CHAPTER

1

An Evidence-Based Assessment of Prescribed Grazing Practices

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1

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INTRODUCTION

Prescribed grazing is inclusive of many interrelated management and conservation activities implemented for purposes of managing grazed ecosystems. It is supported by a loosely organized information base that contains management experience, agency policy and procedures, and scientific information that has been developed throughout the history of the rangeland profession. The components of prescribed grazing are implemented in various combinations to achieve multiple management goals and outcomes under a wide variety of ecological conditions in diverse rangeland ecosystems. A fundamental premise of effective grazing management is that it supports ecosystem sustainability and restoration of degraded ecosystems. Management actions have traditionally emphasized livestock species and number and their temporal and spatial distribution on the landscape (Stoddart et al. 1975; Heitschmidt and Taylor 1991). The management of grazed ecosystems involves multiple human dimensions as well as complex ecological processes, making it difficult and impractical to attempt to separate grazing management from overall enterprise management (Stuth 1991). Therefore, management practices are commonly designed and applied within the context of specific landowner operations, management needs, and natural resource conservation goals. Consequently, prescribed grazing involves a continuum of management activities ranging from extensive management to those that are much more labor and infrastructure intensive.

Context for the initial development of prescribed grazing in the United States originated with management recommendations to promote sustainable use and recovery of rangelands damaged by excessive livestock grazing early in the 20th century (Smith 1896; Wooten 1916; Sampson 1923, 1951; Hart and Norton 1988). Excessively high stocking rates (animal units area^{-1} time^{-1}) common to the late 19th and early 20th centuries were unsustainable, and the negative consequences of those extreme stocking rates adversely affected numerous ecosystems throughout the Great Plains and West. Early rangeland research advocated use of reduced stocking rates and simple grazing systems to impose early season deferment and season-long rest to halt and potentially reverse ecological damage created by severe overgrazing. Increased efficiency of livestock production became an important objective during the 1980s and was associated with the introduction of short-duration grazing to the United States (Savory and Parsons 1980; Savory 1983). These management systems were designed to improve the efficiency of forage harvest, enhance forage quality, and promote livestock production. More recently, prescribed grazing has emphasized broader conservation goals and ecosystem services. Biodiversity conservation, water quality and quantity, woodland encroachment, invasive species, and carbon sequestration are but a few of the current high-profile conservation issues considered within grazed ecosystems. However, this emphasis is rather recent, and the amount of experimental information to date is insufficient to draw valid generalizations regarding these conservation issues.

Even though the primary objective of this body of information is to promote effective grazing management, this is in itself not a sufficient foundation on which to evaluate this important land use. It is essential that the underlying components and processes of effective grazing management be recognized, understood, and documented to ensure that this information base is carefully scrutinized, accurate, and

Prescribed grazing is the management of vegetation harvest by grazing or browsing animals to achieve desired objectives. (Photo: Derek Bailey)

effectively promoted. The primary objective of Rangeland CEAP is to organize and evaluate the current body of scientific information supporting the anticipated benefits of rangeland conservation practices implemented by the US Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). This assessment is intended to provide the foundation for the next generation of planning and assessment procedures that are to emphasize environmental quality and the assessment of multiple ecosystem services in addition to the traditional outcomes of farm and ranch productivity (Maresch et al. 2008).

This chapter evaluates the ecological effectiveness of the major purposes and purported benefits for prescribed grazing as described in the USDA-NRCS National Conservation Practice Guidelines. This standard defines prescribed grazing as managing the harvest of vegetation with grazing and/or browsing animals that is often applied as one component of a broader conservation management system to achieve one or more of the following purposes:

- Improve or maintain desired species composition and vigor of plant communities.
- Improve or maintain quantity and quality of forage for grazing and browsing animals' health and productivity.
- Improve or maintain surface and/or subsurface water quality and quantity.
- Improve or maintain riparian and watershed function.
- Reduce accelerated soil erosion and maintain or improve soil condition.
- Improve or maintain the quantity and quality of food and/or cover available for wildlife.
- Manage fine fuel loads to achieve desired conditions.

This definition is very similar to that provided in the Society for Range Management (SRM) Glossary of Terms (1998)—"the manipulation of animal grazing in pursuit of a defined objective"—and to that of targeted grazing—"the application of a specific kind of livestock at a determined season, duration and intensity to accomplish a defined objective" (Launchbaugh and Walker 2006). Targeted grazing emphasizes objectives associated with landscape dynamics in addition to livestock production. It is important to note that prescribed grazing, as defined above, is a much broader concept than grazing system, which describes a specialized application of grazing management based on recurring periods of grazing, rest, and deferment for two or more pastures (Heitschmidt and Taylor 1991). The NRCS National Range and Pasture Handbook describes prescribed grazing schedules to recommend appropriate periods of grazing, rest, and deferment (USDA-NRCS 2003).

The experimental data addressing these purposes were extracted primarily from the peer-reviewed literature, summarized and incorporated into tabular forms to provide an evidence-based assessment of how well prescribed grazing achieves these stated purposes. In some instances, direct comparisons could be made between intended conservation outcomes and the experimental evidence, but in many others, inferences had to be drawn from the most relevant experimental data to assess the effectiveness of conservation outcomes. Constraints of experimental research have influenced both the type of information available and the investigations selected for inclusion in this assessment. For example, spatial heterogeneity may produce conditions where most pastures under consideration possess generally similar topoedaphic characteristics, but in other cases one or more pastures may possess distinctly different characteristics. Only the first condition characterized by relatively homogeneous site conditions meets the traditional experimental requirements of replication and comparison with experimental controls, while decisions regarding heterogeneous site conditions can be assessed only on a case-by-case basis. Given that the goal of this chapter was to evaluate the preponderance of evidence supporting major grazing management practices, investigations that were unreplicated or that did not have experimental controls, that applied unequal treatments, or that contained minimal data were not included. These requirements were relaxed to some extent for the evaluation of wildlife because investigations addressing responses of specific wildlife species or groups to unique management practices were often limited. Similarly, minor wildlife groups were

not addressed because of limited research evidence and space limitations.

This chapter is organized into six major headings: introduction, evaluation of prescribed grazing purposes, associated considerations, recommendations, knowledge gaps, and conclusions. The evaluation of prescribed grazing purposes is the largest section, and it contains seven secondary headings addressing each of the conservation purposes previously described. Several of these purposes are further subdivided into tertiary headings of stocking rate and grazing system because these two research themes contain a large portion of the experimental information associated with grazing management. In addition to summarizing the experimental evidence relevant to prescribed grazing management, this chapter emphasizes the strengths and weaknesses of the experimental data, provides recommendations for improvement of this conservation practice, and identifies major knowledge gaps in the experimental literature. The overarching goal is to describe the current status of grazing management information to provide a foundation for development of the next generation of prescribed grazing practices. This chapter was commissioned by and is directed toward the NRCS, but it also contains important implications to the broader rangeland profession.

EVALUATION OF PRESCRIBED GRAZING PURPOSES

Improve or Maintain Desired Species Composition and Vigor of Plant Communities

Stocking Rate. Stocking rate has long been recognized as a fundamental variable determining the sustainability and profitability of grazed rangeland ecosystems (Smith 1896; Wooton 1916; Sampson 1923). The objective of stocking rate is to balance the forage demand of grazing animals with that of forage production over an annual forage production cycle. The difficulty encountered when setting and maintaining appropriate stocking rate on rangelands is the high variability of forage production associated with annual and interannual precipitation variation. It is often recommended that stocking rates should be conservatively applied to minimize the detrimental consequences of overstocking during drought on the economic and ecological sustainability of grazed ecosystems.

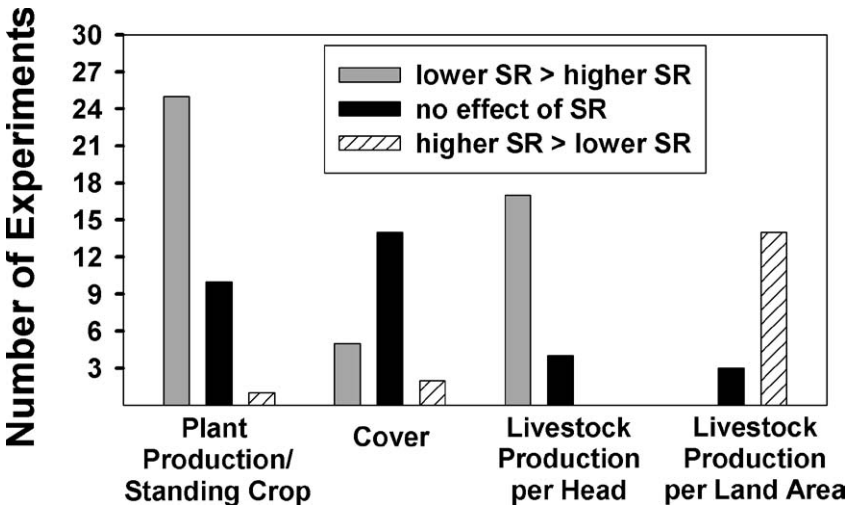

FIGURE 1. Number of investigations reporting significant effects of stocking rate on plant production and cover and livestock production per head and per unit land area.

The importance of stocking rate to the management of grazed ecosystems has attracted considerable research attention over the past several decades. This research has produced consistent relationships between stocking rate and plant production, animal production, and species composition of herbaceous plant communities. Plant production decreases with increasing stocking rate, as does individual animal production (Bement 1969; Manley et al. 1997; Derner and Hart 2007; Derner et al. 2008). In contrast, animal production per land area increases with increasing stocking rate within the limits of ecosystem sustainability. These ecosystem responses to stocking rate have clear production and conservation implications.

The response of several ecosystem variables indicates that stocking rate is at least indirectly correlated with ecosystem function and sustainability. High grazing intensities generally appear to minimize ecosystem function, which often has negative consequences for conservation goals and the provisioning of ecosystem services. Plant production is the most consistent response with 69% (25 of 36) of the investigations reporting greater plant production at lower compared to higher stocking rates (Fig. 1). Twenty-eight percent (10 of 36) showed no difference in plant production with stocking rate. Only four of

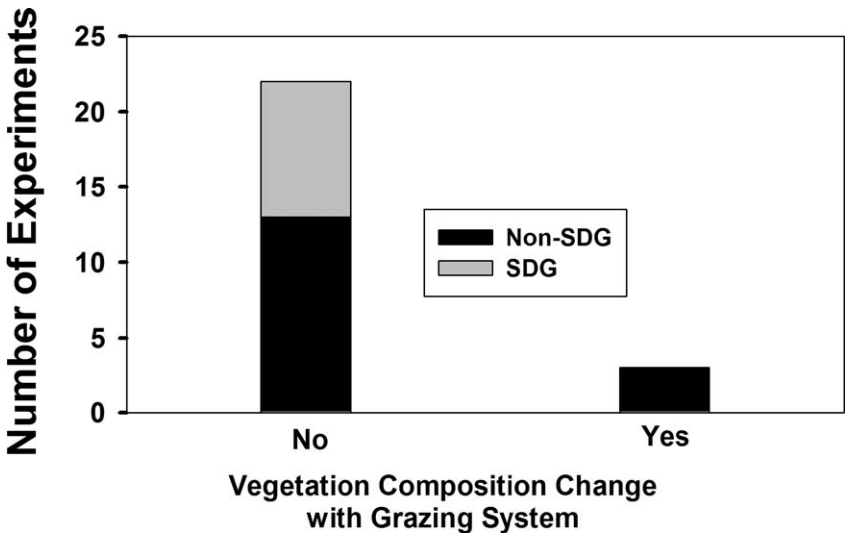

FIGURE 2. Number of investigations reporting significant effects of grazing system, categorized as short-duration and non–short-duration systems, on favorable changes in species composition of plant communities.

these investigations considered plant species diversity or richness in relation to stocking rate, but the trend is for increasing diversity and richness with increasing stocking rate, which is a consistently observed community response to grazing (Milchunas et al. 1988). This response is interpreted as a function of the suppression of grass dominants at high stocking rates, which increases resource availability for subordinate species within the community (Collins 1987; Anderson and Briske 1995; Knapp et al. 1999). However, cases do exist where intensively grazed ecosystems are required to provide specific habitat for flora and fauna (Milchunas and Lauenroth 2008; Derner et al. 2009).

Stocking rate has tremendous potential to modify the species composition of herbaceous vegetation. Significant change in species composition was documented to occur in 71% (17 of 24) of the stocking rate studies evaluated. Plant cover showed a much less consistent response than did either production or species composition with 67% (14 of 21) of the investigations showing no difference with stocking rate compared to 24% (5 of 21) that did show a positive response. Compositional changes largely follow the classical increaser–decreaser patterns outlined by Dyksterhuis (1949) and more recently verified in a global vegetation analysis (Diaz et al. 2007) in which tallgrasses are replaced by midgrasses and midgrasses by shortgrasses. Eight of these studies recorded vegetation responses for ≥ 20 yr and 14 studies for ≥ 10 yr, but significant vegetation change was also recorded in shorter time periods. These vegetation responses also document the occurrence of equilibrium dynamics in which grazing modifies the species composition of plant communities in addition to weather conditions (Fuhlendorf et al. 2001; Briske et al. 2003). The potential for recovery of species composition in response to reduced stocking rates also documents the high degree of resilience associated with many rangeland ecosystems (Milchunas et al. 1988).

Grazing Systems. Although changes in plant species composition are often more qualitatively assessed than the plant and animal production values presented previously, the majority of investigations have not shown a clear benefit of rotational grazing over continuous grazing in promoting secondary succession or improving community composition on rangelands (Holechek et al. 1999, 2006). In our survey of 25 grazing experiments, 86% (18) indicated no difference in species composition for continuous compared to rotational grazing at comparable stocking rates. Only 3 of 25 experiments recorded improvements in species composition, and these were all deferred-rotation rather than short-duration systems (Fig. 2).

Experimental data referencing biotic diversity in grazing systems are limited, especially at regional scales, so definitive conclusions are unattainable at this point. However, the limited experiments addressing plant species diversity do not show that grazing systems enhance plant species diversity (Holechek et al. 2006). In tallgrass prairie, grazing system did not influence plant richness or diversity, but both variables increased with increasing stocking rate (Hickman et al. 2004). Increasing stocking rate reduced the abundance of the several dominant C_4 grass species and increased the expression of several subordinate species. Plant diversity responses to grazing are dependent on the direct response of various species to grazing and the indirect response of other species to grazing-induced release from competition (Milchunas et al. 1988; Anderson and Briske 1995).

Grazing Season and Deferment. Research addressing the season and length of grazing deferment is surprisingly limited given its

importance to grazing management. It is difficult to draw inferences from the few investigations specifically addressing season of grazing, especially given the variability in production and defoliation responses associated with precipitation variation within and among years (Zhang and Romo 1994). These authors were unable to make conclusive recommendations regarding production responses of northern mixed prairie to the seasonality and frequency of defoliation because of weather variation between years. Plant species with unique growth periods and production potentials contribute additional complexity to this assessment (Volesky et al. 2004). This underscores the difficulty of making generalizations regarding the appropriate season of grazing and deferment.

Inferences regarding the appropriate length of grazing deferment can be derived from grazing systems research previously evaluated. Short deferment periods do not yield benefits in those variables measured, that is, plant and animal production, species composition, and soil characteristics. It can be inferred from this extensive data set that successive short deferments of 30–45 d are ineffective in offsetting short, intensive grazing periods of 2–11 d. Conclusions regarding length of deferment have been drawn from comparisons of short-duration and high-intensity, low-frequency systems using 42- and 84-d deferment periods, respectively (Taylor et al. 1993). These authors concluded that 80–90-d deferment periods were required to maintain desired species composition on semiarid rangelands. This interpretation has been corroborated by research conducted in mesic tallgrass ecosystems (Reece et al. 1996). Specific ecological mechanisms limiting increased plant production and improved species composition in response to short-term periodic deferment in rotational systems are not entirely clear, but they are very likely influenced by the time required for plant recovery, especially on semiarid rangelands, and the coincidence of favorable growth conditions with periods of grazing deferment (Briske et al. 2008).

Grazing deferment relative to the onset and recovery from drought has also received minimal attention given its significance to grazing management. However, several conclusions can be drawn from a valuable, but limited data set. First, grazing deferment during drought has minimal potential to enhance plant production or species composition, even though it is often necessary to destock because of insufficient forage availability (Eneboe et al. 2002; Heitschmidt et al. 2005; Gillen and Sims 2006). However, deferment is important to maintain sufficient plant cover and density to protect soil quality and promote plant recovery once rainfall resumes (Wood and Blackburn 1981a&b; Thurow 1991; Dalgleish and Hartnett 2006). Second, grazing deferment is not necessarily required for rapid and effective vegetation recovery from moderate drought conditions (Eneboe et al. 2002; Heitschmidt et al. 2005). Investigations demonstrating the ability of rainfall to override the effects of stocking rate on forage production and species composition indirectly support this interpretation (Milchunas et al. 1994; Biondini et al. 1998; Gillen et al. 2000; Vermeire et al. 2008). Third, in the cases involving severe, prolonged drought, 2 yr or more may be required for recovery of species composition and productivity. Severe, multiyear drought can induce mortality of plants and tillers to retard plant growth following the resumption of rainfall (Briske and Hendrickson 1998; Dalgleish and Hartnett 2006; Yahdjian et al. 2006). Consequently, several growing seasons may to be required for tiller and plant densities to recover to predrought values. Plant mortality was found to be approximately twice as great in heavily compared to more lightly grazed Great Plains rangelands following the multiyear drought of the 1950s (Albertson et al. 1957). Greater plant mortality is likely a consequence of the suppressed root growth and function that is known to occur with severe grazing of individual plants (Crider 1955).

Improve or Maintain Quantity and Quality of Forage for Grazing and Browsing Animals' Health and Productivity

Stocking Rate. Experimental data confirm the occurrence of a consistent trade-off between animal production per head and per land area with increasing stocking rate. Eighty percent (16 of 20) of investigations reported greater animal production per head at low compared to high stocking rates, while 82% (14 of 17)

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showed greater animal production per land area at high compared to low stocking rates (Fig. 1). This trade-off in animal performance is readily explained by the greater availability of plant biomass per individual animal with decreasing stocking rate and greater forage harvest per unit land area with increasing stocking rate. Experimental evidence indicates that both forage quantity and quality decrease with increasing high compared to low stocking rates. Forage quality is most likely to decrease during grazing periods insufficient for appreciable regrowth, where animals initially select the highest-quality forage.

Pattern of tiller defoliation research shows that 80% or more of all tillers can be defoliated in a single grazing period with high stocking rates or grazing intensities (8 of 11 studies). This indicates that high harvest efficiencies and uniform grazing patterns can be obtained with large livestock numbers in certain cases. However, these data also indicate that multiple defoliations occur early within a grazing cycle (four of six studies). It has been suggested that repeat defoliations begin to occur at about the time that 60% of the tillers are initially defoliated and that very high grazing pressures and paddock numbers would be required to minimize the occurrence of multiple grazing events within individual grazing periods (Jensen et al. 1990a). These data challenge the widely held assumption that rotational grazing restricts grazing to a single event per plant during short (5–10-d) grazing periods while simultaneously promoting high plant utilization. This may indicate why minimal differences in plant defoliation patterns have been found between rotational and continuous grazing (Hart et al. 1993b). These detailed investigations were conducted on very small pasture sizes (0.2–24 ha), so caution is warranted when scaling these responses to larger areas. In addition, frequency of defoliation may be more detrimental to plants when defoliation events are separated by periods of regrowth, as indicated below.

Frequency of tiller defoliation consistently increases with increasing stocking rate (9 of 10 studies). Defoliation intensity of individual tillers also increases with increasing stocking rate, but not as rapidly as defoliation frequency (four of five studies).

Forage quality decreased with increasing stocking rate within an individual grazing period in all four studies evaluated and with increasing time of grazing for all three studies that carefully evaluated this relationship. This clearly indicates that animals compete for quality forage, and this process establishes the basis for the negative response of individual animal performance with increasing stocking rate.

Season of plant defoliation has unique and consistent effects on plant production. Individual plant production is most greatly suppressed by defoliation during the middle of the growing season, which coincides with culm elongation and the early boot stage of inflorescence development, especially in bunchgrasses (Olson and Richards 1988). This was documented in six of nine investigations and in all three studies specifically evaluating growth stage responses to defoliation. Early season defoliation had the least detrimental effect on subsequent plant production, and late season defoliation had an intermediate effect. However, plant production is increasingly suppressed with increasing frequency and intensity of defoliation at any stage of growth (five of six studies), confirming the interpretation that multiple defoliations within a growing season are detrimental to plant growth and function (Reece et al. 1996; Volesky et al. 2004). These patterns of grass production responses to defoliation at various phenological stages substantiate the criticism that has been directed toward early season deferment (i.e., range readiness) as a valid conservation practice.

The occurrence of patch grazing has been well documented in several investigations, and it appears to directly relate to the nutritional intake of animals when other constraints on animal distribution are absent (e.g., distance to water and topography). Previously grazed patches support forage of higher nutritional quality, including crude protein, fiber, and digestibility, even though forage quantity may be less than on previously ungrazed patches (Cid and Brizuela 1998; Ganskopp and Bohnert 2006). The primary mechanism contributing to patch grazing is animal aversion to consumption of senescent plant

material, especially current and previous year's culms or stems (Ganskopp et al. 1992, 1993). Consequently, patch grazing may provide a nutritional benefit to animals at low and moderate stocking rates (Cid and Brizuela 1998).

Patch structure is relatively consistent within season and among years, but it is less stable at higher than at lower stocking rates (Willms et al. 1988; Cid and Brizuela 1998). At higher stocking rates, animals begin to selectively graze previously ungrazed patches to maintain sufficient forage intake, and they forage greater distances to achieve this goal (Ring et al. 1985; Ganskopp and Bohnert 2006). Patch grazing can be minimized by the removal of senescent biomass, especially previous year's biomass with fire, mowing, or periodic heavy stocking (Ganskopp and Bohnert 2006). However, the implications of patch grazing have been shifting from that of an inefficient use of forage by livestock to a desirable component of vegetation heterogeneity capable of promoting biodiversity in the Great Plains (Fuhlendorf and Engle 2001, 2004). This is an especially relevant consideration, both within and among pastures, in light of the CEAP initiative, which emphasizes management for environmental quality and multiple ecosystem services as well as production goals.

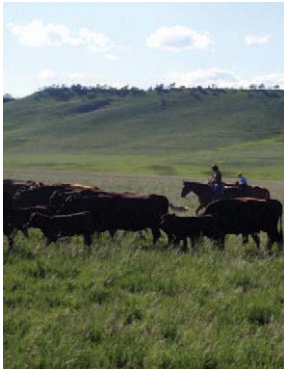
Grazing Systems. Grazing systems represent a specialization of grazing management that defines the periods of grazing and nongrazing (Heitschmidt and Taylor 1991; SRM 1998), and they have been given tremendous emphasis by both managers and researchers. It is important to recognize that constraints of experimental research, including the need for relatively homogeneous site conditions necessary for replication and comparison with experimental controls, has emphasized the potential for various periods of grazing and rest to alter the ecological processes controlling plant and animal production. They are unable to—and therefore do not—address livestock distribution in heterogeneous landscapes or livestock movement in response to site readiness along elevation gradients. However, these latter considerations are also important and have been addressed with experimental data collected with more appropriate experimental approaches.

The major experimental investigations of grazing systems have been categorized by geographic location, ecosystem type, relative stocking rate, and number and size of pastures for each of the respective investigations (Briske et al. 2008). Variables were indicated to differ between continuous and rotational grazing only when they were reported as being statistically significant by the authors. For each experiment, plant and/or animal production (the most quantitative data collected) was characterized as 1) greater for continuous grazing (CG > RG), 2) greater for rotational grazing (RG > CG), or 3) equal if differences did not exist between continuous and rotational grazing (ND). These comparative responses were summarized and presented as separate histograms for those investigations that used similar stocking rates between grazing treatments (Fig. 3A), those that used greater stocking rates for rotational than for continuous grazing (Fig. 3B), and for all stocking rates combined (Fig. 3C). These experimental comparisons of rotational systems included five studies conducted for 9 yr or more, and four had pasture sizes greater than 300 ha, but only two had greater than eight pastures per grazing system.

Eighty-nine percent of the experiments (17 of 19; Appendix I) reported no differences for plant production/standing crop between rotational and continuous grazing with similar stocking rates (Fig. 3A). When stocking rate was less for continuous than rotational grazing, 75% of the experiments (three of four) reported either no differences or greater plant production for continuous grazing (Fig. 3B). Across all stocking rates, 83% of the experiments (19 of 23; Appendix I) reported no differences for plant production between rotational and continuous grazing, 13% (three) reported greater plant production for rotational compared to continuous grazing, and 4% (one) reported greater production for continuous grazing (Fig. 3C; Briske et al. 2008).

Fifty-seven percent of the experiments (16 of 28; Appendix I) reported no differences for animal production per head between rotational and continuous grazing with similar stocking rates, and 36% (10) reported greater per head production for continuous grazing (Fig. 3A). When stocking rate was less for continuous than rotational grazing,

Grazing is a major land use on 188 million hectares of non-federal lands in the Great Plains and western U.S. (Photo: Sonja Smith)



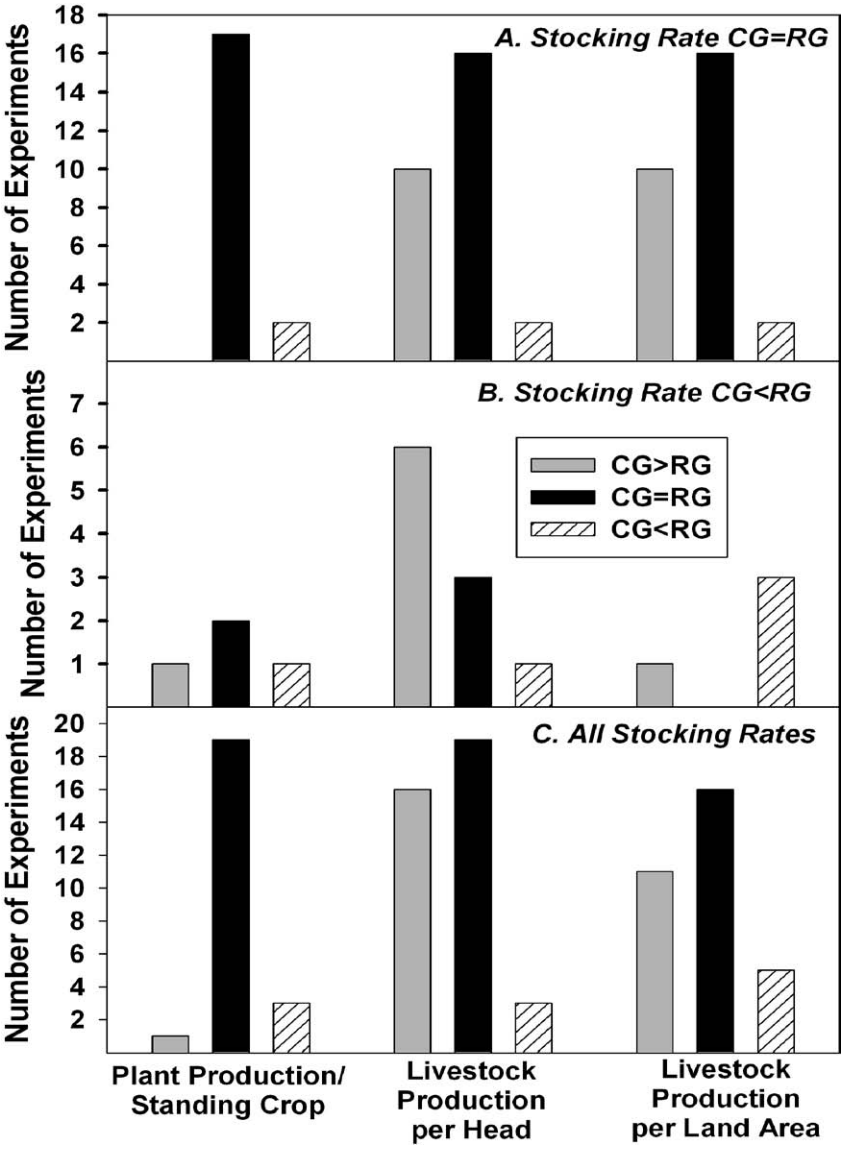


FIGURE 3. Number of published grazing experiments that reported significantly higher, equal, or lower plant and animal production responses for continuous compared to rotational grazing at (**A**) similar stocking rates, (**B**) higher stocking rates for rotational grazing, and (**C**) across stocking rates for all experiments. Animal production is presented as both a per head and a per land area response (from Briske et al. 2008).

90% of the experiments (9 of 10) reported either similar or greater per head animal production for continuous grazing (Fig. 3B). Across all stocking rates, 50% (19 of 38; Appendix I) of the experiments reported no differences for animal production per head between rotational and continuous grazing, 8% (three) reported greater production for rotational grazing, and 42% (16) reported greater production for continuous grazing (Fig. 3C). Fifty-seven percent of the experiments (16 of 28; Appendix I) reported no differences for animal production per unit land area between rotational and continuous grazing with similar stocking rates, and 36% (10) reported advantages for continuous grazing (Fig. 3A). When stocking rate was lower for continuous than rotational grazing, 75% (three of four; Appendix I) of the experiments reported greater animal production per area for rotational grazing (Fig. 3B). Across all stocking rates, 50% (16 of 32; Appendix I) of the experiments reported no differences for animal production per land area between rotational and continuous grazing, 16% (five) reported greater production for rotational grazing, and 34% (11) reported greater production for continuous grazing (Fig. 3C; Briske et al. 2008). A recent ranch-scale investigation comparing four grazing systems over a 7-yr period that was not included in this numerical assessment also reported minimal differences in livestock production among grazing systems (Pinchak et al. 2010).

No evidence was found indicating that grazing systems override livestock preference for site selectivity. Comparisons of continuous season-long and rotational grazing on five range sites in northern mixed-grass prairie found no differences among grass utilization over a 2-yr period (Kirby et al. 1986). This occurred in spite of the fact that the rotational system had both a higher stocking rate and a higher stock density than did the continuous system. Heitschmidt et al. (1989) corroborated these conclusions in mixed-grass prairie in north-central Texas. Paddocks of 30 and 10 ha were used to simulate rotational grazing systems with 14 and 42 paddocks. Livestock selectivity was not modified by either rotational grazing system compared to continuous grazing. These authors concluded that forage availability, rather than stocking density or grazing system, was the primary mechanism that modifies animal selectivity. However, none of these investigations specifically addressed the presence of riparian systems in which livestock frequently congregate (George et al., this volume).

Only four studies were found that directly compared forage quality in rotational and continuous grazing. Forage quality was

comparable among systems in two of the investigations (Jung et al. 1985; Heitschmidt et al. 1987b), and one each favored continuous (Pfister et al. 1984) and rotational grazing (Heitschmidt et al. 1987a). Forage quality was greater for a seven-pasture short-duration system compared to a seven-pasture high-intensity, low-frequency system, but similar to that of a Merrill four-pasture, three-herd system on the Edwards Plateau of Texas (Taylor et al. 1980). Tiller defoliation patterns in continuous and rotational grazing have received only minimal attention, but frequency and intensity of tiller defoliation was greater for rotational grazing in only one (Senock et al. 1993) of four investigations (Hart et al. 1993a; Derner et al. 1994; Volesky 1994). Collectively, the small number of investigations reporting mixed results makes conclusions regarding grazing systems effects on forage quality and defoliation patterns equivocal compared to conclusions addressing plant and animal production, and species composition.

Three categories of evidence exist to explain why intensive rotational grazing systems have not shown greater quantity and quality of forage and animal production in experimental research. First, short, periodic deferments based on established schedules do not always coincide with favorable growth conditions in rangeland environments (e.g., Taylor et al. 1993; Holechek et al. 2001; Gillen and Sims 2006). The amount and variability of rainfall and the associated predictability, duration, and amount of plant growth appear to override the potential benefit derived from the redistribution of grazing pressure in space and time in rotational grazing systems (O'Reagain and Turner 1992; Ash and Stafford Smith 1996; Holechek et al. 2001; Ward et al. 2004). Plant growth and improvement in species composition will be promoted primarily when deferment coincides with environmental conditions favorable for plant growth (Heitschmidt et al. 2005; Gillen and Sims 2006).

Improper grazing can detrimentally affect soil surface characteristics to accelerate runoff and erosion. (Photo: Ken Tate)

> These results refute prior claims that animal trampling associated with high stocking rates or grazing pressures in rotational grazing systems enhance soil properties and promote hydrological function"

Second, rotational grazing may not control the frequency and intensity of plant defoliation as effectively as often assumed (Gammon and Roberts 1978a, 1978b, 1978c; Hart et al. 1993a). Investigations of tiller grazing patterns indicate that it is difficult to achieve a high percentage of tiller defoliation (> 80%) before multiple defoliations begin to occur within a single grazing period (Jensen et al. 1990a; O'Reagain and Grau 1995). These data indicate that grazing management strategies only marginally modify animal selectivity within the range of conditions that have been evaluated. Third, forage quality is not consistently or substantially increased in intensive systems compared to continuous grazing (Denny et al. 1977; Walker et al. 1989; Holechek et al. 2000). The absence of experimental evidence supporting these three major underlying assumptions associated with rotational systems is consistent with the production responses generated from experimental comparisons of rotational and continuous grazing. However, conclusions addressing tiller defoliation patterns are derived from a small number of experiments conducted in very small pastures (0.2–24 ha) that may not be entirely representative of grazing patterns at larger scales.

These experimental results collectively indicate that rotational grazing does not promote primary or secondary production compared to continuous grazing within rangeland ecosystems. These interpretations are consistent with those of previous reviews over the past 50 yr (Heady 1961; Van Poollen and Lacey 1979; Holechek et al. 2001), and they clearly support the long-standing conclusion that stocking rate and weather variation account for the majority of variability associated with plant and animal production on rangelands (Van Poollen and Lacey 1979; Heitschmidt and Taylor 1991; Gillen et al. 1998; Holechek et al. 2001; Derner and Hart 2007).

Improve or Maintain Surface and/or Subsurface Water Quality and Quantity

Stocking Rate. The response of soil hydrological characteristics to grazing largely parallel those of other ecological variables because stocking rate is the most important driver regardless of grazing system (Wood and Blackburn 1981a&b; Thurow 1991). This occurs because the removal of large amounts of plant cover and biomass by intensive grazing reduces the potential to dissipate the energy of raindrop impact and overland flow. The erosive energy of water and the long-term reduction of organic matter additions to soil detrimentally affect numerous soil properties, including the increase of bulk density, disruption of biotic crusts, reduced aggregate stability, and organic matter content, which collectively reduce infiltration rate and increase sediment yield and runoff. Animal trampling is another source of mechanical energy that breaks soil aggregates and is therefore negatively correlated with maintenance of soil structure necessary for high infiltration rates (Warren et al. 1986b; Thurow 1991; Holechek et al. 2000). These results refute prior claims that animal trampling associated with high stocking rates or grazing pressures in rotational grazing systems enhance soil properties and promote hydrological function (Savory and Parsons 1980; Savory 1988). These hydrological responses to grazing are strongly contingent on community composition, with communities that provide greater cover and obstruction to overland flow, such as midgrass-dominated communities having greater hydrological function, including infiltration rate, than shortgrass-dominated communities (Wood and Blackburn 1981b; Thurow 1991).

Grazing System. Short-duration rotational grazing systems decreased soil hydrologic function at heavy to very heavy stocking rates, compared to continuous and deferred-rotation grazing systems at moderate to light stocking rates. The negative changes in vegetation and soil properties controlling infiltration, runoff, and soil loss due to heavy stocking rates generally cannot be overcome by grazing system. These collective results strongly refute claims that animal trampling associated with high stocking rates or intensities under intensive rotational grazing systems enhance hydrological function (Savory and Parsons 1980; Savory 1988).

There is evidence that soil hydrological functions degraded by heavy stocking rates can recover with prolonged rest (i.e., ≥ 1 yr). Thus, rotational grazing may maintain higher soil hydrologic function than continuous grazing

at heavy to very heavy stocking rates if the deferment period is sufficient (i.e., ≥ 1 yr). Similarly, moderately stocked continuous or rotational grazing may maintain a consistently higher level of hydrologic function compared to periodic heavy stocking followed by prolonged deferment for hydrologic recovery.

A few studies have directly examined grazing systems (deferred rotation, rest rotation, and rotational deferment) in comparison with continuous grazing. At moderate stocking rates, at which most extensive rotational systems were studied, rotational grazing systems lead to similar or improved soil hydrologic function compared to moderate continuous grazing (Ratliff et al. 1972; McGinty et al. 1979; Wood and Blackburn 1981b, 1984). As evidenced by Wood and Blackburn (1981) and Thurow et al. (1986), these hydrological responses to grazing system appear to be strongly contingent on plant community composition, with midgrass-dominated communities having greater hydrological function than shortgrass-dominated communities. Gifford and Hawkins (1976) emphasize the importance that range condition or plant community composition has on the hydrological function of a site through time in response to grazing system.

Improve or Maintain Riparian and Watershed Function

There is clear consensus that livestock grazing can degrade riparian plant communities, hydrologic function, and associated ecosystem services. Considerable management attention has been directed toward prescribed grazing practices with the intent to restore, enhance, or maintain rangeland riparian areas. As with upland habitats, it is clear that grazing intensity is a major factor determining riparian response to grazing management. Increased grazing intensity is generally associated with detrimental effects on riparian plant community composition and productivity as well as physical degradation of riparian soils and stream channels. These primary effects can lead to secondary negative effects on stream hydrologic functions, which can cascade to loss of services, such as fish habitat, flood attenuation, and provisioning of clean water. Management of grazing intensity is a viable conservation practice for riparian areas. Season of grazing also determines livestock grazing effects on riparian plant communities, particularly woody plants, and can be managed to conserve riparian habitats and their associated services. Livestock distribution practices such as water developments, supplement placement, and herding are effective means of managing the intensity and season of livestock grazing in riparian areas. Livestock exclusion is an effective practice to stimulate immediate recovery for riparian plant communities degraded by heavy grazing. While the individual effects of some prescribed grazing components (e.g., timing, intensity, and rest) on riparian habitats have been examined, few studies have rigorously examined the effects of different grazing systems on riparian habitats. The effectiveness of grazing management practices on the conservation of riparian habitats is covered in depth in the chapter on riparian herbaceous cover (George et al., this volume).

Reduce Accelerated Soil Erosion and Maintain or Improve Soil Condition

Soil vegetative cover is widely recognized as a critical factor in maintaining soil surface hydrologic condition and reducing soil erosion (Gifford 1985). High stocking rates, regardless of grazing system, that reduce soil surface vegetative cover below a site-specific threshold will increase detachment and mobilization of soil particles due to raindrop impact, decrease soil organic matter and soil aggregate stability, increase soil surface crusting and reduce soil surface porosity, and thus decrease infiltration and increase soil erosion and sediment transport (Blackburn 1984). Regardless of grazing system, sufficient vegetative cover, critical soil cover, or residual biomass must remain during and following grazing to protect soil surface condition (e.g., porosity, aggregate stability, and organic matter content) and dependent hydrologic properties (e.g., infiltration). Site-specific vegetation cover requirements will vary depending on cover type (e.g., vegetation, litter, or rock), soil type, rainfall intensities, and water quality goals (Gifford 1985).

The majority of research examining soil surface hydrologic response to grazing has focused on infiltration or proxies for infiltration, such

"Increased grazing intensity is generally associated with detrimental effects on riparian plant community composition and productivity as well as physical degradation of riparian soils and stream channels."

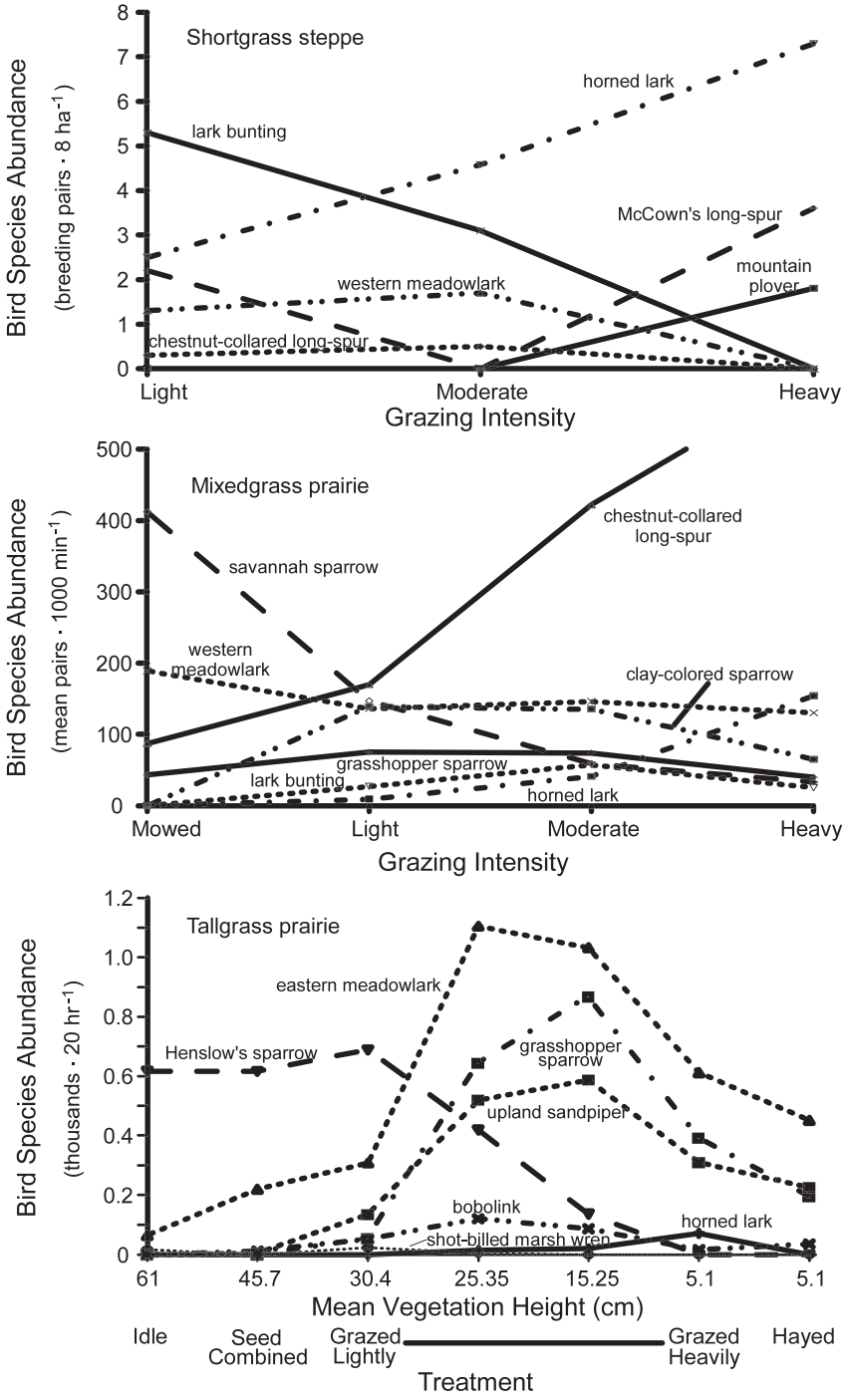


FIGURE 4. Bird species responses to grazing intensity/management treatments for (**A**) shortgrass steppe, (**B**) mixed-grass prairie, and (**C**) tallgrass prairie. Drawn from data in Giezentanner (1970), Skinner (1975), Kantrud (1981), Kantrud and Kologiski (1982), and Milchunas et al. (1998).

as dry bulk density and soil penetrability. A handful of studies have examined soil loss. Increased stocking rates from nongrazed to very heavy are associated with increased soil loss. As with infiltration results, light and moderate stocking rates are generally not different. There is no consistent result for the effect of grazing system on soil loss; in some cases, continuous systems are reported to have less soil loss, and in other studies, rotational systems are reported to have less soil loss. Most of these studies are confounded by comparisons of different stocking rates among systems, and several report that grazing system effect depended on plant community (e.g., shrub understory vs. interspace). There is no compelling evidence that rotational grazing strategies can reduce soil loss. Soil vegetative cover (responding to stocking rate) and inherent soil characteristics are key variables determining site scale soil loss (Pierson et al. 2002).

Improve or Maintain the Quantity and Quality of Food and/or Cover Available for Wildlife

Stocking Rate. Livestock and wildlife may directly compete for plant food resources, and livestock grazing can alter the composition, productivity, and quality of plant food resources. Grazing can alter community structure through removal of recent production and through longer-term effects on plant community composition and productivity. Cover represents an important component of wildlife habitat for escape and concealment from predation as well as for thermal regulation. Cover requirements for specific wildlife species often vary within a season and stage of life cycle (e.g., nesting vs. foraging). Bird (MacArthur 1965; Wiens 1969; Cody 1985), rodent (French et al. 1976; Grant and Birney 1979; Geier and Best 1980; Grant et al. 1982; Kerley and Whitford 2000), lagomorph (Flinders and Hansen 1975), and lizard (Pianka 1966) community composition and diversity are often closely correlated with vegetation structure. Direct behavioral interactions between livestock and wildlife are another potential means by which grazing may affect wildlife populations. Social avoidance can preclude the use of otherwise suitable habitat, and it can be influenced by the numbers of livestock present (Roberts and Becker 1982; Stewart et al. 2002). Trampling of nests represents another possible mechanism of negative interaction between livestock and ground-nesting birds that increases with stocking rate (Jensen et al. 1990b).

There are fewer studies documenting the responses of specific wildlife species or groups to stocking rate or grazing intensity than there are for plant communities. Therefore, studies published in the gray literature, including symposia and technical reports, have been included, but theses, dissertations, or non–data-based publications have not. Limited data availability also requires that inferences be drawn from individual studies rather than groups of studies, as has been done in other sections of this chapter. Wildlife responses are grouped into reptiles, birds, small mammals, and large ungulates to more effectively assess their potentially unique responses and interactions with livestock grazing.

Reptiles. Ten studies reported on lizard communities in grazed versus ungrazed treatments, but only one study assessed lizard populations over five grazing intensities in Arizona (Jones 1979, 1981). The largest negative effect of heavy grazing on lizard density was found in Sonoran Desert grassland (–63%), followed by mixed scrub–dry wash (–54%), chaparral (–41%), and cottonwood–willow riparian (–20%), with no difference in desert scrub. Greater species richness was observed in lightly compared to heavily grazed desert grassland and cottonwood–willow riparian habitat, with no difference in the other three communities. The effects of grazing on lizard communities were related to differences in the cover of short (< 0.3 m) vegetation structure and litter cover, but not necessarily total vegetation cover. While lizard responses to grazing may be expected to be more pronounced than for other groups of organisms because of their relatively specific microhabitat requirements, there are insufficient studies over grazing intensities for generalizations to be drawn.

Birds. Bird responses to stocking rate are well recognized as being species dependent and can be positive, negative, or neutral within any one location and treatment comparison (Bock et al. 1993; Saab et al. 1995; Knopf 1996). Unfortunately, most passerine bird studies have compared only grazed and ungrazed communities, and the intensity of grazing is often not reported. Derner et al. (unpublished data) reviewed 27 bird studies/habitats from the literature, and only 10 included more than one grazing intensity in addition to the long-term ungrazed community. The abundance of individual species within a site can be strongly affected by grazing intensity. For example,

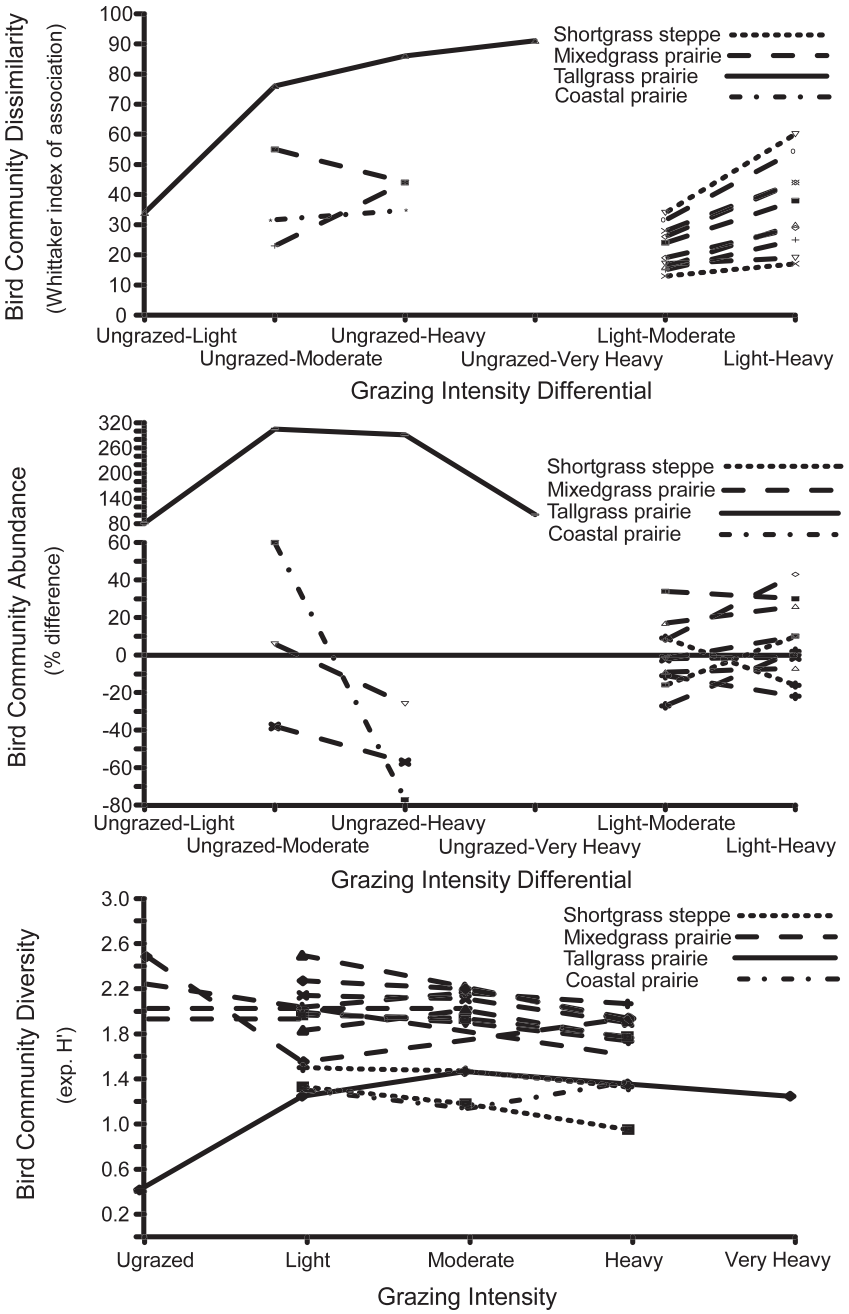


FIGURE 5. Bird community (**A**) dissimilarity (Whittaker [1952] index of community association), (**B**) abundance (% difference between grazing intensity differential), and (**C**) diversity (H′) across grazing intensity gradients for North America studies. Dissimilarity index values range from 0.0 to 1.0, with a value of 0 indicating both treatments having all species in common and in the same proportions (0% dissimilar) and a value of 1.0 indicating no species in common (100% dissimilar). Data from Giezentanner (1970), Johnson and Springer (1972), Skinner (1975), Grzybowski (1980, 1982), Kantrud (1981), Kantrud and Kologiski (1982), and Milchunas et al. (1998).

TABLE 1. Bird community dissimilarity, abundance (numbers), diversity, richness, and dominance in response to grazing averaged by region, evolutionary history of grazing, plant community life form, and plant community type. Forests were not included in region or evolutionary history categories. Plant community types are for major groupings or those with more than one comparison (from Derner et al., unpublished data).

Birds	Precipitation (average mm · yr^{-1})	Dissimilarity (index)	Abundance (high grazed % low grazed)	Diversity (high grazed /low grazed)	Richness (high grazed/low grazed)	Dominance (high grazed/low grazed)	N
By region							
Great Plains	487	0.40	38	1.18	1.02	1.12	38
Southwest[1]	362	0.54	3	0.91	0.90	1.29	4
Northwest[1]	154	0.54	–22	1.25	1.14	0.83	6
Other grasslands	—[2]	0.54	–33	1.10	0.93	0.96	10
By evolutionary history							
Short history	617	0.53	–27	1.06	0.90	0.98	21
Long history	487	0.40	38	1.18	1.02	1.13	37
By life form							
Grassland	483	0.43	30	1.18	1.02	1.09	40
Shrubland	291	0.45	–5	1.10	1.03	1.01	11
Forest	1 182	0.52	–45	0.96	0.68	1.06	7
By community type							
Shortgrass steppe	357	0.29	36	0.94	0.83	1.13	6
Mixed-grass prairie	416	0.35	–2	0.91	0.90	1.25	23
Tallgrass prairie	988	0.61	217	2.52	1.71	0.59	6
Fescue grassland	383	0.60	–31	1.06	1.00	1.09	2
Coastal prairie	—[2]	0.42	–9	0.96	0.54	0.72	2
Southwest grassland	362	0.54	3	0.91	0.90	1.29	4
Shadscale shrubland	154	0.42	–31	1.49	1.43	0.62	2

[1]Northwest includes the Great Basin and all communities west of the Rocky Mountains, except for Arizona, New Mexico, and southern California, which are considered Southwest.

[2]Number of sites reporting precipitation too few to provide a reasonable mean.

horned larks respond positively to increasing grazing intensity in shortgrass steppe, while lark buntings respond negatively (Fig. 4A). Chestnut-collared long-spurs respond positively to increasing grazing intensity in mixed-grass prairie, while savannah sparrows respond negatively (Fig. 4B). The greatest abundance of bird species in tallgrass prairie occurred at intermediate intensities of grazing (Fig. 4C). While species within a site respond differently to grazing intensity, a particular species may also have a varied response among sites. Knopf (1996) suggested that birds may not be generally classified as increasers or decreasers in response to grazing, but that individual species responses to grazing may vary over gradients of potential vegetation structure or aboveground primary production. Although there are examples for regional differences in bird species response to grazing, Derner et al. (unpublished data) concluded that data over gradients of grazing intensity and regional gradients of primary production are too limited to produce good models of bird preferences for particular grazing intensities at particular levels of primary production. Reviews by Bock et al. (1993) and Saab et al. (1995) provide tables of bird species by region within the western United States that show general positive, negative, primary productivity–dependent, or neutral/mixed/uncertain responses to grazing.

At the community level, the change in bird community composition relative to the ungrazed or lightly grazed condition usually increased with increasing grazing intensity (Fig. 5A; Table 1). However, dissimilarity was generally greater when the communities were ungrazed compared to lightly or moderately grazed than when grazing intensity further increased to moderate or heavy. Total bird community abundance showed both positive and negative responses with increasing grazing intensity across and within community types as anticipated (Fig. 5B). Bird community diversity was generally slightly negative with increasing grazing intensity (Fig. 5C). Exceptions were observed for one tallgrass prairie study and some mixed-grass prairie sites where slightly greater diversity occurred at intermediate levels of grazing intensity. In addition to these general diversity patterns, management decisions need to explicitly evaluate the specific habitat needs of bird species of concern.

Most studies of grazing effects on upland game birds (gallinaceous birds) addressed ungrazed versus grazed conditions rather than grazing intensity gradients, much like research for all other wildlife groups. Based on two studies, wild turkeys prefer ungrazed/lightly grazed vegetation and avoid moderately/heavily grazed areas. Similarly, heavy grazing was consistently detrimental to sharp-tailed grouse (three subspecies) because of a loss of nesting cover and tree and shrub density (based on 10 studies reviewed in Kessler and Bosch 1982). There are contrasting positive and negative results from ungrazed/grazed studies for sage grouse and prairie chickens, but sage grouse appear to prefer light/moderate grazed areas over heavy grazed areas, but very high cover in some ungrazed habitat may be avoided as well (some reviewed in Beck and Mitchell 2000). Historical evidence suggests that grazing is detrimental to quail species in the southwestern United States, but recent studies indicate that light to moderate grazing intensities may be beneficial to Mearn's quail by increasing availability of food resources. Montezuma quail prefer high grass cover and tree density, while scaled quail prefer high grass cover and low tree density. In contrast, five studies of bobwhite quail in Texas (see Bryant et al. 1982) suggest that grazing is beneficial if intensities are not too high. In summary, heavy grazing most often results in loss of cover below some optimal level for gallinaceous birds, although light grazing may be beneficial under some circumstances.

Small Mammals. Small mammals can be sensitive to changes in vegetation structure, but they may also be affected by grazing

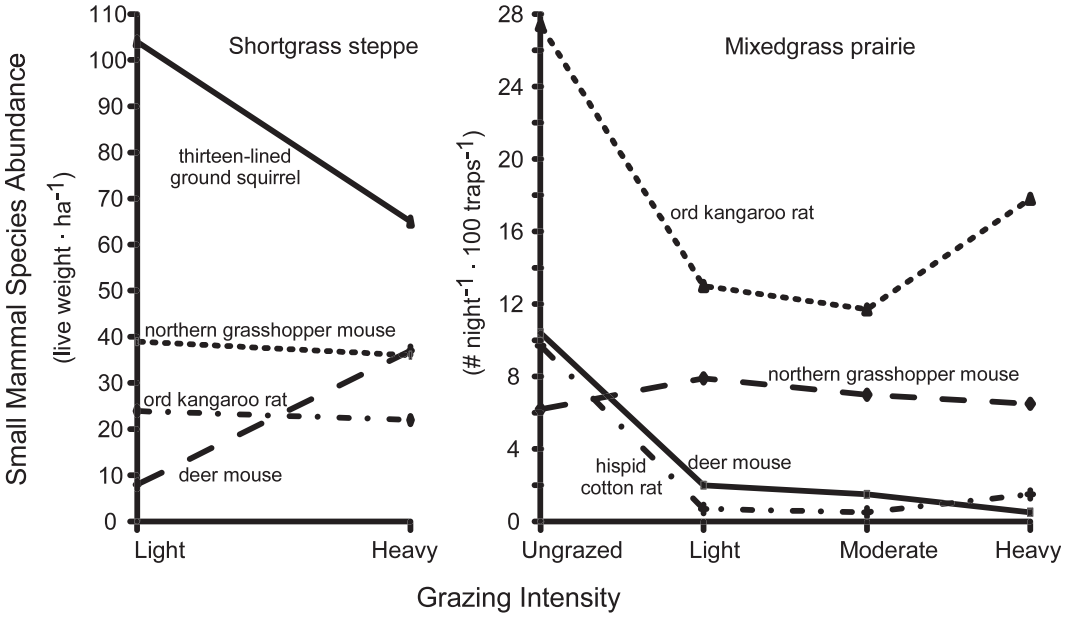


FIGURE 6. Rodent species abundance across grazing intensities in (**A**) shortgrass steppe and (**B**) mixed-grass prairie. Drawn from data in McCulloch (1959) and Grant et al. (1982).

TABLE 2. Rodent community dissimilarity, abundance (numbers), diversity, richness, and dominance in response to grazing averaged by region, evolutionary history of grazing, plant community life form, and plant community type. Forests were not included in region or evolutionary history categories. Plant community types are for major groupings or those with more than one comparison (from Derner et al., unpublished data).

Rodents	Dissimilarity (index)	Abundance (high grazed % low grazed)	Diversity (high grazed/low grazed)	Richness (high grazed/low grazed)	Dominance (high grazed/ low grazed)	Unique species (high grazed/low grazed)	N
By region							
Great Plains	0.35	–27	0.99	0.89	1.11	–2.0	14
Southwest[1]	0.34	24	0.89	0.85	1.41	–1.0	6
Northwest[1]	0.43	8	0.81	0.95	1.60	–0.8	19
By evolutionary history							
Short history	0.41	12	0.83	0.93	1.55	–0.9	25
Long history	0.35	–27	0.99	0.87	1.11	–2.0	14
By life form							
Desert	0.18	–43	0.85	0.73	1.40	–1.5	2
Grassland	0.34	13	0.73	0.92	1.30	–1.4	4
Shrubland	0.38	–0	0.73	0.76	1.62	–1.7	12
Savanna	0.43	14	0.92	1.51	1.53	1.0	3
Forest	0.30	–55	0.82	0.75	0.96	–1.0	2
By community							
Shortgrass steppe	0.19	–9	1.24	1.0	0.68	0.0	1
Mixed-grass prairie	0.32	–18	0.81	0.78	1.29	–2.9	9
Grassland	0.47	–13	0.79	0.62	1.53	–5.8	4
Sand sage shrub	0.19	–23	0.82	0.91	1.10	–0.6	5
Tallgrass prairie	0.48	–50	1.34	1.1	0.80	–0.5	4
Desert grassland	0.41	58	0.91	0.92	1.41	–0.8	4
Shadscale shrubland	0.53	1	0.57	0.6	2.36	–2.0	2
Atriplex shrubland	0.52	–27	0.63	0.96	1.81	0.0	2
Sagebrush shrubland	0.30	30	0.76	0.86	1.49	–1.5	6
Northwest grassland[2]	0.34	13	0.73	0.95	1.30	–0.3	4

[1]Northwest includes the Great Basin and all communities west of the Rocky Mountains, except for Arizona, New Mexico, and southern California, which are considered Southwest.

[2]See Savanna for Northwest savannas.

induced modification of seed and arthropod food resources. Derner et al. (unpublished data) reviewed 24 rodent studies/habitats from the literature, and only six included more than one grazing intensity in addition to long-term ungrazed exclosures. The responses of individual species of small mammals to grazing intensities are similar to birds, but they differ from birds at the community level. Like birds, some rodent species are favored by grazing, some decline, and others are relatively neutral (Fig. 6 A and B). The response of some

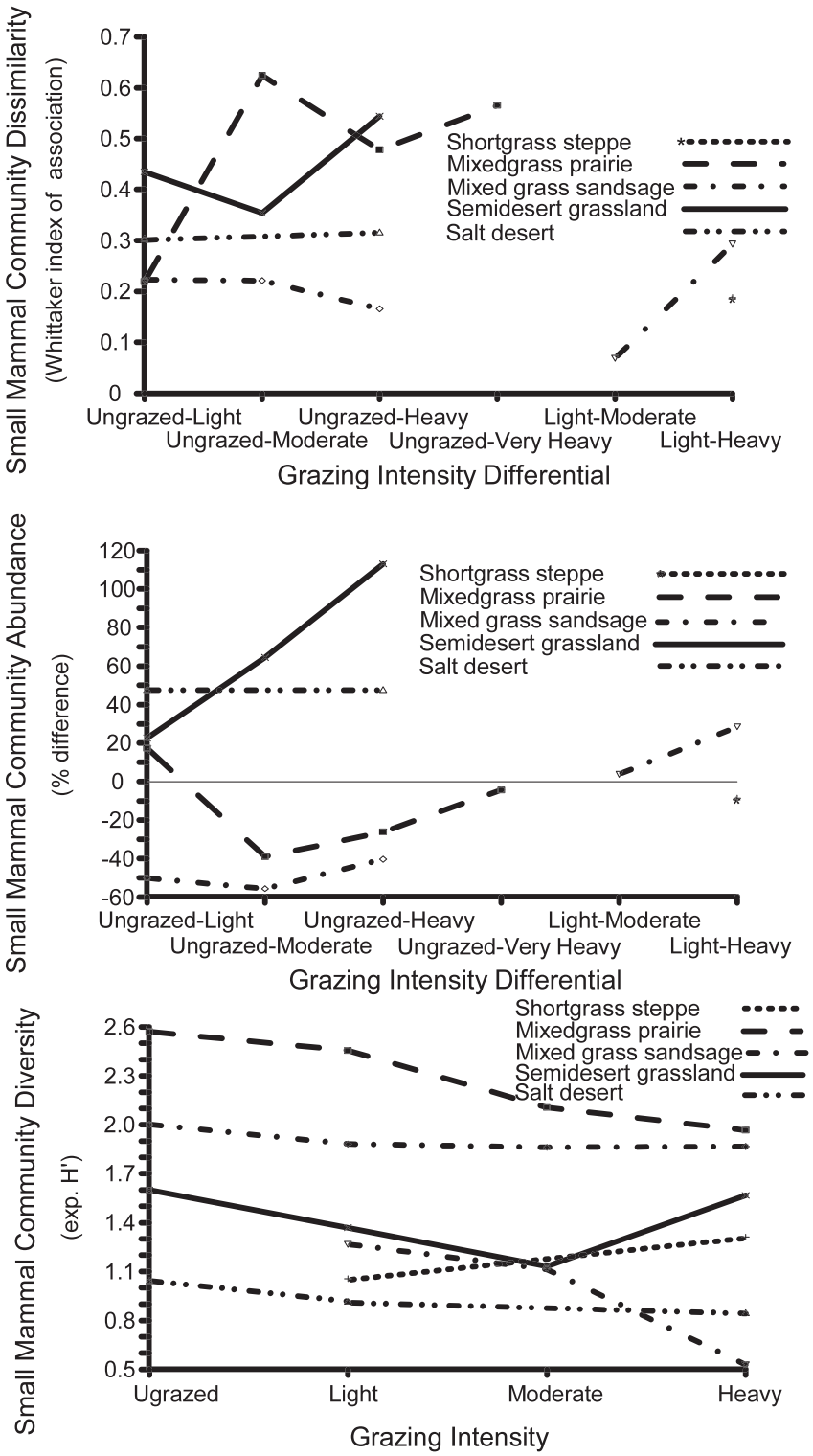


FIGURE 7. Rodent community (**A**) dissimilarity (Whittaker [1952] index of community association), (**B**) abundance (% difference between grazing intensity differential), and (**C**) diversity (H′) across grazing intensity gradients for North America studies. Dissimilarity index values range from 0.0 to 1.0, with a value of 0 indicating both treatments having all species in common and in the same proportions (0% dissimilar) and a value of 1.0 indicating no species in common (100% dissimilar). Data from Frank (1940), Smith (1940), McCulloch (1959), Grant et al. (1982), Rice and Smith (1988), and Bich et al. (1995).

species to grazing intensity can be substantial. Generalizations concerning rodent responses to livestock grazing intensity are less developed than those for birds, in part because of fewer studies but also because of less consistent population responses.

Derner et al. (unpublished data) assessed the number of rodent species unique to various grazing intensities to evaluate the general patterns of declining rodent diversity with increasing grazing intensity. Greater numbers of species were likely to be captured on ungrazed or lightly grazed communities than on moderately or heavily grazed communities. However, 19 of 41 cases also displayed species unique to the more intensively grazed communities as well, but in only five cases was the total number of unique species greater on the more intensively grazed community. The net effects by region and evolutionary history were unique and unexpected. The numbers of unique species associated with heavy grazing were smaller in the Great Plains than in the Southwest or Northwest and in ecoregions with long rather than short evolutionary histories of grazing (Table 2). Deserts, grasslands, and shrublands displayed somewhat similar reductions in rodent species with increasing grazing intensity, and the losses were greater compared to savannas and forests. The greatest reductions in rodent species with increasing grazing intensities occurred in mixed-grass prairie. In general, no consistent trends could be discerned for changes in rodent species composition with grazing intensity relative to ungrazed or lightly grazed condition (dissimilarity; Fig. 7A) or abundance; Fig. 7B). Rodent diversity generally declines or is unchanged with increasing grazing intensity, with the exception of a shortgrass steppe study (Fig. 7C). Declines in rodent diversity with grazing intensity were only small to moderate when they were observed.

Bird responses to grazing are highly species specific and positive, negative and neutral outcomes occur. (Photo: USDA: Gary Kramer)

Other Small Mammals. Heavily grazed or "overgrazed" communities are generally preferred over ungrazed or lightly grazed communities by black-tailed jackrabbits in eastern Texas (Taylor and Lay 1944), the Mojave Desert in California (Brooks 1999), the sand hills of Colorado (Sanderson 1959), and southern Arizona (Taylor et al. 1935) and by Great Plains jackrabbits in mixed-grass (Smith 1940) and tallgrass prairie (Phillips 1936) of Oklahoma. Schmutz et al. (1992) observed that rabbits became more abundant as range conditions deteriorated in desert grassland. MacMahon and Wagner (1985) suggested that many areas of the Chihuahuan and Sonoran deserts initially altered by fire suppression and livestock grazing do not return to previous conditions when large herbivores are excluded because lagomorphs and rodents, favored by the initial changes, maintain the vegetation at early seral stages. In contrast, Flinders and Hansen (1975) found that cottontail rabbits were more abundant in moderately than in either lightly or heavily grazed shortgrass steppe, white-tailed jackrabbits showed no preference, and black-tailed jackrabbits were more abundant in lightly and moderately compared to heavily grazed communities. Changes beneficial to rabbits with increasing grazing intensity include increased rabbit mobility and improved forage due to increases in annuals.

Wild Ungulates. There is a large body of research addressing dietary and habitat use overlap between livestock and deer and elk. In general, high dietary overlap is observed between cattle or sheep and elk, compared with much lower overlap between cattle or sheep and deer (Skovlin et al. 1968; Mackie 1970; MacCracken and Hansen 1981; Berg and Hudson 1982; Loft et al. 1991). However, dietary overlap between deer and cattle can increase with increasing intensity of cattle grazing (Mackie 1981; Vavra et al. 1982; Severson and Medina 1983). Habitat use is often separated in time because of seasonal migrations of deer and elk and in space because of topography or cover requirements (Skovlin et al. 1968; Mackie 1970; Berg and Hudson 1982). For example, mule deer, elk, and cattle observations on slopes steeper than 10 degrees averaged 50%, 42%, and 18%, respectively. Dietary overlap between domestic and native herbivores is generally greatest during the period in which the herbivores are most nutritionally stressed (Olsen and Hansen 1977; Mackie 1981), and habitat overlap is most likely to occur when wildlife are at lower elevations during winter, which often represents the period of greatest nutritional stress (Wallmo et al. 1981).

Increasing grazing intensities by livestock are likely to create a bottleneck in the quantity and quality of forage for wild ungulates during nutritionally stressed periods (e.g., winter or drought). More generalist, large-rumen livestock are better able to utilize dormant grass forage than deer under conditions of low forage availability in heavily compared to moderately or lightly stocked pastures (MacMahan and Ramsey 1965). Dietary overlap between cattle

and pronghorn is low, and Schwartz et al. (1977) found that pronghorn were able to maintain seasonal diet qualities on long-term pastures heavily grazed by cattle similar to what they did on lightly grazed pastures in shortgrass steppe under nondrought conditions. In contrast, a pronghorn die-off was attributed to very heavy grazing by domestic animals during a drought (Hailey et al. 1966). Other studies of livestock grazing effects on pronghorn populations also show mixed responses.

In contrast, habitat overlap is a prerequisite to facilitation of one herbivore by another. Positive or facilitative effects of livestock grazing on associated wildlife species may result from a reduction in the amount of unpalatable, standing dead material (Short and Knight 2003) or increased protein content and digestibility of forage available late in the season (Clark et al. 2000; see below). Both competition and facilitation can act simultaneously, and competition can be the strongest factor (Hobbs et al. 1995). Longer-term facilitative relationships may be based on a dichotomy in diet preference of grass versus forbs and shrubs. For example, grazing by deer and livestock can potentially shift community composition toward a composition favored by other species of herbivores.

Grazing can potentially be used as a tool to enhance wildlife populations, and this may be particularly true when season of grazing or deferment of grazing is used to meet specific wildlife goals. In some situations, wildlife and livestock may overlap in habitat use only during particular times of the year. For examples, breeding birds may nest only during spring/early summer and require specific conditions during that time. Elk and deer may move down from forested mountainous habitat during the winter to occupy foothills and plains more likely to be used for livestock grazing. Grazing may be imposed or deferred, depending on cover and foraging requirements of specific species. Some waterfowl or some upland game species require dense nesting cover, whereas some birds, such as mountain plover or curlews, choose nesting sites with very little cover and will not nest in ungrazed or lightly grazed habitat. Many of the examples of season-of-use studies come from wildlife refuges or experimental sites where livestock use is optional and management options are flexible.

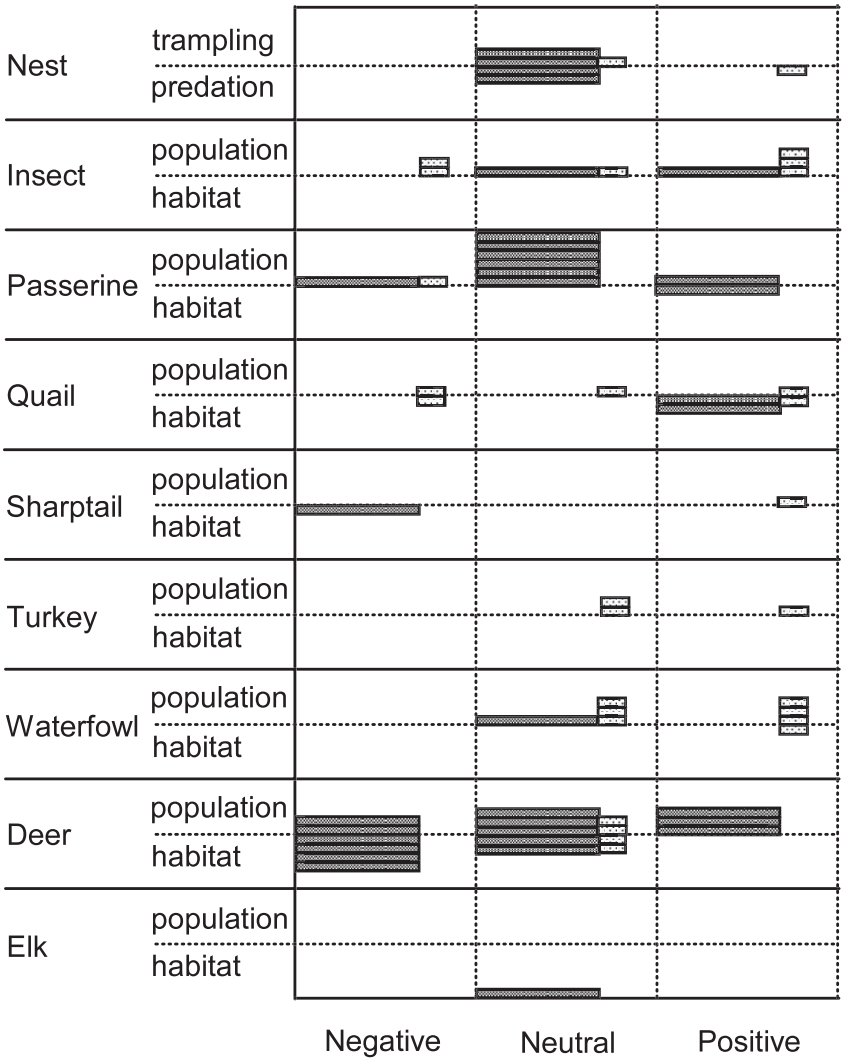


FIGURE 8. Responses of nine wildlife categories to rotational compared to continuous livestock grazing systems summarized as neutral, negative, or positive. Each wildlife category is subdivided into a population (upper) and a habitat (lower) section to indicate the mechanism of livestock impact. The large dark bars represent studies without confounding experimental designs, and the small lightly shaded bars represent studies with design problems. Each study may have one to four response variables, so each bar does not represent a single study.

Successful use of season of grazing may result from a facilitation effect of grazing by livestock on forage for other ungulates. Alpe et al. (1999) showed that early summer grazing improved forage quality for wild ungulates in autumn and winter if livestock was removed in time to allow sufficient regrowth, but that late season livestock grazing decreased forage quality for wild

ungulates. Successful use of season/deferment of grazing may also be possible when pastures that are not frequently used by wildlife are available; otherwise the removal of livestock from one pasture must outweigh the effects of increased stocking rate in adjacent pastures. Even in these cases, experimental outcomes can be neutral, positive, negative, or mixed, depending on wildlife species or timing of grazing (Medin 1986; Alpe et al. 1999; Mathis et al. 2006).

Grazing Systems. Wildlife responses to rotational and continuous grazing at relatively similar grazing intensities and within similar plant communities are evaluated in this section. Studies investigating different pastures within the same grazing system are also considered separately and clearly identified when used. Studies are organized by wildlife taxonomic groups and summarized across all groups and mechanisms for positive, neutral, or negative responses to grazing system.

Birds. Although passerine birds represent the most studied group of wildlife in response to grazing intensity (see section above), only two published studies of rotational compared to continuous grazing were located. However, there are a number of unpublished theses, studies within pastures of an individual system or that compare rotational grazing with ungrazed communities that were not considered here. The dissertation of Kempema (2007) was unique because it assessed several grazing periods of increasing duration, so it is summarized here. These studies report that passerine responses to grazing systems compared to continuous grazing were most often neutral (Fig. 8). The rotational systems had the least vegetative heterogeneity at both small and large spatial scales because of the reduced capacity for selective grazing at the bite and patch scale by livestock compared to continuous grazing. This was accompanied by a decrease in bird species richness with decreasing duration of grazing (long-continuous richest). In contrast, the short-duration system had the highest densities of the most species. For most bird species (11), there was no significant grazing system effect on density, and for the three species that showed significant density effects, the responses were both positive and negative. Nest success was also similar among the three grazing systems. The small number of passerine studies specifically conducted in grazing systems precludes the development of general conclusions.

Ungulate responses to grazing are equivocal so that no broad conclusions can be drawn. (Photo: USDA: Gary Kramer)

Grazing systems studies on gallinaceous birds frequently evaluated nest trampling or nest predation, often conducted with artificial nests. All studies without confounded designs show neutral responses to grazing system (Fig. 8). Larger densities of livestock in smaller pastures of rotational systems do not appear to increase trampling losses under the densities and in the habitats studied. A higher density of livestock in some pastures and longer rests in others appears to produce a similar mean effect. Trampling of nests is often found to increase linearly with stocking density (Bientema and Müskens 1987; Paine et al. 1996; Kempema 2007), and the ecological significance of nest trampling is greater in more productive ecosystems that support greater stocking density. In contrast, Koerth et al. (1983) found trampling losses of nests to be similar between short-duration and continuous grazing, even though the short-duration system was stocked at a higher rate (5.3 vs. 8.0 ha · steer^{-1}). Nest trampling may not be linear with stocking density because livestock

may travel less in smaller pastures (Koerth et al. 1983 and citations therein). Alternatively, a reduction in diet selection may increase search time exploring new pastures during repeated rotations (Spalinger and Hobbs 1992; Wilmshurst et al. 1999), and large herd size may result in more temporally constant activity levels among livestock (Paine et al. 1996).

Direct studies of population or habitat responses between grazing systems are few, but positive responses have been reported for rotational grazing systems compared to continuous grazing for bobwhite quail in response to increased bare ground and greater forb densities (Fig. 8). There are too few studies for sharptail or turkey to draw any meaningful conclusions concerning the effect of grazing system. No grazing systems studies were found for prairie chickens or sage grouse, but some management recommendations have been made, including multiyear periods of rest to restore vegetative cover (Hagen et al. 2004).

Vegetative cover is an important habitat requirement for waterfowl, although very dense vegetation can be detrimental to nest-site selection (Kantrud 1990). Ignatiuk and Duncan (2001) observed no difference in duck nest success in an extensive study of once-over rest-rotation or deferred-rotation systems and continuous grazing, while additional studies compared only pastures within grazing systems or conditions following changes in grazing regime (Fig. 8). When rest periods were from 1 to 3 yr, Gilbert et al. (1996) observed increasing duck nest densities with increasing years of rest, and regression analyses suggested that a 6- to 7-yr rest would be necessary for recovery to that of an ungrazed condition. Other waterfowl studies with confounding experimental designs also suggest that long rest periods may be beneficial, but there are too few waterfowl studies of grazing systems to form robust conclusions.

Large Ungulates. Grazing systems research has been conducted with elk, deer, and pronghorn antelope, but the pronghorn study compared rest-rotation only with ungrazed pastures. Eight studies that included 18 response variables were found comparing grazing systems with continuous grazing for deer. The most common deer response to grazing system was negative, followed by neutral and then positive responses (Fig. 8). However, population-level responses for deer were equally split between positive and neutral for rotational compared to continuous grazing. Studies assessing habitat characteristics important to deer were most often negative in rotational grazing systems compared to continuous. Only one grazing system study reported on social avoidance by deer, and it showed deer–livestock competition in the short-duration system compared to continuous grazing that was attributed to habitat modification rather than deer leaving the pasture (Cohen et al. 1989). Responses of deer to rotational systems are generally mixed so that no clear trends can be established.

Only one study was located that directly compared elk responses in a deferred-rotation grazing system compared to season-long grazing and found no significant response when averaged over grazing intensities (Fig. 8) but did find a highly significant interaction of grazing system with grazing intensity (Skovlin et al. 1968, 1975, 1983). Elk preferred season-long to deferred rotation at the light grazing intensity, but preferred deferred to season-long rotation at the high grazing intensity. Elk utilized individual plants that had not been grazed by cattle, and cattle use of numbers of individual plants at the low grazing intensity was greater under the rotation system. Forage quantity and preference for areas receiving little or no prior current-year use by livestock can regulate elk movement across larger landscapes as well (Mackie 1970). These results and the observation that elk preference strongly increased with decreasing grazing intensity even from light to ungrazed treatments are in accordance with the within-system studies showing a high degree of elk sensitivity to livestock grazing intensity and selection for ungrazed units or treatments, unutilized/little utilized areas within grazed pastures, and ungrazed individual plants. However, the studies within various pastures of a single rotational grazing system are often cited to support rotational grazing as benefiting elk populations. Three of these studies found no social avoidance between elk and livestock for selection of ungrazed pastures. Livestock grazing facilitated use by elk the year following grazing in two studies, and elk avoided currently and previously grazed pastures in the other study.

> "…the most frequent wildlife response was no differences between continuous and rotational grazing systems, with the remaining cases equally divided among positive and negative."

"The response of soil organic carbon to stocking rate is equivocal, based partially on the limited number of investigations that have been conducted."

Summary of Wildlife and Grazing Systems. The limited number of available studies does not permit generalizations concerning wildlife responses to grazing systems and when or where or for which species positive, negative, or neutral responses may be predicted. There appear to be many false claims and few valid studies in the literature (Kirby et al. 1992), and this assessment applies to the literature addressing wildlife responses to grazing systems. Collectively, comparative wildlife responses to rotational and continuous grazing were that 17 showed no difference, eight were negative, and eight were positive (Fig. 8). These experimental data indicate that the most frequent wildlife response was no differences between continuous and rotational grazing systems, with the remaining cases equally divided among positive and negative. However, most wildlife groups showed mixed responses to grazing system, and it is clear that there are conditions where rotational grazing systems benefit a wildlife species or group, but the opposite response is documented as well. Much more is known about wildlife responses to grazing intensities than grazing systems, but even here the majority of studies assess grazed and long-term ungrazed communities, which are generally not relevant to prescribed grazing management (Krausman et al., this volume).

Manage Fine Fuel Loads to Achieve Desired Conditions

Grazing does reduce fine fuel loads, and it can therefore modify both fire frequency and intensity (Belsky and Blumenthal 1997; Briggs et al. 2002; Fuhlendorf and Engle 2004). This interpretation is supported by the well-documented inverse relationship between stocking rate and aboveground herbaceous standing crop (Bement 1969; Milchunas and Lauenroth 1993; Manley et al. 1997; Derner and Hart 2007). It is often hypothesized that woody plant encroachment is partially a consequence of reduced fire regimes associated with livestock grazing (Scholes and Archer 1997; Swetnam and Betancourt 1998; Briggs et al. 2005). However, beyond these broad generalizations, there are only limited experiential data to support grazing as a means of fuel management (Belsky and Blumenthal 1997; Davies et al. 2010). This is perhaps not that surprising given that fire–grazing interactions are strongly influenced by site, year, season, and specific fire conditions (Davies et al. 2009).

Patterns of fire and grazing appear to be critically linked on the landscape (Fuhlendorf and Engle 2004). Grazing may increase the variability on fire occurrence by reducing the amount and increasing the heterogeneity of fine fuel distribution (Holdo et al. 2009). Grazed patches have less fine fuel that is less likely to burn than ungrazed patches that contain larger amounts of combustible fine fuel (Collins and Smith 2006; Kirby et al. 2007). However, grazing increased fuel homogeneity in a bunchgrass-dominated rangeland by reducing biomass of individual plants to a greater extent than biomass in the plant interspaces (Davies et al. 2010).

Weather and fuel conditions further increase the complexity of the relationship between fuel load and fire frequency and intensity. For example, fine fuel load is strongly correlated with fire intensity when fuel moisture is held constant, but when fuel moisture is low, intense fires can be carried by much lower fuel loads (Twidwell et al. 2009). This will be influenced by the season, time of day, and specific weather conditions associated with individual fires. It is no coincidence that most wildfires occur during extreme fire conditions; during these extreme conditions, fire can be carried by a wide range of fuel loads. Therefore, it should not be assumed that fire frequency and intensity decrease linearly with decreasing fuel loads resulting from greater grazing intensities.

The relative proportions of fine and coarse fuel loads can also influence the relationship between grazing and fire frequency and intensity. Woody plant encroachment is often associated with a reduction in the amount of fine fuel, but coarse fuel loads often increase substantially (Hibbard et al. 2001; Norris et al. 2001; Briggs et al. 2002). Although coarse fuels have higher ignition temperatures, closed-canopy woodlands can be highly flammable during extreme fire conditions. Therefore, the role of grazing as a tool for fuel management is generally supported, but it should be cautiously evaluated on a case-by-case basis because fire potential in influenced by interactions among several ecosystem variables (Fuhlendorf et al., this volume).

ASSOCIATED CONSIDERATIONS

Livestock Distribution

Animal selectivity and foraging behavior within landscapes has received considerable attention on rangelands (Bailey et al. 1996; Launchbaugh and Howery 2005). Herbivores naturally select preferred plants and landscape positions over others (Van Soest 1994), resulting in differential patterns of species use within communities and management units when stocking rates are not excessive and pastures are of sufficient size (Bailey et al. 1996; Launchbaugh and Howery 2005). Rangelands have traditionally been managed to increase uniformity of vegetation use by livestock and maximize livestock gains within the limits of individual animal performance and long-term ecosystem sustainability (Bement 1969). This management approach has been effective and sustainable from the standpoint of livestock and forage production (e.g., Hart and Ashby 1998), but it often does not mimic the pattern of historic disturbance regimes (Fuhlendorf and Engle 2001) or create habitat structure required for many grassland bird species (Knopf 1996; see Deferment and Rest section below). Livestock distribution and grazing behavior can be modified by adjusting the location of supplemental feed and water, implementation of patch burns, and herding (Williams 1954; Ganskopp 2001; Fuhlendorf and Engle 2004; Bailey 2005) in addition to the traditional practice of fencing.

Experimental data evaluating the most critical variables associated with livestock distribution were evaluated from 51 studies and two reviews. Treatment responses were categorized into 1) general distribution effects, 2) steep-slope use, 3) high-elevation use, 4) distance from water, 5) plant preferences, 6) uniformity of grazing, and 7) riparian use. All 51 studies were short term (< 5 yr), and the vast majority of them used cattle as the livestock species (41). Pasture sizes used in these investigations were generally large (22 > 200 ha). Recent investigations have incorporated technological advances involving GPS devices (e.g., collars) to track individual animal movement to provide spatial- and temporal-explicit use patterns. Strategies for modifying patterns of livestock distribution have shifted from specific practices (e.g., fences, salt, and water placement) to the modification of animal behavior (e.g., attractants, genetic selection, breeds, and type of animal) over the past two decades. Livestock distribution in response to specific conservation practices have received relatively little attention with the exception of prescribed burning (see Fuhlendorf et al., this volume).

The experimental data verify that many of the common assumptions regarding livestock distribution and preferences for specific sites

Rangelands play an important role in the global carbon cycle because of the large reservoirs of organic and inorganic carbon they contain. (Photo: Brandon Bestelmeyer)

Prescribed grazing must balance the forage demand of animals with the physiological requirements of plants to be sustainable. (Photo: USDA: Lynn Betts)

and conditions are valid. Water distribution (11 of 15 studies), steep slopes, and high elevations (13 of 17 studies) unequivocally influenced livestock distribution. Livestock by and large prefer riparian to upland areas (e.g., Bowns 1971; Smith et al. 1992; Howery et al. 1996, 1998), burned to nonburned areas (Coppedge and Shaw 1998; Biondini et al. 1999), previously grazed compared to ungrazed areas (Ganskoppp and Bohnert 2006), and fertilized to nonfertilized areas (Samuel et al. 1980). Range riding and/or herding of animals also effectively modified livestock distribution (Skovlin 1957; Bailey et al. 2008). A clear exception to these generalizations is that salt location has only a minor influence on grazing distribution within a growing season (five of seven studies; Ganskopp 2001). Standard approaches to modifying livestock distribution are warranted, but it appears that they can only minimize animal selection and preferences rather than completely eliminate them (Jensen et al. 1990a).

Grazing and Soil Organic Carbon

Rangelands play an important role in the global C cycle because of 1) an extensive land area, 2) large reservoir of sequestered C that could be released back into the atmosphere with improper management, 3) potential for high rates of soil organic carbon (SOC) accumulation by restoration of degraded rangelands, and 4) a vast pool of soil inorganic C as carbonates in semiarid and arid rangeland soils that may allow sequestration or release of CO_2 (Schuman et al. 1999; Derner and Schuman 2007; Svejcar et al. 2008). SOC sequestration is influenced by climate (Derner et al. 2006), biome type (Conant et al. 2001), management (grazing, N inputs, restoration, and fire; Follett et al. 2001; Mortenson et al. 2004; Derner and Schuman 2007; Bremer and Ham 2010; Pineiro et al. 2010), and environmental conditions (drought and climate change; Jones and Donnelly 2004; Ingram et al. 2008; Svejcar et al. 2008). Rangelands are typically characterized by short periods of high C uptake (2–3 mo $\cdot$ yr^{-1}), long periods of C balance or small losses (Svejcar et al. 2008), and climate-driven interannual variability in net ecosystem exchange (Zhang et al. 2010). Three main drivers that will control the fate of C sequestration in rangelands are 1) long-term changes in production and quality of above- and belowground biomass; 2) long-term changes in the global environment, such as rising temperatures, altered precipitation patterns, and rising CO_2 concentrations, that affect plant community composition and forage quality; and 3) effects of short-term weather conditions (e.g., droughts) and interannual variability in climate on net C exchange (Ciais et al. 2005; Soussana and Lüschert 2007; Ingram et al. 2008; Svejcar et al. 2008; Zhang et al. 2010).

Application of appropriate management practices, such as proper stocking rates, adaptive management, and destocking during drought conditions on poorly managed rangelands (113 M ha), could result in sequestration of 11 Tg C · yr^{-1}, and continuation of sustainable management practices on the remaining rangelands would avoid losses of 43 Tg C · yr^{-1} (Schuman et al. 2001).

SOC sequestration rates decrease with longevity of the management practice (Derner and Schuman 2007), indicating that ecosystems reach a "steady state" and that changes in inputs would be required to sequester additional C (Conant et al. 2001, 2003; Swift 2001). The response of SOC to stocking rate is equivocal, based partially on the limited number of investigations that have been conducted. Sixty-two percent (five of eight) of the investigations showed no response of SOC to stocking rate (Smoliak et al. 1972; Wood and Blackburn 1984; Warren et al. 1986a; Biondini et al. 1998; Schuman et al. 1999) with one showing a decrease (Ingram et al. 2008) and two showing an increase in response to increasing stocking rate (Manley et al. 1995; Reeder and Schuman 2002). The two investigations showing an increase in SOC with increasing stocking rate occurred in the northern mixed-grass prairie during a relatively wet period (Manley et al. 1995; Reeder and Schuman 2002). It has been demonstrated that increasing SOC in these grasslands may partially result from increasing dominance of the shallow-rooted, grazing-resistant species blue grama (*Bouteloua gracilis*), which incorporates a larger amount of root mass in the upper soil profile than do midgrass species that it replaces (Derner et al. 2006). In a global analysis, Milchunas and Lauenroth (1993) found that in 19 of 34 comparisons, SOC was less in grazed than ungrazed communities, and results were similarly mixed for root biomass.

Contributions of Individual Plant Research to Grazing Management

Many of the assumptions on which grazing management is founded originated from defoliation experiments conducted with individual plants. Suppression of plant photosynthesis, root growth cessation, support of regrowth by carbohydrate reserves, and regulation of tillering by apical dominance represent several of the major assumptions (Briske and Richards 1995). The relevance of these individual plant-based assumptions to grazing management has recently been questioned in an assessment of plant and animal production responses to grazing systems (Briske et al. 2008). In several instances, these plant-based assumptions have shown little correspondence with the outcomes observed in grazing systems. Since the development of these plant-based assumptions in the mid-20th century, some have been substantiated, but others have been refuted from the vantage point of greater scientific understanding derived from more sophisticated experimental techniques. Several plant-based assumptions that have been validated and invalidated are summarized below. Unfortunately, these assumptions often prevail long after they have been refuted by substantial experimental evidence.

Valid Plant-Based Interpretations. Numerous plant-based interpretations were developed early in the profession to cope with widespread overgrazing and rangeland degradation that prevailed in the late 19th and early 20th centuries. These were often based on observation and general inference because knowledge of plant physiology was very limited during this period and did not substantially improve until the mid-20th century. Several of the more important plant-based interpretations that have been supported by current science are summarized below.

Leaf Removal and Subsequent Growth. Photosynthetic leaf area provides the energy source for plant growth and reductions in leaf area suppress both plant photosynthesis and growth (Sampson 1923). This interpretation has been well supported with additional insights addressing the various contributions of leaf canopy position and leaf age (Caldwell et al. 1981; Gold and Caldwell 1989). The validity and consequences of this well-established process are reflected in the adverse effects of severe and multiple defoliations on plant growth within a growing season.

An important caveat associated with plant defoliation experiments, even when conducted with field-grown plants, is that the defoliation intensities imposed are often very severe compared to actual defoliation

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patterns documented in the field. Eight of 12 defoliation studies evaluated defoliated plants at ≤6 cm, and three of these eight defoliation intensities were imposed on large tallgrass species. This suggests that while this research is valuable for understanding mechanisms of plant response to defoliation, caution should be used in translating these responses to actual grazing management applications.

Root Growth and Function. Root growth and function are increasingly suppressed with increasing intensity and frequency of defoliation because they are entirely dependent on energy derived from photosynthesis (Crider 1955). This interpretation has also been well supported by subsequent research investigating specific physiological mechanisms, including root respiration and nutrient absorption kinetics (Ryle and Powell 1975; Macduff et al. 1989). However, even though suppression of root growth following severe defoliation of individual plants is well established, the evidence that intensive defoliation suppresses root biomass within plant communities remains equivocal (Milchunas and Lauenroth 1993; McNaughton et al. 1998; Johnson and Matchett 2001). A specific mechanism has not been provided for this inconsistency, but it likely has to do with compensating root growth by less intensively grazed plants within the community or a shift in species composition to species that allocate a greater proportion of biomass belowground. Contrasting grazing responses between individual plants and communities demonstrates that caution should be used when extrapolating individual plant responses to communities and ecosystems.

Defoliation-Induced Competitive Interactions. The ability of disproportionate defoliation intensity among adjacent plants to modify intra- and interspecific competitive interactions to favor less severely grazed plants was initially proposed by Mueggler (1972). This interpretation has been substantiated with more recent and sophisticated research using isotopes of phosphorous (Caldwell et al. 1985, 1987) and nitrogen (Hendon and Briske 2002) demonstrating that both the frequency and intensity of defoliation can modify belowground competition. This series of physiological effects on competitive interactions is partially reflected in the widely observed patterns of increaser and decreaser plant species and grazing-induced changes in the species composition of plant communities.

Invalid Plant-Based Interpretations. Several well-established interpretations derived from individual plant response to defoliation have been invalidated with the advent of more sophisticated experimental procedures. This brief summary of refuted interpretations is intended not to criticize this early work, but merely to indicate that the knowledge base supporting grazing management has and will continue to advance as more research information is obtained.

Apical Dominance and Tillering. Apical dominance was promoted as the primary mechanism controlling tiller initiation following defoliation of perennial grasses. It was based on the direct hypothesis of auxin action indicating that removal of the apical meristem terminated supply of the growth inhibitor auxin to the axillary buds near the base of the tiller and thereby allowed their outgrowth into new tillers (Leopold 1949). Physiologists considered this concept invalid in the 1950s, Jameson (1963) concluded that this interpretation of apical dominance was not supported by evidence for rangeland grasses, and this conclusion was corroborated by a larger data synthesis of perennial grasses (Murphy and Briske 1992). The traditional concept of apical dominance as applied in grazing management was a partial and overly restrictive interpretation of tiller initiation in perennial grasses. A complete understanding of the mechanisms contributing to tiller initiation is yet to be developed, but it is likely a multivariable processes regulated by several interacting physiological and environmental variables (Tomlinson and O'Connor 2004).

Carbohydrate Reserves as Indicators of Regrowth. Carbohydrate reserves were proposed as an index of potential plant regrowth, and this concept was frequently applied in grazing management during the latter half of the 20th century and is still applied in limited cases. Since carbohydrate reserves decrease following plant defoliation, it was widely assumed that they must be

a major source of carbon supporting leaf regrowth (Briske and Richards 1995). A more thorough evaluation of plant carbon balance indicated that root carbohydrates were used primarily within root systems rather than being allocated aboveground to support regrowth and that reserve pools of perennial grasses contained very small amounts of carbon that contributed to regrowth for only 1–3 d before leaf photosynthesis once again became the primary carbon source (Richards and Caldwell 1985). Moreover, it appears that a consistent, positive relationship between the size of the carbon reserve pools and grass regrowth had never been established in support of this widely used interpretation (Busso et al. 1990). In retrospect, the concept of carbohydrate reserves was founded on an oversimplified interpretation of carbohydrate patterns in grasses, and it never had great relevance to grazing management. Residual leaf area and the availability of meristems, in the presence of favorable environmental conditions, are now recognized to provide more reliable indicators of plant regrowth following defoliation (Briske and Richards 1995). Ironically, emphasis on the maintenance of carbohydrate reserves in perennial grasses inadvertently applied these valid indicators of plant growth and thereby indirectly contributed to efficient grazing management.

The hierarchical structure of ecological systems describes the nested levels of ecological organization that coincide with increasing complexity and interaction among components within systems. This hierarchical structure determines why it is possible for even well-established processes at the level of individual plants to not directly translate to communities and ecosystems. For example, recall that the well-established reduction in root growth following intensive defoliation of individual plants is not consistently expressed as a reduction of root biomass within grazed communities (Milchunas and Lauenroth 1993; McNaughton et al. 1998). This inconsistent response suggests that processes and interactions within populations or communities are overriding or mitigating the negative root response of at least some of the plant species. Reductionist investigations of individual plants produce valuable mechanistic insights, but they may be too narrow in scope to identify important interactions and trade-offs at higher scales to make them relevant for direct management application (Briske 1991). Plant-based research over the past century indicates that grazing management recommendations should not be developed exclusively from processes derived at the individual plant level without at least partial verification of the anticipated response within communities or ecosystems. This is a rather sobering conclusion after nearly a century of individual plant-oriented research, but it does provide evidence of maturation and progress within the rangeland profession.

RECOMMENDATIONS

The following recommendations have emerged from our evaluation of the benefits of NRCS prescribed grazing practices with the relevant experimental literature. They are presented to enhance the effectiveness of the current conservation planning standard and to emphasize the CEAP goals addressing environmental quality of managed lands, including the assessment of multiple ecosystem services.

Priorities and Approaches to Conservation Planning

Conservation planning would benefit from a substantial shift in priorities that deemphasize the independent development of facilitating practices (e.g., fencing, roads, and pipelines) and reemphasize integration of these practices with adaptive management decisions (e.g., stocking rate, drought management, and monitoring) to promote environmental quality of rangelands as recommended by CEAP. With the clear exception of improved livestock distribution, there is no indication that facilitating practices alone directly promote effective environmental conservation. The function of grazed ecosystems is similarly controlled by several dominant environmental variables, albeit over diverse social and environmental conditions, that are expressed in dynamic forage production patterns within and among years establishing that management decisions, especially during critical periods, can have profound effects on grazed ecosystems. The environmental variables and many of the social variables cannot be directly managed, but

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recognition and planning for their occurrence with effective adaptive management plans at both the tactical and the strategic level can minimize their detrimental consequences to both production and conservation goals. Increased development and delivery of contingency planning protocols are required to effectively cope with these variable conditions common to most grazing enterprises. These tools should emphasize dynamic stocking rate determinations and provisions to support flexible management strategies, including effective destocking and restocking tactics and the potential to develop reserve forage supplies (e.g., Sharrow and Seefeldt 2006; Hanselka et al. 2009; Torell et al. 2010).

We recommend that additional decision support tools and guidelines be developed to inform adaptive grazing management decisions, especially during critical events and seasons. Current information and technology will support development of novel, comprehensive approaches for implementing dynamic stocking rate determinations that can be effectively incorporated into management plans and monitored by landowners. An undertaking of this magnitude will require investment of considerable intellectual and financial capital, but the experimental evidence strongly confirms that site-appropriate stocking rates represent the very foundation of sustainable grazing management and associated conservation benefits. These tools could target specific landowners via conservation planning or be more generally accessible through AFGC, (American Forage and Grassland Council), GLCI (Grazing Lands Conservation Initiative), SRM (Society for Range Management), or SWCS (Soil and Water Conservation Society) publications and venues or made available on NRCS websites. Incentives could be variously structured to encourage use and adoption of these tools and approaches. Conservation plans may even require participation in a set number of instructional activities to attain and maintain program eligibility.

Forage Inventory Assessment and Monitoring

Development and implementation of forage inventory and monitoring protocols in grazed ecosystems requires greater emphasis. This will require that the process of balancing forage production with animal demand be placed in the broadest possible context to include forage inventory, seasonal plant growth dynamics, and drought management over both short- and long-term periods (e.g., Sharrow and Seefeldt 2006; Hanselka et al. 2009). Static seasonal or annual stocking rates provide a broad reference, but they are insufficient to addresses wide seasonal and interannual variation in forage production common to most rangelands. Consequently, emphasis on static stocking rates results in systems being over- or understocked the majority of the time (Hart and Ashby 1998). Spatial variability of forage production, associated with variation in soils, landscape position, and local precipitation patterns, also minimizes the value of static, regional stocking rates. Use of the grazing pressure index, describing animal units per unit of forage mass over a period of time, has been recommended to standardize stocking rates and improve clarity of animal–forage relationships (Smart et al. 2010).

Stocking rates based on residual forage, determined as a percentage of site-specific annual forage productivity, minimizes the probability of over- and undergrazing at both spatial and temporal scales (Bement 1969; Clary and Leininger 2000). Management based on residual forage ensures sufficient vegetative cover to protect soils during drought and dormant seasons, enhances the capacity for plant regrowth, and provides food and cover for wildlife during stress periods. Stocking rates established to promote environmental quality on rangelands may also promote heterogeneity in structure and diversity of flora and fauna because livestock are less likely to graze uniformly across local topographic–plant community gradients within pastures.

Experimental information and available technology support development of a comprehensive approach for implementing dynamic stocking rate determinations that can be effectively incorporated into management plans with landowner participation. An undertaking of this magnitude will require investment of considerable intellectual and financial capital, but the experimental evidence directly confirm that site-appropriate stocking rates represent the very foundation of sustainable grazing management and

associated conservation benefits. Management for appropriate stocking rates not only supports conservation goals, but it also forms the basis for effective drought management strategies and sustainable long-term economic returns (Manley et al. 1997; Hart and Ashby 1998; Torell et al. 2010).

Alternative approaches are required to more directly and effectively incorporate dynamic, site-specific stocking rate assessments into overall management strategies and conservation planning. Landowner incentives could be provided to encourage adoption of forage inventory and monitoring as well as the grazing adjustments suggested by these protocols. These tools and guidelines are required to more closely estimate actual forage utilization or grazing intensity so that this information can be integrated into an adaptive management framework that emphasizes and supports flexible grazing management. Existing annual forage production curves emphasizing specific reference points that are critical to the attainment of various management and conservation goals (e.g., midpoint and end of growing season, critical wildlife requirements, and sensitivity of riparian zones) require greater attention and user friendly access. Readily accessible monthly and seasonal precipitation probabilities derived from long-term regional climatic records would also support forage inventory decisions (Andales et al. 2006). These tools may represent simple, direct measures of forage availability as well as more complicated procedures to forecast drought and forage production that could be implemented in various combinations at various temporal and spatial scales. Specific recommendations to support dynamic stocking rate determinations and promote adaptive management are summarized below.

Estimation of Residual Biomass to Determine Grazing Intensity. Estimates of residual forage could be used as a means to determine site- and period-specific stocking rates and grazing intensities, especially during drought conditions. This is a well-established management procedure that has a strong ecological basis focused on soil protection, continued surface hydrological function, and maintenance of sufficient residual plant material to provide a source of regrowth when rainfall occurs (Bement 1969; Bartolome et al. 1980; Blackburn 1984; Gifford 1985; Clary and Leininger 2000). Recommendations could be incorporated within conservation plans requesting that land managers periodically monitor residual biomass, at intervals and locations relevant to management objectives, following a prescribed set of procedures. These residual biomass records could be maintained as part of the ongoing conservation plan to support longer-term stocking rate adjustments and overall adaptive management (Bement 1969; Clary and Leininger 2000).

Forage Production and Drought Forecasting. Major technical advances have occurred in the forecasting of forage production and drought that could be used to support both tactical (within the growing season) and strategic (multiple growing seasons) grazing management decisions at regional levels. Forage production models such as GPFARM (Great Plains Framework for Agricultural Resource Management; Andales et al. 2006) could be linked with 6–14-d, 1-mo, and 3-mo precipitation and temperature forecasts through the NOAA Climate Prediction Center (http://www.cpc.noaa.gov/index.php) to provide regional projections of forage availability. Drought projections are also provided by US Drought Monitor (http://www.drought.unl.edu/DM/monitor.html) and the Vegetation Drought Response Index (http://drought.unl.edu/vegdri/VegDRI_Main.htm). This index integrates satellite-based (MODIS) observations of vegetation conditions based on NDVI, climate data, and other biophysical information, such as land cover/land use type and soil characteristics. Maps of the Vegetation Drought Response Index have been produced every 2 wk beginning in 2009 throughout the conterminous United States that deliver continuous geographic coverage over large areas, provide regional to subcounty-scale information of drought effects on vegetation, and have inherently finer spatial detail (1-km^2 resolution) than other commonly available drought indicators, such as the US Drought Monitor. Incorporation of soil water forecasts (http://www.cpc.ncep.noaa.gov/products/Soilmst_ Monitoring/US/Soilmst/Soilmst.shtml) could further promote the accuracy of these forage production projections. Forage projections could be developed for

> "The vast majority of experimental results indicate that there is no clear advantage of any one grazing system over another in terms of ecological benefits."

The importance of effective tactical and strategic decisions to successful grazing management is widely acknowledged, but only poorly documented. (Photo: Alexander Smart)

specific periods of management interest and provide probabilities for forage responses to dry, average, and wet conditions to ascertain various levels of management risk. Forecast information could interface with existing forage production curves previously developed by the NRCS to generate various forage inventory projections to inform management planning.

Drought Contingency Planning. It is essential that monitoring protocols be linked to drought contingency planning and management actions. It is widely recognized that the commonly employed strategy of "optimistic inaction" regarding stocking rate adjustments in response to developing drought is a major contributor to long-term rangeland degradation (Stafford Smith and Foran 1992; Thurow and Taylor 1999; Torell et al. 2010). However, it is irresponsible to delay or fail to implement drought contingency planning based on the unpredictability of drought given its frequent occurrence on most rangelands (Thurow and Taylor 1999). Renewed emphasis on drought contingency planning must integrate both economic and ecological considerations to effectively encourage managers to adopt and implement destocking options in relation to drought.

Conservative stocking rates and the formation of reserve forage or grass banks are well-established strategies for contending with economic and environmental aversion to drought risk (Thurow and Taylor 1999). During normal or wet years, these grass banks could serve as restoration programs to support prescribed burning or to promote critical ecosystem services (i.e., biodiversity and carbon sequestration). Flexible stocking is also an effective means to cope with variable precipitation and forage production (Stafford Smith and Foran 1992; Torell et al. 2010). Cow-calf herds should represent only a conservative component of total livestock holdings because of the high cost of adjusting cow numbers relative to the potential for short-term gain. Equal forage allocation to cow-calf and stockers has been recommended for ranching operations in the western United States (Torell et al. 2010). It is important to recognize that flexible stocking conveys additional costs and financial risks that will require specific decision-making tools to expand its adoption, and it may not be appropriate for risk-averse managers (Tanaka et al., this volume).

The Role of Grazing Systems

It is extremely difficult to experimentally mimic livestock movements and defoliation patterns associated with various applications of grazing strategies used by managers. However, grazing systems research has carefully evaluated the ecological responses of individual plants and communities, including wildlife populations, soils and surface soil hydrology, and their feedbacks on livestock performance, including forage intake and weight gain per animal and per unit area. These major ecological variables integrate numerous ecosystem processes sufficiently well to provide reliable guidance for the implementation and evaluation of the ecological consequences associated with grazing systems. The vast majority of experimental results indicate that there is no clear advantage of any one grazing system over another in terms of ecological benefits. Conclusions derived from these experimental data provide a sufficient basis to establish ecological guidelines for the evaluation and application of grazing systems in conservation planning and ecosystem assessment. These data directly corroborate the long-standing conclusions that weather

variability and stocking rate account for the majority of variation associated with plant and animal production and species composition changes on rangelands (Heitschmidt and Taylor 1991; Holechek et al. 2001; Derner and Hart 2007). This interpretation further emphasizes the importance of effective adaptive management to the successful operation of grazed ecosystems, including the establishment of clear goals, monitoring of resource conditions, and the ability to make appropriate and timely management adjustments. Stated in another way, there is no indication that grazing systems possess unique properties that enable them to compensate for poor management (Briske et al. 2008).

This interpretation also emphasizes that it is not sufficient to evaluate only whether grazing management is effective; we also need to determine why it is effective. This information is essential to guide development of effective conservation practices by determining whether emphasis should be focused on facilitating practices or on adaptive management skills. Although largely undocumented, the importance of effective adaptive management to successful grazing management is widely acknowledged, and it requires much greater emphasis than it has received (Stuth 1991; Brunson and Burritt 2009; Hanselka et al. 2009). Both research and monitoring are required on ranch-scale operations to more clearly evaluate the contribution of adaptive management to the success of conservation practices and to investigate the interaction between adaptive management and various grazing systems at the ranch level (e.g., Jacobo et al. 2006).

Deferment and Rest

Few evidence-based conclusions can be drawn regarding the appropriate season for grazing deferment and the benefits of long-term rest. This is partially illustrated by the inconsistent vegetation responses associated with the application of rest-rotation systems (Holechek et al. 2001). Minimal advantages may have resulted because one season of complete rest may not have been sufficient to compensate for more intensive use of grazed pastures in previous years. Vegetation responses to season of grazing and deferment are highly dependent on 1) the timing and amount of precipitation received during the growing season, 2) the intensity of defoliation, and 3) the opportunity for regrowth following defoliation. Research is required to quantify the benefits of long-term rest (> 1 yr) and alternating seasons of pasture use in successive years. Limited evidence suggests that exclusion of livestock is not necessary for recovery from moderate drought on well-conditioned rangeland (Heitschmidt et al. 2005; Gillen and Sims 2006), but it may be beneficial following severe drought that has induced substantial tiller and plant mortality (Dalgleish and Hartnett 2006; Yahdjian et al. 2006). Plants subject to light and moderate grazing often show less drought-induced mortality than plants that have been severely grazed prior to drought (Albertson et al. 1957).

Grazing can potentially be used as a tool to manage wildlife populations, and this may be particularly true when season of grazing or deferment of grazing is used to meet specific wildlife goals. Seasonal livestock use may especially benefit wildlife where only part of the range is desirable wildlife habitat and social avoidance or seasonal migration are important considerations, facilitation through improved forage quality has been demonstrated, or specific nesting requirements are an issue. In these cases livestock grazing may be imposed or deferred, depending on cover and foraging requirements of specific wildlife species. For example, some waterfowl or some upland game species require dense nesting cover, whereas some birds, such as mountain plover or curlews, choose nesting sites with very little cover and will not nest in ungrazed or lightly grazed habitat. Successful use of seasonal and deferred grazing may also be possible when pastures with limited wildlife value are available to minimize livestock use in adjacent pastures that contain critical wildlife habitat.

Stronger Linkages between Science and Management

NRCS Conservation Practice Standards should be routinely informed by both scientific and management knowledge external to the agency to ensure that the most current and vetted information available is incorporated into the conservation planning process. This represents a formidable challenge because science and management are not directly comparable endeavors (Provenza 1991), and this may partially explain why

> "The knowledge gaps identified in this synthesis need to be at least partial addressed to promote the development and adoption of more effective conservation practices in grazed ecosystems."

The diverse ecosystem services originating from rangelands require greater recognition and valuation. (Photo: USDA: Gary Kramer)

stronger science–management linkages have not been forged in the rangeland profession. Experimental research has focused on specific aspects of grazing management, including stocking rate, grazing system, and livestock distribution, in a static and independent manner, rather than on their dynamic interaction within adaptively managed ecosystems. The critical but poorly defined contribution of adaptive management to grazed ecosystems is a major impediment to the development of linkages between research and management because decision making is often excluded from experimental research even though it is central to grazing management (Briske et al. 2008; Brunson and Burritt 2009). Research requires systematic collection of information to document outcomes of various grazing strategies, while the outcomes of conservation practices standards are seldom monitored and documented. This often results in the difficult task of comparing quantitative research results with qualitative and often anecdotal management information. New organizational structures are needed to bridge the gap between research and management to support and incentivize a more comprehensive framework for conservation planning (Boyd and Svejcar 2009; Svejcar and Havstad 2009). The NRCS may wish to adopt a more formal research–management framework to address conservation programming that could be convened each time a conservation practice standard undergoes reevaluation.

Substantial differences between rangeland science and management have presented barriers to their integration throughout the history of the rangeland profession. The extensive

synthesis of experimental information provided in this document and the science–management partnership forged by this 3.5-yr undertaking represents an important initial step in attaining this goal. Greater integration and information exchange among researchers and managers would create a "win–win" situation for the profession by facilitating development of evidence-based conservation practices. This represents a necessary step if Conservation Practice Standards are to effectively adopt CEAP recommendations to provide regular assessments of the societal benefits of taxpayer investments in conservation practices. It would also enable the management community to play a more direct role in establishing the rangeland research agenda, as suggested in the following section. Effective monitoring of conservation practice outcomes will be crucial for enhancement of science–management linkages by providing a quantitative source of information exchange between these two groups.

KNOWLEDGE GAPS

The following knowledge gaps were identified in the process of summarizing and interpreting the experimental literature associated with prescribed grazing. It is anticipated that by highlighting these poorly understood issues, they may receive additional research attention and funding to promote greater understanding. It is critical that these knowledge gaps be at least partially addressed to promote the development and adoption of more effective conservation practices in grazed ecosystems.

Ecosystem Processes and Services in Grazed Ecosystems

Traditionally, grazing research has focused on several ecological variables, including plant and animal production and, to a lesser extent, patterns of species composition change and wildlife responses and habitat. These variables provide a valuable, but admittedly narrow foundation on which to assess ecosystem services and environmental quality in grazed ecosystems. Research programs designed to increase our understanding of ecosystem processes and the provisioning of ecosystem services are desperately needed. Relevant topics include plant functional groups, soil health and sustainability, biodiversity, carbon sequestration, greenhouse gas emissions, drought and drought recovery, and spatial heterogeneity of ecosystem and landscape structure.

Ecosystem Restoration and Conservation Strategies

Even though grazing management was initiated to halt and reverse the adverse effects of overgrazing on rangeland ecosystems, restoration of grazed ecosystems has received limited research attention in the past several decades. Research has been focused primarily on optimization of livestock production during the past 30 yr with use of intensified grazing systems. Consequently, experimental information regarding the season of utilization or deferment that is most appropriate to restore degraded ecosystems or to promote various conservation strategies is limited. Research addressing individual bunchgrass responses to defoliation in the field indicates that mid-growing season is the most sensitive period for defoliation. However, we are unaware of community-level field studies that corroborate this conclusion. Similarly, individual plant research has imposed very severe defoliation intensities compared to observed utilization rates in grazed ecosystems so that the direct application of these results to management is limited. Plant, community, and ecosystem responses to realistic grazing patterns would benefit from further documentation.

Contributions of Adaptive Management

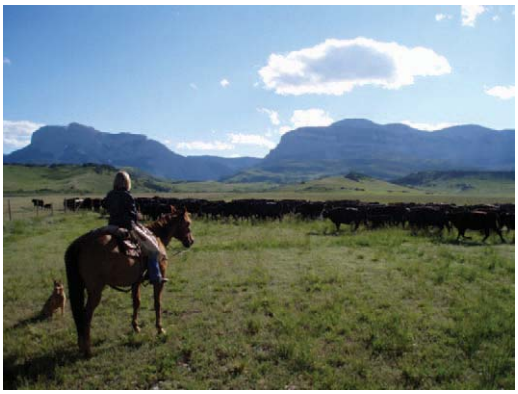
Management goals, abilities, and opportunities as well as personal goals and values (e.g., human dimensions) are inextricably integrated within grazing management, and they are likely to interact with the adoption and operation of grazing systems to an equal or greater extent than the underlying ecological processes (Briske et al. 2008). Therefore, research and monitoring approaches need to explicitly document the contribution of adaptive management within ecosystems to promote a more comprehensive understanding of successful grazing management (Brunson and Burritt 2009; Budd and Thorpe 2009). The potential synergistic effects of grazing systems and adaptive management inputs have not been examined experimentally at the level of the ranch enterprise (Briske et al. 2008; Brunson

"Research and monitoring approaches need to explicitly document the contribution of adaptive management within ecosystems to promote a more comprehensive understanding of successful grazing management."

and Burritt 2009). Successful research in this area will require direct involvement of social and political scientists addressing these critical human dimensions issues and their interactions with ecological systems. A novel experimental approach used by Jacobo et al. (2006) compared adjacent ranches that had employed unique grazing systems to achieve the optimal production outcome. The strength of this approach is that it enables researchers to evaluate outcomes reflecting the entire ranch enterprise, including the capacity to adaptively manage for the best possible outcomes, within the context of the respective grazing system. This approach simultaneously evaluates ecological and managerial responses, but it has yet to be determined whether it will be possible to distinguish between these two responses. Similarly, incentives and barriers of various social institutions influencing the adoption of conservation practices have received minimal research emphasis given their importance to the management of complex adaptive systems (Stafford Smith et al. 2007).

Evaluation of Large-Scale Ecosystem Responses

Grazing research has not adequately assessed the effects of grazing at large scales (Bailey et al. 1996; Archibald et al. 2005), which often demonstrate the occurrence of patch- and area-specific grazing. Smaller experimental pastures usually result in more uniform distribution of grazing intensity, which may not appropriately describe how domestic grazing animals utilize large landscapes or, in the case of native ungulates, how they migrate regionally. The direct application of research results obtained in small-scale experiments (< 200 ha) to large ranch enterprises may not be entirely appropriate because the ecological processes of interest often do not scale in a linear fashion (Fuhlendorf and Smeins 1999; Peters et al. 2006). Investigations of the potential benefits of grazing systems at large scales require further evaluation, and the evaluation metrics should involve a variety of ecosystem services, such as firm-level production, biodiversity concerns, watershed function, and wildlife habitat.



Current NRCS grazing practices are appropriate in many respects, but multiple opportunities exist to improve their effectiveness. (Photo: Sonja Smith)

Integration of Complex Ecosystem Components

The complexity of grazed ecosystems resides in the broad array of interacting variables associated with both ecological and human systems. A wide range of ecological variation is associated with rainfall regime (i.e., amount, seasonality, and intra- and interannual variability), vegetation structure, composition, and productivity and soils, prior land use, and livestock characteristics (i.e., breeds, prior conditioning, and previous experience). This tremendous ecological variability is paralleled by large, but unappreciated variability associated with the commitment, ability, goals, and opportunities of managers and associated stakeholders dependent on the services of these ecosystems (Briske et al. 2008; Brunson and Burritt 2009). The success and benefits that accrue from conservation practices within these complex systems is dependent on three unique activities. First, the conservation practices must be based on sound managerial and ecological principles; second, practices must be effectively incorporated into the overall conservation plan; and, third, they must be appropriately applied, maintained, and monitored by ecosystem managers. The third component addressing manager or landowner commitment and capability is most widely overlooked and can be addressed only from a human dimensions perspective.

A robust ecosystem management framework capable of accommodating both ecological processes and human activities, as well as their interactions, is required to conceptualize, interpret and manage complex adaptive systems characteristic of rangelands. This will require the development of an information base that consists of local knowledge, management and policy experience, and science-based information mediated through an adaptive institutional framework

(Herrick and Sarukhan 2007; Reynolds et al. 2007). This framework must be coupled with current and emerging technologies to provide estimates of remotely sensed data to address multiple feedbacks between the social and ecological components at several scales. Ecological site descriptions may provide the platform on which to integrate these sources of information, but the rangeland profession is lacking an institutional structure to house and coordinate relevant ecosystem components and processes at landscape and regional scales (Bestelmeyer et al., this volume). Approaches that involve integration of ecological scales and human dimensions, coupled with effective monitoring protocols capable of evaluating both ecological and social metrics, will likely drive the next major advance in effective rangeland stewardship.

CONCLUSIONS

An extensive evaluation of the published experimental evidence relevant to grazing management broadly supports the overall USDA-NRCS approach to prescribed grazing and validates the ecological foundations of many of the purposes addressed in this conservation practice standard. The equivocal nature of a portion of these findings is a consequence of experimental research and conservation planning pursuing different objectives, with unique approaches that are often conducted at different scales and an unfortunate legacy of minimal interaction between science and management within the rangeland profession. Nevertheless, inferences drawn from these experimental data indicate that the NRCS conservation purposes addressing prescribed grazing can potentially be realized, if implemented appropriately, as indicated by the ability for grazing management practices to affect all seven stated conservation purposes. The challenge of grazing management is establishing the appropriate relationships between various management practices and the intended purposes or outcomes, in diverse environmental and social conditions, especially when multiple and often competing purposes are involved.

The experimental data unequivocally document that stocking rate, coupled with effective livestock distribution, is the single most important management variable influencing production and conservation goals in grazed ecosystems. Therefore, guidelines, tools and incentives that promote appropriate management decisions have the potential to enhance the effectiveness of conservation outcomes and increase the cost–benefit ratio of conservation investments. Guidelines promoting the goal of balancing forage production with animal demand should be placed in the broadest possible context to include forage inventory, seasonal plant growth dynamics, and drought management over both the short and the long term. Existing annual forage production curves emphasizing specific reference points that are critical to the attainment of various management and conservation goals, supported by monthly and seasonal precipitation probabilities, require greater emphasis and user-friendly access to support forage inventory decisions. The adoption of this approach will require a major shift in NRCS programmatic emphasis from those promoting facilitating practices in the form of infrastructure development to those promoting timely and effective adaptive management actions.

Experimental evidence indicates that grazing systems, in the absence of adaptive management, explain little additional variability beyond that of stocking rate and weather variation for the variables of plant and animal production, species composition of plant communities, soil surface hydrological function, and wildlife populations. In addition, the major assumptions on which short-duration rotational grazing is partially based, including greater control over grazing patterns, minimization of multiple defoliations within individual grazing periods, and greater forage quality, have received only equivocal experimental support. Current evidence suggests that implementation of grazing systems, without incorporation of the additional elements of prescribed grazing, is insufficient to address the array of complex and dynamic conditions inherent to grazed ecosystems. However, the potential contributions of grazing systems to broader conservation goals and ecosystem services, at landscape or regional scales, and their potential

> "CEAP provides an excellent platform to promote greater science–management integration by bringing together researchers and NRCS personnel for an evidence-based assessment of Conservation Practice Standards"

interactions with adaptive management have yet to be evaluated.

Several important knowledge gaps have been identified in the experimental literature associated with prescribed grazing. These include 1) grazing effects on ecosystem services, 2) ecosystem restoration and conservation strategies, 3) contributions of adaptive management actions, 4) evaluation of larger-scale ecosystem responses, and 5) integration of information within complex ecosystems. The greatest deficiency encountered in this evaluation of supporting experimental data was the paucity of information documenting the impact of adaptive management on grazing management effectiveness and conservation outcomes. It is critical that these knowledge gaps be at least partially resolved in the near future to promote further advances in the ecology and management of grazed ecosystems.

The overarching conclusion of this assessment is that even though the current conservation practices for prescribed grazing are appropriate in many respects, reorganization to implement three major modifications would greatly increase their effectiveness. First, greater emphasis should be placed on programs to support management skills and management effectiveness beyond that of financial incentives supporting the independent development of infrastructure. There is no clear indication that installation of facilitating practices in the form of water developments and fencing directly contribute to conservation benefits in the absence effective management. Second, a system of regular and frequent monitoring needs to be incorporated into conservation planning to directly assess both the short-term and the long-term benefits derived from conservation practices. Monitoring information will directly support adaptive management to optimize conservation outcomes per unit investments and document the ecological benefits of conservation practices on the nation's rangelands as recommended by CEAP. Third, incorporate the intent and recommendations of CEAP by focusing on environmental quality, ecosystem services, and societal benefits associated with prescribed grazing in addition to sustainable production outcomes (e.g., Dunn et al. 2010).

Revisions to this conservation practice standard should be informed by both scientific and management knowledge external to the agency to ensure that the most current and vetted information available is incorporated into conservation planning and assessment procedures. CEAP provides an excellent platform to promote greater science–management integration by bringing together researchers and NRCS personnel, as well as other stakeholders, for an evidence-based assessment of Conservation Practice Standards and approaches to conservation planning. We recommend that this integrated science–management team approach should be formalized in the agency and used to revise Conservation Practice Standards and set priorities and goals for conservation planning.

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APPENDIX I A.

Published experiments used to evaluate plant and animal production to continuous grazing (CG) and rotational grazing (RG) at (a) equal stocking rates and (b) higher stocking rates for rotational grazing. See Figure 3 for a graphical presentation of the comparative results (modified from Briske et al. 2008).

Study	Location	Ecosystem	Length (yr)	Grazing system
Stocking rate equal for rotational and continuous grazing				
McCollum et al. (1999)	Oklahoma	Tallgrass prairie	5	Short-duration grazing (SDG)
Gillen et al. (1998)	Oklahoma	Tallgrass prairie	5	SDG
Cassels et al. (1995)	Oklahoma	Tallgrass prairie	5	SDG
Owensby et al. (1973)	Kansas	Tallgrass prairie	17	Deferred rotation
Wood and Blackburn (1984)		Southern mixed-grass prairie	5	High-intensity/low-frequency and deferred rotation
Kothmann et al. (1971)	Texas	Southern mixed-grass prairie	8	Merrill
Merrill (1954)	Texas	Southern mixed-grass prairie	4	Merrill
Fisher and Marion (1951)	Texas	Southern mixed-grass prairie	8	Rotational
McIlvain and Savage (1951)	Oklahoma	Southern mixed-grass prairie	9	Rotational
Derner and Hart (2007a)	Wyoming	Northern mixed-grass prairie	25	SDG
Manley et al. (1997)	Wyoming	Northern mixed-grass prairie	13	SDG and deferred rotation
Biondini and Manske (1996)	North Dakota	Northern mixed-grass prairie	6	SDG
Hart et al. (1993)	Wyoming	Northern mixed-grass prairie	5	SDG
Hepworth et al. (1991)	Wyoming	Northern mixed-grass prairie	4	SDG and deferred rotation
Hart et al. (1988)	Wyoming	Northern mixed-grass prairie	6	SDG and deferred rotation
Rogler (1951)	North Dakota	Northern mixed-grass prairie	25	Deferred rotation
Derner and Hart (2007b)	Colorado	Shortgrass prairie	9	SDG
Smoliak (1960)	Alberta, Canada	Shortgrass prairie	9	Deferred rotation
Hubbard (1951)	Alberta, Canada	Shortgrass prairie	6	Deferred rotation
Laycock and Conrad (1981)	Utah	Sagebrush–grassland	7	Rest-rotation
Hyder and Sawyer (1951)	Oregon	Sagebrush–grassland	11	Rotational
Holechek et al. (1987)	Oregon	Mountain rangeland	5	Rest-rotation and deferred rotation
Murray and Klemmedson (1968)	Idaho	Cheatgrass (*Bromus tectorum*) dominated	3	Seasonal rotation
Martin and Severson (1988)	Arizona	Grass–shrub complex	13	Santa Rita, 1-herd, 3-pasture, 3-yr rotation
Martin and Ward (1976)	Arizona	Desert grassland	7	Alternate-year seasonal rest
Winder and Beck (1990)	New Mexico	Semidesert	17	3-pasture rotation
Gutman et al. (1990)	Israel	Mediterranean grassland	2	Rotational
Gutman and Seligman (1979)	Israel	Mediterranean Foothill Range	10	Rotational
Ratliff (1986)	California	Annual grassland	8	Rotational

	No. of paddocks in rotation	Size of paddocks (ha)	Plant production/standing crop	Livestock production per head	Livestock production per land area
	8	1.8–3.3		CG > RG	CG > RG
	8	1.8–3.3	ND		
	8	1.8–3.3	ND at peak standing crop RG > CG at end of grazing season		
	3	24	RG > CG	CG > RG	CG > RG
	4	120	ND		
	4	?		RG > CG	RG > CG
	4	24		ND	ND
	5	4		ND	ND
	3	6.7–10		ND	ND
	8	1–2	ND		
	4–8	1–3	ND	ND	ND
	6	32	ND		
	8	24		ND	ND
	4–8	1–3		ND	ND
	4–8	1–3	ND	ND	ND
	3	9.4		RG > CG	RG > CG
	7	65		ND	ND
	2	61	ND	CG > RG	CG > RG
	3	27–40		ND	ND
	3	447–777	ND	ND	ND
	3	850		CG > RG	CG > RG
	2	57–67		ND	ND
	4	?	ND	ND	ND
	3	308–1 979	ND		
	24	0.004	ND		
	3	?		ND	ND
	6	25.5–33.0	ND	CG > RG	CG > RG
	3	25.5–33.8	ND	ND	ND
	3	30	ND	CG > RG	CG > RG

APPENDIX I A. *continued*

Study	Location	Ecosystem	Length (yr)	Grazing system
Stocking rate equal for rotational and continuous grazing				
Heady (1961)	California	Annual grassland	5	Deferred rotation
Barnes and Denny (1991)	Zimbabwe	Veld	6	SDG
Fourie and Engels (1986)	South Africa	Veld	4	SDG
Fourie et al. (1985)	South Africa	Veld	4	SDG
Kreuter et al. (1984)	South Africa	Veld	3	SDG
Walker and Scott (1968)	Tanzania		2	Rotational
Bogdan and Kidner (1967)	Kenya	Woodland–grassland	5	Rotational, deferred rotational
Higher stocking rate for rotational grazing				
Jacobo et al. (2000)	Argentina	Temperate grasslands	3	SDG
Heitschmidt et al. (1987)	Texas	Southern mixed-grass prairie	4	SDG
Heitschmidt et al. (1982a)	Texas	Southern mixed-grass prairie	2	SDG
Heitschmidt et al. (1982b)	Texas	Southern mixed-grass prairie	19	Merrill
Reardon and Merrill (1976)	Texas	Southern mixed-grass prairie	20	Deferred rotation
Hirschfeld et al. (1996)	North Dakota	Northern mixed-grass prairie	2	SDG
Volesky et al. (1990)	South Dakota	Northern mixed-grass prairie	2	SDG
Kirby et al. (1986)	North Dakota	Northern mixed-grass prairie	2	SDG
White et al. (1991)	New Mexico	Blue grama	6	SDG
Pitts and Bryant (1987)	Texas	Shortgrass prairie	4	SDG
Anderson (1988)	New Mexico	Tobosa (*Hilaria mutica*) dominated	2	SDG

APPENDIX I B. Literature cited in the construction of Appendix I A above.

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	No. of paddocks in rotation	Size of paddocks (ha)	Plant production/standing crop	Livestock production per head	Livestock production per land area
	3	5.4	ND	CG > RG	CG > RG
	4–8	?		ND	ND
	6	5		CG > RG	CG > RG
	6	5	ND		
	6	?		CG > RG	CG > RG
	3	5		CG > RG	CG > RG
	3–4	0.6–0.8		CG = RG	CG = RG
	10–12	45	ND		
	16	33	CG > RG		
	10	4		ND	RG > CG
	4	?		ND	RG > CG
	4	?	ND		
	8	16.25	ND		
	16	2.2		CG > RG	RG > CG
	8	16	RG > CG		
	9	45–210	ND		
	16	3	ND	ND	ND
	10	3.5	ND	CG > RG	CG > RG

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