within an adaptive, goal-oriented management approach to implement successful planned grazing management programs. When evaluated as a body, comparisons of research methods and results and practical experiences of successful planned grazing practitioners identify a number of areas that explain why such different perceptions have arisen. When evaluated using a paradigm encompassing basic ecological and biological principles, these results provide insights that allow the formulation of guidelines for implementing planned grazing management programs that can more effectively meet vegetation, production and financial goals in variable environments relative to continuous grazing and conservative stocking.

Managers need to know how to work adaptively within their operations to produce the best results and minimize inherent problems. Successful ranchers modify their management to achieve the best possible outcomes in terms of profitability and enhancing or maintaining ecosystem health. Researchers have much to learn by working with successful ranchers. Examples of this research approach have compared continuous grazing with an intensive grazing system on commercial ranches (Earl and Jones 1996; Jacobo et al. 2006). The ranches were adaptively managed for the best possible outcomes within the constraints of each system. Using this approach, many of the constraints inherent in the way some grazing systems research has been conducted could be avoided. Monitoring ranches that have been successfully operating intensive grazing management for many years, often decades, might also be the only way we can address the pertinent question raised by Burke et al. (1998) on the much neglected subject of time needed to register changes in rangeland ecosystems. Simulation modeling represents an additional and complementary research approach where cost and logistics preclude field experimentation over large spatial and temporal scales (e.g., Hahn et al. 1999; Beukes et al. 2002; Diaz-Solis et al. 2003; Teague and Foy 2004). This approach is well suited to evaluating the managerial and ecological components of grazing systems, both independently and in combination.

Published research and experience from ranchers has indicated that the following management factors are the keys to achieving desired goals: (1) Careful grazing and financial planning to reduce costs, improve work efficiency, enhance profitability, and achieve environmental goals; (2) Providing sufficient growing season deferment to maintain or improve range condition; (3) Grazing grasses and forbs moderately during the growing season for a short period and allowing adequate recovery; (4) Timing grazing to mitigate detrimental effects of defoliation at critical points in the life cycle of preferred species inter- and intra-annually; (5) Where significant regrowth is likely, grazing the area again before the forage has matured too much; (6) Flexible stocking to match forage availability and animal numbers in wet and dry years, or having a buffer grazing area available; (7) Using fire to manage livestock distribution; and (8) Using multiple livestock species. These can be achieved with more control in multi-paddock systems but the same principles can be applied in pauci-paddock systems as practiced by many ranchers in many countries.

The benefits of properly implemented, planned grazing management, as well as the results of poorly implemented programs have been evident for many years on commercial livestock enterprises in many countries, and are also evident from research trials. For those managers who wish to use simple, less management-intensive operations, various pauci-paddock systems can be employed to plan recovery periods during the growing season with or without using planned rotational grazing. The outlined management guidelines will maximize benefits and minimize potentially negative results. More intensive management with appropriate use of multi-paddock systems can increase productivity and improve rangeland health if managed appropriately using the guidelines above. The key to sustainability using these high-intensity systems is high stock density with short grazing periods and moderate utilization, followed by recovery periods to maintain forage nutritional status and productivity. More even animal distribution is automatically achieved by such a system, and the benefit of this to livestock production is already evident from research studies involving small paddocks and to wild and domestic animals on large ranches. In the variable climate associated with all range ecosystems, management needs to be flexible so animal numbers match forage amounts and animals are presented with high quality material in both wet and dry years. As each ranch and rancher is different we have carefully avoided suggesting whether less or more-intensive management is better. We have throughout concentrated on providing information that will aid in improving management for any level of management intensity.

Managing grazing does not necessarily involve more fencing. Fire can be used to spread grazing pressure and minimize the negative effects of overgrazing on more heavily used patches and areas in a grazing unit and enhance vegetation structural heterogeneity and wildlife habitat. Rotational grazing may also be partly implemented through methods other than intensive fencing, including rotating access to water sources (Martin and Ward 1970), strategic supplementation (Bailey and Welling 2007), herding (Bradford 1998; Coughenour 1991; Butler 2000; Bailey 2005; Bailey et al. 2008), and manipulating animal behavior (Provenza 2003a; Launchbaugh and Howery 2005).

Science is a tool to help people understand the processes of nature (Provenza 2000). With regard to grazing management, researchers have used this device primarily to understand interrelationships among physical and biological processes that link soils, plants and herbivores. They have not, as Briske et al. (2008) point out repeatedly, focused on the most important feature of the system, namely the human element of management. Understanding processes is of little value without the flexibility to continually create in the face of uncertainty, and that is what the human element at its best brings to the table in the form of management. Thinking in terms of grazing systems is far less important than understanding processes and determining how to achieve management goals using that knowledge. What matters is feedback from constantly monitoring and continually adjusting the movements of herbivores to ensure the nutrition and health of soils, plants, herbivores and ultimately people. All of that depends upon animals frequently moving across landscapes, whether driven by their needs for nutrients, a herder, rotations through fenced paddocks, fire, or predators (Provenza 2003b; Provenza et al. 2003). People are the glue that links soils, plants and herbivores in grazing systems, and if we really want to understand the innovation and integration essential to the successes of those relationships, we must understand what the best managers do (Provenza 2003a).

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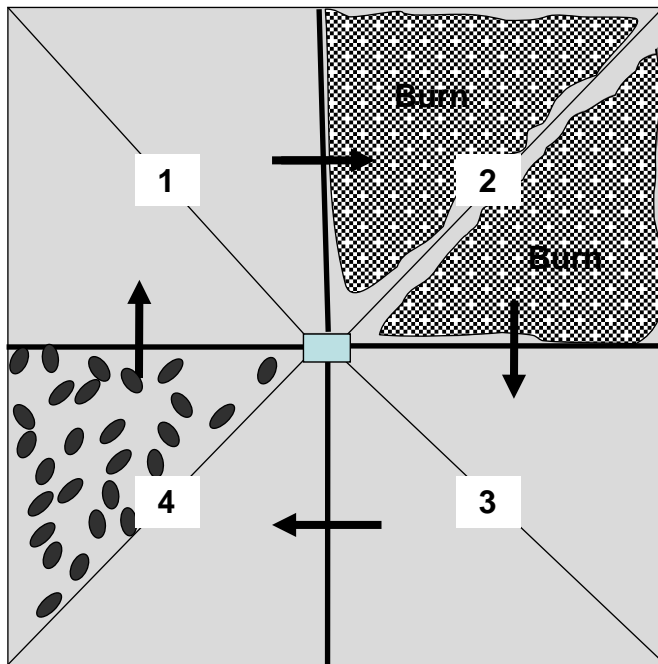
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Block 1. Rest for a full growing season but use as emergency drought grazing reserve

Block 2. Apply spring burn followed by RG when ready to graze. 1st grazing priority, graze again whenever ready

Block 3. 2nd in priority for grazing after block 2 that has recently been burned

Block 4. 3rd priority grazing when neither the 1st or 2nd priority blocks are ready to regaze

Figure 1. Open-Camp Grazing Management (Venter and Drewes 1969; Tainton et al. 1999)

- Year 1. Following a spring burn to remove residual low-quality material, grazing should be closely controlled and selective grazing minimized using Rotational Grazing (RG). The most recently burned paddock is grazed whenever it has recovered sufficiently from the previous grazing, but before the forage has matured and become unacceptable to animals.
- Year 2. In the second season this paddock is rated second in priority, the newly burned paddock assuming the priority position. Selective grazing should be controlled as effectively as possible during this second season using RG but, in practice, unacceptable material invariably begins to accumulate because of the reduced razing control. The now maturing less preferred (Increaser) plants cannot be grazed without damage to the more preferred (Decreaser) species in the sward, and so the development of tuftiness becomes unavoidable.
- Year 3. During the third and subsequent seasons (where there are more than four paddocks) selective grazing becomes progressively worse as the more recently burned paddocks receive priority treatment. At the beginning of the growing season when forage growth is slow, and in dry years, most of the paddocks will be grazed before the 1st priority paddock is ready to graze again. In wet years, and from the fourth year onwards, the paddocks may remain ungrazed during the peak growth period and they will largely be used as buffer grazing areas during periods of slow growth when the preference paddocks cannot supply sufficient grazing.
- Year 4. The paddock is eventually rested for a full growing season and burned (where there is a large quantity of residual material, burning may also often be advisable in the spring prior to the paddock entering rest). The paddock then enters the cycle once more as the first preference paddock.