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Conservation of Pattern and Process: Developing an Alternative Paradigm of Rangeland Management

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Abstract

This article examines the question of how well the rangeland management profession has served conservation of patterns and processes that support multiple ecosystem services. We examine the paradigms under which rangeland management operates and argue that our profession developed under the utilitarian paradigm with the primary goals of sustainable forage for livestock production. While optimization of multiple rangeland products and services has always been a consideration, a comprehensive set of principles have not be been developed to advance this concept. We argue that fire and grazing, often viewed as mere tools used for production goals, should rather be viewed as essential ecosystem processes. Rangeland management continues to operate under the utilitarian paradigm appropriate to societal values of the 20th century and by and large has failed to provide management guidance to reverse degradation of several highly valued ecosystem services. We support this argument with evidence that biodiversity has declined on rangelands in the past half century and that much of this decline is due to management goals that favor a narrow suite of species. The full suite of ecosystem services valued by society will only benefit by management for heterogeneity, which implies that there is no one goal for management and that landscape-level planning is crucial. Explicitly incorporating heterogeneity into state-and-transition models is an important advancement not yet achieved by our profession. We present new principles for rangeland management formed on the basis of conservation of pattern and process. While recognizing that many rangelands have significant deviations from historic plant communities and disturbance regimes, we suggest that management for conservation of pattern and process should focus on fire and grazing to the extent possible to promote a shifting mosaic across large landscapes that include patches that are highly variable in the amount of disturbance rather than the current goal of uniform moderate disturbance.

Resumen

Este artículo examina la pregunta de que tan bien los profesionales en manejo de pastizales han aplicado los patrones y procesos en la conservación de los servicios multiples que proveen los ecosistemas. Examinamos los paradigmas bajo los cuales opera el manejo de pastizales y discutimos el desarrollo de nuestra profesión bajo el paradigma utilitario con el principal objetivo de sustentabilidad forrajera para la producción de ganado. Mientras que la optimización de los múltiples productos y servicios de los pastizales han sido consideradas un paquete completo de principios no ha sido desarrollado para avanzar en este concepto. Discutimos que el fuego y el pastoreo a veces son vistos como simples herramientas usadas para objetivos de producción cuando deberían ser vistas como partes esenciales de los procesos del ecosistema. El manejo de pastizales continúa operando bajo el paradigma utilitario típico de los valores sociales del siglo XX y por mucho ha fallado en proveer directrices de manejo para revertir la degradación de varios servicios valiosos de los ecosistemas. Apoyamos este argumento con evidencia de que la biodiversidad ha decaído en los pastizales en la mitad del siglo pasado y mucho de esta disminución se debe a los objetivos de manejo que favorecen a un reducido número de especies. El juego completo de servicios valuados por la sociedad solo beneficiara con el manejo por heterogeneidad el cual implica que no hay un objetivo para el manejo y que la planeación a nivel paisaje es crucial. Incorporando de manera explícita modelos de estado y transición es un avance importante que no ha sido logrado por nuestra profesión. Presentamos nuevos principios para el manejo de pastizales desarrollados en base a procesos y patrones de conservación. Mientras reconozcamos que muchos pastizales tienen desviaciones significativas de históricas comunidades de plantas y regímenes de disturbio, sugerimos que el manejo por conservación de patrones y procesos deberá enfocarse en fuego y pastoreo en medida de lo posible para promover el cambio en un mosaico a través de grandes paisajes que incluyen parches que son altamente variables en la magnitud de disturbio en lugar de objetivos actuales de disturbio uniforme y moderado.

Key Words: biodiversity, fire, grazing, landscape ecology, pyric herbivory, shifting mosaic

INTRODUCTION

Conservation of natural resources has been described as progressing through three sequential paradigms (Callicott 1990; Weddell 2002). The first was the utilitarian paradigm, which was based largely on conservation to maintain long-term and sustainable production with the objective of providing the

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most benefit for the many (Pinchot 1947). Gifford Pinchot is considered the dominant influence for this perspective, which is based on conservation to maintain economic stability. Motivated by the spirituality of conservation and emerging from ideas of Ralph Waldo Emerson, Henry David Thoreau, and John Muir, the protectionist paradigm aims to protect nature from humans by setting aside or reserving lands, national parks, and wilderness areas from human influence. Utilitarianism and protectionism were often viewed as dichotomous perspectives. The third paradigm, ecosystem management, emphasizes conservation of processes and interrelatedness of parts by maintaining processes (grazing, fire, water cycling, nutrient cycling, and so on) with the objective of ultimately maintaining the full suite of biodiversity (Leopold 1949). Many attribute the ecosystem management paradigm to Aldo Leopold, who developed it to counter a land management system that he viewed as exploitive and without science at its core. While rangelands have benefited from conservation based on all three of the paradigms, the rangeland management profession developed largely under the utilitarian paradigm with the primary long-term goals of sustainable forage for livestock production and conserving production potential by minimizing soil erosion. Optimizing for all ecosystem services, while mentioned even early in the range profession history, has had limited application on large landscapes.

Because of these goals, conservation strategies in rangeland management have focused largely on minimizing irreversible soil degradation and loss of dominant forage species (Holechek et al. 2004). Traditional rangeland management consequently promoted late successional plant communities capable of sustaining livestock production. When the management goal is light or moderate disturbance and late successional plant communities, many native species of fauna and flora dependent on disturbance and earlier successional plant communities are neglected.

Under the utilitarian paradigm, livestock grazing and wildlife have often been viewed as competing rather than complementary (Stoddart et al. 1975), and grazing has been viewed more as a land use than as a process that promotes a pattern that is essential to ecosystem structure and function. In a similar way, the essential role of fire as an ecosystem process with importance equal to climate and soil (Axelrod 1985; Pyne 1991; Bond and van Wilgen 1996; Bond and Keeley 2005) has been replaced with the view that fire is merely a vegetation management tool (one among many other tools) applied primarily to benefit livestock production. This difference in how grazing and fire are viewed is not trivial if ecosystem services are important rangeland management goals. Viewing fire or grazing as tools interchangeable with herbicides and mechanical methods (e.g., Riggs et al. 1996; Scifres 2004) ignores the historical and ecological significance of these processes to biodiversity and patterns inherent to rangelands. In this article, we use biodiversity to present evidence of the essential role of pattern of process to ecosystem services. We discuss biodiversity as encompassing ecological patterns and processes according to the definition by West (1993, p. 2): "biodiversity is a multifaceted phenomenon involving the variety of organisms present, the genetic differences among them, and the communities, ecosystems, and landscape patterns in which they occur."

Concomitant to development of the conservation paradigm, the science of ecology has progressed from studies that rely on many replications of small plots to studies that emphasize pattern and process at multiple temporal and spatial scales. Watt (1947) and later Turner (1989) connected pattern to process, which led to *landscape ecology* as a discipline that has increased scientific attention to heterogeneity. In spite of these developments, rangeland management and research have failed generally to recognize the importance of scale and heterogeneity to biodiversity and ecological processes (Fuhlendorf and Smeins 1996, 1999; Briske et al. 2003). Increased interest in biodiversity conservation and the role of scale and heterogeneity are indications that traditional approaches to the science and management of rangelands may be inadequate to effectively embrace multiple uses at sufficient scales to meet society's expectations.

In this article, we argue that a *conservation of pattern and process* paradigm is a rational alternative to the utilitarian paradigm for the rangeland profession. While a conservation-based paradigm is neither novel nor entirely counter to the historical underpinnings of the profession (see Rumburg 1996), we argue that if rangelands are to fully meet the expectations of society, it will require fundamental and substantial change in the principles of our discipline and ultimately to the application of management at the landscape level. We also argue that focusing on soil protection and plant species composition as the primary indicators of rangeland condition to the exclusion of processes and life forms other than vascular plants impedes our profession's development and the profession's ability to meet society's values placed on rangeland ecosystem services. The paradigm of conservation of pattern and process broadly includes conservation of all species and life forms, habitat structures, and processes across complex landscapes. We examine rangeland conservation under the utilitarian paradigm followed by describing the conservation of pattern and process paradigm as it could be applied to rangeland management. We conclude by providing a framework for the conservation paradigm through a modified set of rangeland management principles that concomitantly address the current status of North American rangeland and societal values. Throughout, we supplement our focus on North American rangelands with citations from rangelands from other continents (e.g., Australia and Africa). We focus on rangelands that developed with a strong influence of grazing and/or frequent fire, but we broaden this to include rangelands that developed with infrequent fire.

BASIS AND LIMITATIONS TO THE UTILITARIAN PARADIGM

We rightly take pride in our profession's contributions to management that grew out of concern over destructive grazing practices and unregulated livestock use of private and public rangelands after the Civil War (Sampson 1952; Pieper 1994; Holechek et al. 2004). Driven largely by society's concern about reduced potential of these lands to produce forage for livestock resulting from an increase of undesirable species (i.e., species with low productivity and low livestock forage value) and eroded soil, pioneers of our profession discovered and successfully implemented practices that conserved rangeland production potential (i.e., desirable forage species and soil) for future utilitarian purposes. The first unified theory of rangeland conservation was based on the seminal paper by E. J. Dyksterhuis (1949) in which he proposed that condition of rangelands be based on the proportions of *increaser*, *decreaser*, and *invader* species in the plant community. Species were classified on the basis of their response to grazing such that increased grazing pressure would promote *increaser* and *invader* species and cause a decline in *decreaser* species. The species most preferred by livestock were classified as *decreasers*, and management was intended to promote *decreaser* dominance. The highest-quality rangeland vegetation from a livestock production context (excellent or good condition) was most similar to the climax plant community and thus not recently disturbed by grazing or fire (Pendleton 1989).

The definition of rangelands as ecosystems capable of supporting grazing animals led to management focused largely on manipulating domestic livestock grazing (Holechek et al. 2004). Some 60 yr after Sampson's (1952) early book on rangeland management, sustainable livestock grazing and economic returns continue to drive rangeland management decisions (Dunn et al. 2010), and conservation continues to focus primarily on maintaining or enhancing livestock production (Toombs and Roberts 2009). The utilitarian roots of range management that promoted protecting the soil and vegetation from disturbance and maintaining the output of products (Holechek et al. 2004) led to four foundational principles of rangeland management that focused on manipulating livestock grazing. These principles of rangeland (grazing) management are to 1) maintain proper stocking rate (number of animals per unit area per unit time), 2) achieve proper distribution of animals in space (generally considered to be spatially uniform grazing use), 3) achieve proper forage utilization in time, and 4) use the proper kind and class of grazing animals to match or obtain the desired plant community. These strategic principles, accompanied by many tactical rules of thumb, formed the basis for rangeland management as practiced today.

Ranchers do not normally manage with the goal of achieving excellent range condition across their ranch, but they have succeeded in managing for uniform grazing and increasing the proportion of desirable forage grasses while reducing bare ground—managing for the middle (Fuhlendorf et al. 2009). Applying the utilitarian paradigm has therefore achieved a measure of success reflected by improved range condition in the United States over the past century (Fig. 1; Holechek et al. 2004). The distribution of range condition (highest percentage in good and fair condition and lowest of excellent and poor) reflects meaningful achievement toward the management goal of obtaining uniform, moderate utilization necessary to minimize soil loss and rangeland area in poor condition. Goals of increasing dominance of important forage species and reducing bare ground have been achieved through cross fencing, water development, and other practices that promote uniform, moderate utilization while minimizing ungrazed and heavily grazed areas.

This is not to say that the scientific underpinnings of rangeland management have not advanced since Stoddard. The theoretical framework of rangeland management recently shifted focus from equilibrial to nonequilibrial dynamics, state-and-transition models, and rangeland health (Briske et al. 2003, 2005). Although an important advance in rangeland science and management, the shift largely refined the utilitarian model because single plant communities remain the primary management goal rather than embracing spatial and temporal heterogeneity. Policies of federal agencies have advanced the utilitarian model. For example, the US Department of Agriculture Natural Resource Conservation Service, through its Environmental Quality Incentive Program, invested primarily in improving and maintaining livestock production with most of the practices promoting uniform distribution of grazing animals and limiting the dominance of species of minimal forage value for livestock (Toombs and Roberts 2009). While management that achieves uniform grazing distribution and moderate forage utilization can benefit soil protection, water quality, and habitat for some wildlife species, the practices often fail to provide for habitat requirements and ecological processes that may be dependent on the extremes of a disturbance gradient (Knopf 1996; Fuhlendorf et al. 2006). Highly palatable and rare species ("ice cream plants") that are expected to be sacrificed under grazing practices designed to achieve uniform grazing use of abundant forage plants is yet another example of inattention to pattern and process under traditional rangeland management (Stoddart and Smith 1943; Vallentine 2001).

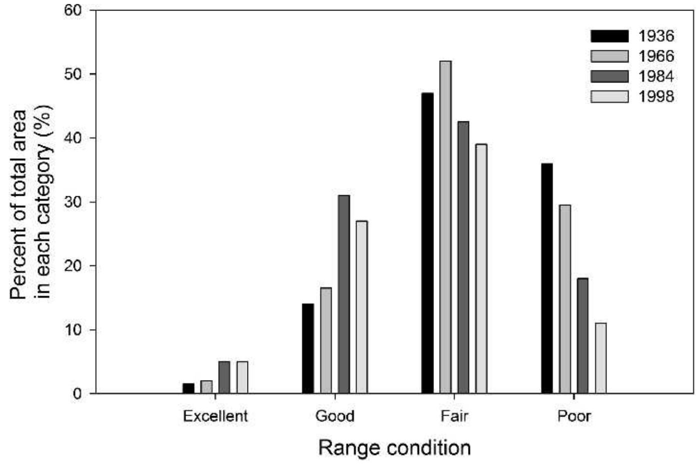

Figure 1. Proportion of US privately owned rangelands in each of four range condition classes from 1936 to 1998 (modified from Holechek et al. 2004).

Rangeland monitoring has focused recently on rangeland health, leading to conservation management based on reducing bare ground, stabilizing soil (Pellant et al. 2005), and anticipating threshold changes (Bestelmeyer et al. 2003). Rather than focusing on climax plant communities, the current plant community and soil conditions are compared to a potential natural community and desirable plant communities—a single reference community phase (Pellant et al. 2005). Therefore, monitoring continues to focus largely on maintaining desirable forage species and minimizing bare ground with a single state, phase, or condition considered the most appropriate for any ecological site (Bestelmeyer et al. 2003, 2009). This ignores the role of pattern and process of disturbance and enhancement of ecosystem services other than livestock production, and it reinforces the notion that a single plant community and homogeneity of the landscape are the

Table 1. Requirements to ensure processes and habitat for imperiled species on rangelands. These examples demonstrate that managing complex landscapes to achieve homogeneous accumulations of litter and minimizing bare ground will lead to undesirable biotic and abiotic changes on many rangelands.

Species/process	Location	Requirement	Citations
Biological diversity	Globally	Landscape heterogeneity	Christensen (1997), Wiens (1997), Fuhlendorf and Engle (2001), Fuhlendorf et al. (2006, 2009), Tews et al. (2004)
Diversity of insects	Grassland/steppe	Heterogeneity	Bestelmeyer and Wiens (2001), Dennis et al. (1998), Engle et al. (2008)
Diversity of mammals	Rangeland	Heterogeneity	Ceballos et al. (1999), Dean et al. (1999)
Diversity of birds	Rangelands	Heterogeneity	Knopf (1994), Fuhlendorf et al. (2006), Gregory et al. (2010), Reinkensmeyer et al. (2007)
Ecosystem stability	General	Heterogeneity	Holling and Meffe (1996), van de Koppel and Rietkerk (2004)
Soil aggregate stability and nutrient cycling	General	Heterogeneity	Herrick et al. (2002), Augustine and Frank (2001), Anderson et al. (2006)
Grazing patterns	General	Heterogeneity	Senft et al. (1987), Stuth (1991), Fuhlendorf and Engle (2004), Fryxell et al. (2005), Fuhlendorf et al. (2009)
Fire behavior	General	Heterogeneity	Fuhlendorf and Engle (2001), Archibald et al. (2005), Kerby et al. (2007), Fuhlendorf et al. (2009)
Hydrology	General	Heterogeneity	Belnap et al. (2005), Ludwig et al. (2000), Eldridge et al. (2002)
Blowout penstemon (*Penstemon haydenii*)	Central Great Plains	Bare ground	Stubbendieck et al. (1993)
Western juniper (*Juniperus occidentalis*)	Intermountain West	Low frequency of fire	Miller and Rose (1999)
Black-tailed prairie dog (*Cynomys ludovicianus*)	Shortgrass prairie	Low vegetation structure	Milne-Laux and Sweitzer (2006), Augustine et al. (2007), Northcott et al. (2008)
Mountain plover (*Charadrius montanus*)	Shortgrass prairie	Bare ground or heavy grazing	Derner et al. (2009), Knopf and Rupert (1995)
Aspen (*Populus tremuloides*)	Intermountain West	Periodic fire with limited herbivory	Bartos et al. (1991), White et al. (1998)
Henslow's sparrow (*Ammodramus henslowii*)	Tallgrass prairie	Ungrazed and unburned for >2 yr	Coppedge et al. (2008), Herkert (1994)
Plains cottonwood (*Populus deltoides*)	Great Plains	Periodic bare ground	Braatne et al. (1996), Mahoney and Rood (1998)
Gopher tortoise (*Gopherus polyphemus*)	Gulf coastal plain	Frequent fire	Ashton et al. (2008), Landers and Speake (1980)
Ruffed grouse (*Bonasa umbellus*)	Northern forests and mountains	Young forest <20 yr	Jones et al. (2008), Dessecker and McAuley (2001)
Sage thrasher (*Oreoscoptes montanus*)	Intermountain West	Sagebrush without juniper	Reinkensmeyer et al. (2007)
Horned lark (*Eremophila alpestris*)	Western North America	Recently disturbed areas	Reinkensmeyer et al. (2007)
Upland sandpiper (*Bartramia longicauda*)	Tall and mixed prairie	Recently burned prairie	Fuhlendorf et al. (2006)
Cotton rat (*Sigmodon hispidus*)	Tallgrass prairie	Unburned and ungrazed prairie	Cully and Michaels (2000)
Regal fritilary (*Speyeria idalia*)	Tallgrass prairie	Unburned and ungrazed prairie	Swengel (1998), Vogel et al. (2007)
Black-backed woodpecker (*Picoides arcticus*)	Western Forests	High fire severity, recently burned	Hutto (1995), Koivula and Schmiegelow (2007)
Cassin's sparrow (*Aimophila cassini*)	Great Plains	Undisturbed shrubland	Kirkpatrick et al. (2002)

appropriate targets for rangeland management. This is not a phenomenon confined to North America. Recent studies of piospheres in Australia (James et al. 1999; Hoffmann and James 2011) and communal grazing in Africa (Rutherford and Powrie 2011) suggest that management that would be considered inappropriate from a traditional rangeland management approach might actually contribute to regional patterns of biodiversity. Therefore, it should be of little surprise that the definition of *poor* range condition, often termed the at-risk community phase (Briske et al. 2005, 2008), is strikingly similar to habitat requirements of many imperiled plant and wildlife species in a variety of rangeland types from across the world that are highly valued by society (Table 1). Furthermore, the concurrent loss of abundance of these species on rangelands worldwide could be viewed as indicators of significant deviations from historic processes.

This evidence indicates that biodiversity and ecological processes have not moved forward as fundamental elements of the rangeland profession. This is likely a legacy of larger agricultural and rural society in the first half of the 20th century that viewed wildlife as competitors and conflicting with livestock production and disturbance as reducing productivity reflected in early range management textbooks (Stoddard and Smith 1943; Sampson 1952). Although the profession's attitudes and perceptions of wildlife have changed over time, wildlife continue to be considered by the rangeland profession to be largely a source of economic return or a land use objective rather than as an ecosystem component (Holechek et al. 2004). In contrast to systematic efforts to establish indicators of rangeland health to include ecological processes (water cycle, energy flow, and nutrient cycles) and biotic integrity that supports ecological processes (Pellant et al. 2005), no systematic effort has translated scholarly efforts (e.g., West 1993) into principles and practices for conserving biodiversity or restoring the full suite of ecological processes on complex rangeland landscapes. Efforts to focus on ecological processes are often limited to a single process without consideration of the full potential suite of processes (e.g., water purification, water cycle, carbon sequestration, nitrogen cycling, and so on). Rangelands continue to be described as simple homogeneous states despite the volumes of data that suggest that these complex systems are in fact dynamic in space and time and that complex patterns are essential to a full suite of ecosystem services (Table 1). Despite changing social perspectives that question the range profession's self-image associated with livestock (Brunson and Steel 1994) and research demonstrating that grazing was not responsible for all changes in rangeland ecosystems (Westoby et al. 1989), the science and management of rangelands have lagged behind other disciplines—and arguably the public—in embracing an expanded view of rangelands as complex ecosystems that support multiple land use objectives and provide a full suite of ecosystem services including biodiversity (West 1993; Krausman 1996; Havstad et al. 2007).

The evidence clearly indicates that utilitarian principles of rangeland management that focused on dominant forage species and soil protection represent a century of scholarly effort that improved rangelands throughout the world. However, society dictates and research confirms that livestock-centric approaches are incapable of providing an effective template that optimizes all ecosystem services. Svejcar and Havstad (2009, p. 30) suggested, "Science has provided basic principles for management tied to the spatial and temporal scales and uses of the 20th-century land manager. . . . What has changed is the demand for a wider variety of goods and services." This statement acknowledges that providing ecosystem services in addition to livestock production requires a new rangeland management paradigm that links pattern and process at multiple scales.

Ample evidence indicates that rangeland capacity to produce goods and services valued by 21st-century society has declined in the past half century or so. The North American Breeding Bird Survey is one of the longest (1966 to present) and most extensive ecosystem monitoring efforts covering most of North America and evaluating birds across all landscape types. Classification of species based on their preferred habitat type (grassland, aridland, forest, and wetland) indicates that some species groups are stable (forests) or even increasing (wetlands), while those associated with rangelands (defined here as grasslands and aridlands) are the most rapidly declining group of species in North America (Fig. 2). Examples include the McCown's longspur (2.1% annual decline, 1966–2006), Henslow's sparrow (8.3% annual decline, 1966–2006), and Cassin's sparrow (1.5% annual decline, 1966–2006; Sauer et al. 2008). Diverse communities of species require habitat heterogeneity that includes intensively disturbed habitats (i.e., bare ground and relatively short-statured vegetation) and habitats with minimal disturbance dispersed as a shifting mosaic across a complex landscape (Fig. 3; Table 1; Knopf 1996; Fuhlendorf et al. 2006, 2009). Studies of rangeland birds from the shortgrass steppe (Knopf 1996), intermountain West (Reinkensmeyer et al. 2007), and Africa (Skowno and Bond 2003; Krook et al. 2007; Gregory et al. 2010) have also indicated similar relationships in which bird community composition is dependent on variable patterns of fire and grazing. While other factors are certainly involved, declines in grassland and aridland birds of North America were simultaneous with nationwide improvements in rangeland condition and rangeland health, as our profession has defined these terms (Holechek et al. 2004). This suggests that our approach to defining rangeland condition and health is insufficient to determine ecosystem health that reflects societal values. A recent meta-analysis of the relationship between animal species diversity and habitat heterogeneity found that over 80% of all studies surveyed found a positive relationship (Tews et al. 2004). Studies included relationships with arthropods, birds, mammals, amphibians, and reptiles in all types of ecosystems across the globe, clearly supporting the view that heterogeneity is the root of biodiversity and therefore should be the basis for conservation of rangelands and other ecosystems (Wiens 1997; Fuhlendorf et al. 2006).

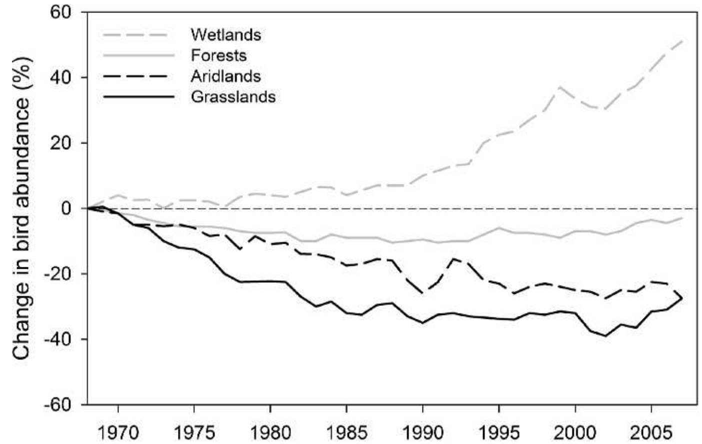

Figure 2. Change from a baseline of 1966 in bird populations associated with four major habitat types reported by the North American Breeding Bird Survey (North American Bird Conservation Initiative, U.S. Committee, 2009). Rangeland habitats are most closely approximated by grasslands and aridlands, which have seen the greatest decline since 1966 in birds native to these habitats.

RANGELAND MANAGEMENT TO CONSERVE PATTERN AND PROCESS

Conservation of rangeland biodiversity is most threatened by regional losses of rangeland through cultivation, woody plant

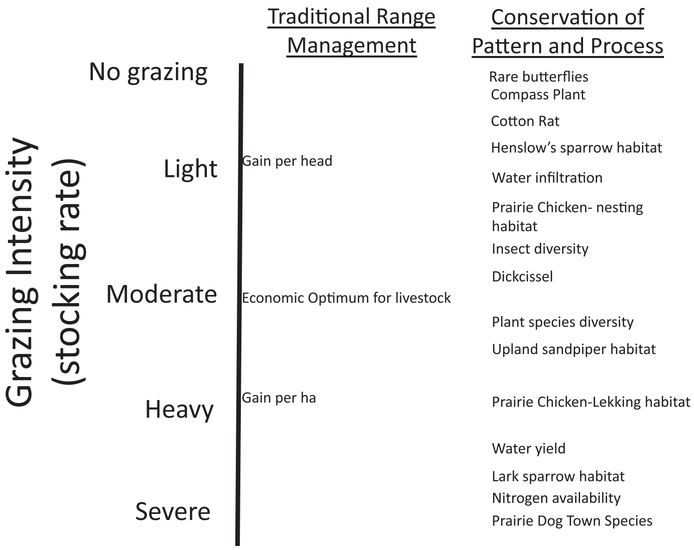

Figure 3. Objectives achieved through the utilitarian paradigm ("proper" range management) when constrained to a single stocking rate contrasted to complete rangeland conservation in which stocking rate varies in space and time. Conservation of pattern and process examples are mostly from North American prairies, but examples also exist for Mountain Big Sagebrush (Reinkensmeyer et al. 2007) and African (Gregory et al. 2010) rangelands.

encroachment, suburban sprawl, invasive species, and desertification. Conservation must first consider large-scale patterns on rangelands and areas that have experienced severe fragmentation and/or species invasions are constrained by those changes (Fuhlendorf et al. 2002). This is particularly relevant in areas of the American West where annual grasses are rapidly altering plant composition and function to a new state. Thus, historic patterns and processes may not be appropriate or feasible. Large-scale fragmentation and alteration make conservation decisions more complex. Yet they do not alter the reality that disturbance processes shape plant community structure, biodiversity, and ecosystem function even when those disturbances are highly altered from historic conditions.

For large-scale patterns, it is useful to compare the foundational principles of rangeland (grazing) management as a framework for contrasting conservation management under the utilitarian paradigm with an alternative paradigm to rangeland management that conserves pattern and process. We approach this by developing new principles for rangeland management based on several key aspects related to grazing management principles, namely, grazing intensity and distribution of grazing in time and space. To these we add fire because most rangelands of the world are fire-dependent ecosystems and because, until recently, fire has received infrequent attention in both the science and the management of rangelands (Axelrod 1985; Bond and Keeley 2005). We do not include kind and class of animals because matching the type of animal with the environment is equally important to utilitarian management and management for conservation of pattern and process.

Grazing Intensity

Grazing intensity (proportion of the aboveground net primary production consumed by grazing animals) is considered the most important principle of grazing management (Heitschmidt and Taylor 1991; Milchunas and Lauenroth 1993; Holechek et al. 2004). Although grazing intensity and stocking rate are not synonyms, the two are often discussed together because the concepts overlap considerably. Numerous experimental studies have demonstrated that optimum animal gains per unit area are accomplished through fairly heavy stocking, optimum gain per individual animal occurs at light stocking, and economic optimum is near moderate stocking where 25–30% of the forage is harvested (i.e., moderate utilization) by domestic livestock (Hart et al. 1988; Heitschmidt and Taylor 1991; Torell et al. 1991). Achieving moderate utilization is a challenging objective for nonequilibrial ecosystems because of highly variable interannual weather patterns. Under utilitarian management, "proper" stocking (i.e., moderate utilization) maintains the dominant forage species, minimizes soil loss, and optimizes economic returns.

From a conservation perspective, optimal stocking rate becomes much more complex because no single stocking rate is optimum for all species and processes (Fig. 3). Table 1 includes examples of species that either require heterogeneity (from severely disturbed to undisturbed habitat) or require habitat that is either severely disturbed or undisturbed. Because no single stocking rate is most appropriate for all species and processes, there is no single "proper" stocking rate if the goal is biodiversity by maintaining ecosystem processes. Therefore, there is a conservation paradox of grazing intensity because the full range of stocking rates must be present at the appropriate scales to maintain biodiversity. This paradox can be addressed within the conservation of pattern and process paradigm by focusing on heterogeneity in space and time and considering grazing as a disturbance process that interacts with other disturbances across complex landscapes (Fuhlendorf and Engle 2001; Archibald et al. 2005; Fuhlendorf et al. 2009). At the landscape scale, this necessitates that managers consider the context of landscapes in making decisions. Removal or moderation of grazing on patches may be most important on landscapes that are uniformly and heavily grazed, while landscapes with minimal grazing should focus on creating disturbed and variable habitats. At the local scale, management should strive to achieve a dynamic management such that the system is variable at small scales while stable at increasing scales if conservation of biodiversity is the objective. Inherent to this approach is that no single species or plant community is maximized across all spatiotemporal points; rather, the full suite of species and conditions for that system would be optimized. This will not be consistent with some objectives in some places. Thus, recognition should be given that maximizing any one thing is to the detriment of others.

Distribution of Grazing in Space and Time

The management goal of most grazing systems, termed "management to the middle" (Fuhlendorf et al. 2006, 2009), promotes uniform dominance of the most productive forage species while maintaining efficient use of these species through moderate and even use across the landscape (Stoddart et al. 1975; Bailey 2004). The focus on uniform utilization in space and time resulted from the growth of range management during a time when the primary concern on rangelands was overuse and concentration of animals near water and other attractants. As expressed by Stoddart et al. (1975), "Overgrazing on a range is not dependent entirely upon the number of animals; all the attendant results can be realized locally if stock are not distributed properly." Standardized uniform and efficient utilization developed from the attempt to maximize livestock production (e.g., Hart et al. 1993) and minimize degradation of riparian areas (Vallentine 2001; Bailey et al. 2006). To conserve the larger landscape, sacrifice areas, particularly around specific watering and mineral locations, often would be targeted for moderated grazing (Vallentine 2001). Although still necessary in some situations (e.g., riparian areas), this focus developed into a standard that may now be a historical artifact no longer appropriate for meeting the full suite of conservation goals. That no "proper" stocking rate exists for all aspects of rangeland ecosystems applies equally to distribution of grazing in space and time.

When animals are allowed to graze at moderate stocking rates across a large landscape, their distribution in space and time is highly variable and dependent on water, topoedaphic features, vegetation structure and composition, and previous disturbance (Heitschmidt and Taylor 1991; Ash and Stafford Smith 1996; Bailey et al. 1996; Holechek et al. 2004). Animals will preferentially select previously grazed or otherwise disturbed areas that have short-statured regrowth, a phenomenon that works counter to uniform moderate grazing (Coppedge and Shaw 1998; Fuhlendorf and Engle 2001; Limb et al. 2010b). This kind of selective grazing behavior results in heterogeneous vegetation structure and composition within the landscape where some local areas are heavily grazed and some areas can be ungrazed or nearly so (Coppedge and Shaw 1998; Fuhlendorf and Engle 2004). Assuming that the disturbance is not static and becomes a regime that shifts across the landscape, this heterogeneity or mosaic generally benefits biodiversity (see reviews by Adler et al. 2001; Fuhlendorf and Engle 2001).

A negative perception of heterogeneity arose out of concern that heavily grazed locations will be grazed heavily and repeatedly over a series of years, resulting in loss of productivity, soil damage, and impaired water quality. While this is an understandable concern when disturbance is static and treated as a discrete event, historically it functioned because of the dynamic nature of the interactions and scales of multiple disturbance regimes. A consequence of the alteration of these regimes has been the decline of disturbance-sensitive and disturbance-dependent plants, such as compass plant (*Silphium laciniatum* L.) and blowout penstemon (*Penstemon haydenii* S. Watson). Species that require vegetation structure at the extremes of stocking rate—either heavy use or no use—are also susceptible to decline from grazing management for the middle (Table 1).

To counter this, our profession has often applied high stock density and rotational grazing by cross fencing pastures to force less selectivity and more uniformly utilize each paddock in the rotation so as to minimize bare ground and maintaining late seral stage vegetation (Savory 1999). Although this management has been argued to be consistent with historic grazing patterns with migrating large ungulates (Savory 1999), in practice the intent is typically to uniformly graze (often multiple times) each year, resulting in a landscape that has little or no ungrazed vegetation. Ironically, rotational grazing has been viewed as a conservation-based alternative to continuous grazing because it reduces patch grazing and heterogeneity (Teague et al. 2004, Teague et al. 2009). However, the management objective of uniform grazing is not consistent with meaningfully variable grazing patterns across the landscape that are essential to heterogeneity that supports the conservation of biodiversity (Fuhlendorf et al. 2006) and in some cases animal productivity (Anderson et al. 2006; Limb et al. 2011). Broad grazing ecology research from the Serengeti and South Africa demonstrates that grazing animals benefit from local, heavy utilization or patch grazing on grazing lawns through increased forage quality and nitrogen availability (McNaughton 1984; McNaughton et al. 1997; Archibald et al. 2005). The utilitarian paradigm of uniform distribution of grazing in space and time is incapable of maintaining or enhancing biodiversity and productivity on rangelands at large scales.

Fire as a Rangeland Ecosystem Process

Utilitarian management views fire as a vegetation management tool primarily used to control unwanted plants (Scifres and Hamilton 1993; Ansley and Taylor 2004; Holechek et al. 2004) even though rangeland ecologists were among the first to recognize the central role of fire in developing and maintaining ecosystems (Humphrey 1962). Fire regime was referred to as the "fire climate" to reflect the duality of fire in both formation and maintenance of rangeland—equivalent to climate (e.g., see Wright and Bailey 1982). However, the utilitarian approach limits fire to maintain dominant forage species and control of woody plants while minimizing factors that are perceived as negative to simple livestock objectives (Holechek et al. 2004). Management recommendations also caution against the increase of undesirable forage species, exotic plants, bare ground, and soil erosion (Teague et al. 2010), which, while justified, fail to account for the effect of *no fire* on fire-dependent landscapes.

Most rangelands of the world evolved with lightning ignitions and anthropogenic fires (Pyne et al. 1996). Although some rangelands have been degraded by an increase in fire frequency (e.g., Great Basin, USA; Whisenant 1990), fire suppression and barriers to using prescribed fire led to fire exclusion on the vast majority of rangelands that resulted in woody plant encroachment and biosimplification of many rangelands worldwide (Humphrey 1962; Hamilton and Ueckert 2004). Invasion of woody plants into grasslands is a dominant cause of the global loss of rangelands over the past several decades (Fuhlendorf et al. 2002; Bond and Keeley 2005; Limb et al. 2010a). Fire clearly maintains herbaceous dominance in many grasslands, but even in rangelands with persistent herbaceous dominance with infrequent fire return intervals, fire can be used to restore heterogeneity and alter grazing patterns in a manner than enhances biodiversity (Anderson et al. 2006; Fuhlendorf et al. 2009). Most rangeland fauna and flora respond to fire in a manner similar to grazing intensity in the sense that some species increase and others decrease after fire depending on time since fire, fire season, and fire intensity (Fuhlendorf et al. 2006; Reinkensmeyer et al. 2007).

The conservation of pattern and process paradigm suggests that historical and potential plant communities are complete as management guides only if fire is included in the landscape. Fire is a pattern-driving process on rangelands that interacts with other disturbances to contribute to heterogeneity. While fire can be a useful tool for managing woody plant invasion, it is shortsighted to relegate fire to a toolbox of other options considering that its importance as an evolutionary process has been exhaustively documented. Management of rangelands focused on maintaining or enhancing biodiversity cannot be accomplished without restoring historic fire regimes, including variable fire season and fire intensity together with other disturbance interactions, across the landscape. This is as true in rangelands with long fire intervals as it is in systems with frequent fire. Furthermore, the simple reintroduction of fire is not the only requirement because fire should interact with other disturbances to create a dynamic pattern—a shifting mosaic of fire, grazing intensity, and vegetation structure—across the landscape that preserves the historical processes under which most rangeland evolved (Fuhlendorf and Engle 2001). Some landscapes may have crossed thresholds where the mere restoration of fire may have limited impact (e.g., closed-canopy juniper woodlands) or because of their susceptibility to shifting to a new state (brome-invaded Great Basin shrublands), but once these degraded landscapes have been restored, interactive patterns of fire and grazing should be a conservation objective. In the interim, holding these at risk communities in a relatively stable state will constrain the species that can be conserved to only species that fit that stable state. Thus, research and management focused on maintenance of historical plant communities without considering spatial and temporal patterns of disturbance processes will always have limited success.

NEW PRINCIPLES FOR CONSERVATION OF PATTERN AND PROCESS ON RANGELAND ECOSYSTEMS

Our appeal is that range science and management should embrace a broader conservation perspective using biodiversity and ecosystem processes as primary guiding principles (Fig. 3; Table 2) while recognizing that livestock production, a service that results from healthy rangelands, will not be the primary driving factor in management decisions. Therefore, we propose the following principles of rangeland conservation of pattern and process. We are certain these principles are not exhaustive, and they are not intended to entirely replace all of the traditional principles of range (grazing) management. Instead, we intend these principles to serve as an initial starting place for developing a new conservation paradigm for rangelands.

1. Maintenance of large continuous tracts of rangelands is critical for conservation of patterns and processes so that disturbance processes can interact with complex landscapes and form multiscaled mosaics.
2. Grazing intensity (i.e., stocking rate) is the primary factor influencing the effect of grazing on rangeland, but no single grazing intensity is "proper." For ecosystems that evolved with grazing, all evolutionarily appropriate grazing intensities are, by definition, essential to conservation of biodiversity across large, complex landscapes.

Table 2. Attributes of traditional range management contrasted with range management aimed at conservation of processes and patterns.

Attributes	Traditional range management	Conservation of pattern and process
Outcome	Single use/optimal livestock production	Biodiversity and processes
Distribution	Uniform	Nonuniform
Ungrazed area	Minimal	Substantial
Severely grazed area	Minimal	Substantial
Rate of rotation among fenced units	Rapid	None or slow
Application of fire	Uniform	Patches
Fire perspective	Brush control tool for forage production	Critical ecological process
Philosophy of management goals	Uniformity	Heterogeneity
	Simplicity	Complexity
	Equilibrium	Dynamic
	Management for the middle	Management for extremes

3. Obtaining uniform distribution of grazing in time and space across a landscape is neither possible nor desirable. Managing grazing distribution for heterogeneity as a shifting mosaic across the landscape should be the goal.
4. Shifting mosaics are necessary for maintaining ecosystem structure and function and achieving multiple objectives. Managing for a single condition, state, phase, or successional stage might maximize and sustain livestock production but will not be capable of promoting biodiversity or multiple uses.
5. Conservation of rangelands ultimately should consider all species of animals and plants. Individual species and groups can be used as diagnostic indicators of response to management, but plants and animals should not be considered "sacrifice species" or "management objectives" across an entire landscape.
6. Disturbance regimes, such as fire and grazing, are as vital to ecosystem structure and function as climate and soils. They must be viewed as interactive processes if we are to have any hope of maintaining biodiversity.

MANAGEMENT IMPLICATIONS

The rangeland management profession has clearly advanced natural resource conservation worldwide. Our discipline has grown from the initial concern of maintaining sustainable forage and livestock production on rangelands to one of conservation of complex rangeland landscapes for multiple uses that encompass all ecosystem services, including agriculture, biodiversity, and aesthetics. While we have made an important transition in recognizing the importance of these other services, we must begin to apply management that will achieve these broader goals. We must also recognize that no single state exists in space or time that is most desirable for all objectives, and the patterns that exist (both inherent topoedaphic and disturbance driven) on rangelands are fundamentally important to the functioning of these complex ecosystems. We need to embrace management and monitoring approaches that encourage conditions that support all native plants, animals, and ecological processes at large scales—conservation management. Recent research has demonstrated that conservation management can be consistent with agricultural production objectives (Fuhlendorf and Engle 2004; Limb et al. 2011). These studies indicate that management that promotes heterogeneity can provide greater stability and at least equivalent productivity on North American grasslands. Thus, these new principles hold promise both at small scales to meet production and single species objectives and at large scales to conserve biodiversity. This will require critical planning at multiple scales while always being cognizant of the landscape context. Thus, policy would need to encourage various states and conditions that are dynamic at small scales and increasingly stable at larger scales. This will be a dramatic shift from our current management and will necessitate a much deeper level of planning, monitoring, and understanding of rangelands.

Changes in our research approaches and the development of a paradigm for conservation of pattern and process would offer several benefits to the rangeland profession. First, by focusing on pattern and processes rather than simple management objectives, system sustainability will be maintained, and thus conservation and production can be achieved simultaneously. Second, by changing our conservation paradigm, the range profession will be a leader in broadening the conservation ethic and working with other natural resource disciplines to move to a more systems-based approach that is capable of efficiently linking science, management, and policy. Finally, rangeland science will be in a strategic position that is in line with societal views on the importance of rangelands and the goods and services expected from their management (Brunson and Steel 1994). Implementation will face many social and policy barriers. It is our hope that this article will serve as a catalyst for a rigorous and spirited dialogue on the contextual specifics of the paradigm and how to implement it on rangelands worldwide.

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