REVIEW ARTICLE

A Management Framework for the Transition from Livestock Production toward Biodiversity Conservation on Great Plains Rangelands

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ABSTRACT

Management for biodiversity and other ecosystem services from North America's rangelands has received increasing attention as recognition of the societal value of those services and payment mechanisms for them have grown. This, combined with adverse effects of livestock management on North American rangeland biodiversity and predictions of a warmer and drier climate reducing rangeland productivity, has led some rangeland scientists to call for a paradigm shift from utilitarian-driven management to biodiversity conservation management. A challenge for rangeland science is to describe management changes required for this shift and to elucidate consequent ecological and economic tradeoffs. On the basis of two criteria, direct alteration of biodiversity and alteration of one or more drivers of biodiversity, a framework of ten ecological conditions is proposed for making the transition from livestock-centered management toward biodiversity-centered management on Great Plains rangelands: (1) composition and productivity of plant communities; (2) herbivory patterns; (3) fire regimes; (4) habitat contiguity; (5) stream hydrology; (6) temporal ecological variability; (7) herbivorous mammal communities; (8) fate of ungulate production; (9) apex predators; and (10) size of management units. Reflecting trends in rangelands elsewhere around the world, a shift toward management for biodiversity on the Great Plains may be facilitated by changes underway in land ownership and by a potentially increasing number of landowners for whom livestock production is of secondary importance to lifestyle and natural amenity benefits from the land.

Keywords: *biodiversity-centered management, ecological conditions, ecosystem services, grazing, livestock-centered management*

Management for biodiversity and other ecosystem services from North America's rangelands has received increasing attention as recognition of the societal value of those services and payment mechanisms for them have grown (Havstad et al. 2007, Goldstein et al. 2011). Predictions of a warmer and drier climate across most of the continent's rangelands raise concerns about the sustainability of current livestock production practices (Mader et al. 2009, National Global Change Research Program 2014). Changes in rangeland ownership are fostering a shift in landowner management goals from livestock production toward lifestyle and natural amenity values (Torell et al. 2005, Hodur et al. 2012, Sorice et al. 2012), reflecting similar ownership and management changes that are underway in grasslands around the world, including Australia (Mendham et al. 2012), Patagonia (Worrall and Essick 2004) and southern Africa (Lindsey et al. 2009). The above trends have led some rangeland scientists to call for a paradigm shift from utilitarian-driven management focused on livestock production to conservation management that supports all native species and ecological processes at large scales (Fuhlendorf et al. 2012). What such a shift will require is informed by a substantial body of literature developed over the last two decades concerning the effects of livestock ranching on North American rangeland biodiversity and how to mitigate those effects for particular taxonomic groups (e.g. Knopf 1996, Knopf and Samson 1997, Connelly et al. 2004), ecological processes (e.g. Truett et al. 2001, Fuhlendorf et al. 2009) and rangeland ecosystems generally (Flieschner 1994, Freilich et al. 2003, Samson et al. 2004, chapters in Briske 2011).

To facilitate this paradigm shift, a practical and simple management framework may be useful for rangeland researchers and managers working on the transition from management centered on livestock production toward management that increasingly incorporates biodiversity conservation. We propose here such a framework

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Figure 1. General boundary of Great Plains region, US, of mixed- and short-grass prairies.

tailored to the ecological and management conditions of the Great Plains (Figure 1), a region of largely intact mixed-grass and shortgrass prairies of which at least 90% are grazed by livestock, primarily cattle (*Bos taurus*) (Samson et al. 2004). The framework is based on the identification of ten common livestock-centered management practices, broadly defined, that we believe exert particularly adverse effects on biodiversity according two criteria: (1) direct and substantial alteration of biodiversity and (2) substantial alteration of one or more ecological drivers of biodiversity, including alteration of conditions that enable drivers to operate at meaningful intensities and scales. Though focused on the Great Plains, the framework could be adapted to other rangelands and to incorporate other activities affecting rangeland biodiversity.

The Management Framework

We constructed the management framework by comparing each of ten common livestock-centered management (LCM) practices we judged to have the greatest negative effects on biodiversity with its counterpart biodiversity-centered management (BCM) practice. The term "common" denotes LCM practices that are employed to varying degrees by many, though not necessarily most, private and public rangeland managers in the Great Plains. Moreover, LCM and BCM practices described here represent the extreme ends of a continuum of management practices in the region. Many livestock ranchers and protected area managers employ a mix of LCM and BCM practices.

The effects of LCM and BCM practices on livestock productivity and biodiversity are complex, synergistic and often poorly understood. In presenting our proposed management framework, we summarize the main features of these practices and their effects. We offer this framework for testing, both through research addressing particular questions and, especially, by the growing number of rangeland managers who, often through trial and error, are looking for ways to improve biodiversity conservation on their lands.

Composition and Productivity of Plant Communities

Common LCM approach: Alter species composition and soil conditions

The most extreme vegetative manipulation under LCM is the frequent conversion of native plant communities to monotypic hayfields of non-native species (Freilich et al. 2003). Broadleaf selective herbicides and diverse mechanical land treatments, sometimes combined with overseeding, have been used for decades to increase livestock forage grasses and to minimize vegetative heterogeneity (Schuman and Rauzi 1985, Fuhlendorf et al. 2002, Holechek et al. 2011). In addition to direct large-scale changes in plant species composition, effects include reduced abundance and richness of forbs caused by broadleaf herbicide application (Fuhlendorf et al. 2002), shifts in bird species composition caused by furrowing (Rich 2005), decline of Greater Sage-Grouse (*Centrocercus urophasianus*) populations caused by sagebrush (*Artemisia* spp.) control (Connelly et al. 2004), and reduced abundance of Sprague's Pipit (*Anthus spragueii*) in areas of introduced grasses (Jones 2010). These practices, combined with uniform grazing practices, create single-state conditions and simplified ecosystem structure at the landscape scale (Fuhlendorf et al. 2012).

BCM approach: Manage for native plant communities

Variation in aspect, slope, soil and moisture, among other factors leads to inherent small-scale and large-scale variation in species composition and structure of prairie plant communities (Milchunas et al. 1989). Under BCM, ecological processes, particularly fire and grazing (discussed below), are allowed to interact with this pattern of topoedaphic conditions and plant communities at multiple scales. These interactions of pattern and process generate a shifting mosaic of habitat heterogeneity that is a cornerstone for Great Plains biodiversity (Anderson 2006, Fuhlendorf et al. 2012). BCM therefore aims to restore and maintain natural topoedaphic and plant community patterns by not employing management interventions such as overseeding and herbicidal and mechanical treatments. Specialized approaches of targeted management, however, may be required to address serious threats, such as exotic species invasions.

Herbivory Patterns

Common LCM approach: Manage for uniform grazing intensity

A common rule of thumb in rangeland management is "take half leave half," whereby the distribution of livestock is managed so that they graze half of the standing forage down to a uniform height (Bailey et al. 2010, Briske et al. 2011, Holechek et al. 2011). The Natural Resources Conservation Service (NRCS), the U.S. government's primary agency providing assistance to livestock producers, extensively promotes these practices by financing prescribed grazing and the installation of fencing and watering facilities (Toombs and Roberts 2009). As discussed below, the distribution of water sources is crucial because cattle generally do not forage more than 1.6–3.2 km from water (Holecheck et al. 2011). Agriculture and Agri-Food Canada also endorses uniform grazing (Bailey et al. 2010). The result is that the full spectrum of habitats that support diverse assemblages of prairie birds and rodents (Knopf 1996, Briske et al. 2011), ranging from ungrazed, tall and dense vegetation to intensely utilized sites with little or no vegetation, are missing (Fuhlendorf et al. 2012). Decoupling of grazing and fire (see below) exacerbates the problem of vegetative uniformity across the landscape. More generally, the common LCM practice of achieving an optimal stocking rate (Briske et al. 2011) is problematic for biodiversity because no single stocking rate is optimum for all species and processes (Fuhlendorf et al. 2012).

BCM approach: Manage for grazing heterogeneity and multi-scale selection by herbivores

Natural grazing and browsing patterns of bison (*Bison bison*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), deer (*Odocoileus virginianus* and *O. hemionus*), and black-tailed prairie dogs (*Cynomys ludovicianus*) interacted with fire to create habitat heterogeneity at multiple scales across the landscape (Samson et al. 2004). Cattle grazing can be managed to create habitat heterogeneity and, particularly when combined with patch fires, can be applied at larger spatial scales under continuous grazing rather than rotational grazing regimes (Derner et al. 2009, Fynn 2012). How well this can mimic historic natural conditions is unclear. In studies that compared bison and cattle, bison consumed a higher proportion of grasses and sedges relative to forbs and woody vegetation, exhibited much larger foraging patches, and spent less time in wooded areas and near water while foraging, among other differences (Knapp et al. 1999, Allred et al. 2011, Kohl et al. 2013). Although one small-scale (4.9 ha pastures) study in tallgrass prairie found that differences between bison and cattle foraging had minor effects on plant communities (Towne et al. 2005), longterm effects may be substantial at larger scales where animals can interact with complex landscapes (Allred et al. 2011, Kohl et al. 2013).

Fire

Common LCM approach: Suppress fires or conduct prescribed fires

Prairie fires were common before Euro-American settlement (Anderson 2006), but LCM generally entails fire suppression or, much less frequently, prescribed burning to create uniform, optimal forage conditions (Fuhlendorf et al. 2011). Fire suppression has led to widespread invasion of shrubs and trees in grasslands, with negative effects for both livestock production and biodiversity. Prescribed fires are often employed to control woody plants and to maintain forage species important for livestock, but grazing animals are rarely allowed to interact with fire to create a shifting mosaic of habitat heterogeneity (Fuhlendorf et al. 2009, 2012). Moreover, checkerboard land ownership is a management barrier to allowing landscape-scale fires.

BCM approach: Manage for periodic and variable patch fires

Great Plains biodiversity depends on the interplay of grazing and periodic fires ignited by both lightning and indigenous people (Knopf and Samson 1997, Fuhlendorf et al. 2009). Compared to natural fires, traditional burning patterns by indigenous people were generally at smaller scales and created a patchwork of burned sites that limited large extreme fires and interacted with landscape complexity to increase habitat heterogeneity (Lewis and Ferguson 1988). Pyric herbivory, whereby grazers preferentially graze recently burned sites, creates a shifting mosaic of grassland habitats that support a relatively high diversity of grassland birds, mammals and insects (Fuhlendorf et al. 2006, Churchwell et al. 2008, Coppedge et al. 2008, Augustine and Derner 2012). The interaction of fire and grazing is also important for other aspects of ecosystem structure and functioning, including nutrient cycling and control of invasives (Fuhlendorf and Engle 2004).

Habitat Contiguity

Common LCM approach: Fragment habitats

Fences installed to manage livestock are the most ubiquitous feature fragmenting Great Plains landscapes. Fence construction supported by NRCS and U.S. Bureau of Land Management continues to increase fence density across western U.S. rangelands (Connelly et al. 2004, Toombs and Roberts 2009). Fences alter natural foraging patterns, movement and migration of ungulates (Gates et al. 2011) and cause wildlife mortality (Wolfe et al. 2007, Stevens et al. 2012). Many grassland birds avoid nesting near novel vertical structures such as fences and shelter belts or trees at the edges of stock ponds, and nest mortality is greater near such features because they attract predators and nest parasites (Freilich et al. 2003, Shaffer et al. 2003, Coppedge et al. 2008).

BCM approach: Manage for habitat contiguity

For many species that are highly adapted to prairies, habitat contiguity requires a largely two-dimensional landscape without novel vertical structures—fences, trees, buildings—that are much higher than native prairie vegetation. For example, absence of fences enables freer movements for migration and escape by pronghorn, Greater Sage-Grouse, and Lesser Prairie-Chickens (*Tympanuchus pallidicinctus*) (Wolfe et al. 2007, Gates et al. 2011, Stevens et al. 2012) and permits large-scale foraging patterns by bison and other ungulates (Fuhlendorf et al. 2009). For many grassland birds, absence of vertical structures is important for nest-site selection and brood rearing (Freilich et al. 2003, Shaffer et al. 2003, Coppedge et al. 2008).

Stream Hydrology

Common LCM approach: Alter streams to improve water availability

Water impoundments constructed for livestock (stock ponds) and water diversions and spreader dikes for irrigating hay meadows are ubiquitous on 1st to 4th order streams across much of the Great Plains. Uplands of the Great Plains are characterized by intermittent prairie streams that exhibit extreme variation in flow with ephemeral pools during dry periods (Dodds et al. 2004). Uplands have few natural small bodies of water (less than 10,000 sq m), but due primarily to construction of stock ponds since the early 1940s, densities of small water bodies are now at least 0.1–0.3/sq km across the region, and 0.3–4/sq km in many areas (Renwick et al. 2005). Stock ponds alter upland biodiversity by: (1) fragmenting prairie streams, thereby impeding movement and recolonization by aquatic organisms; (2) modulating downstream flow resulting in reduced flooding and recharge of ephemeral pools and alteration of biogeochemical processes (interception and temporary storage of runoff in regions with high pond density may approach 100%); (3) promoting uniform grazing by livestock; and (4) providing exotic habitats which act as stepping stones to upland areas for invasion by non-native aquatic species that require standing water and by riparian species that require moist conditions (Smith et al. 2002, Dodds et al. 2004, Havel et al. 2005, Renwick et al. 2006).

BCM approach: Manage for natural stream flows

Large variations in flow of intermittent and perennial prairie streams are vital to biogeochemical and ecological processes that create a diversity of habitats and support unique assemblages of prairie fish and other organisms (Smith et al. 2002, Dodds et al. 2004). Fluctuation in stream flows and the availability of water also strongly influence grazing patterns; scarce water sources can be expected to create more variable grazing conditions across the landscape as animals must travel further between water and grazing sites (Allred et al. 2011). Bison readily forage more than 10 km from water—possibly much more—and thus, in contrast to cattle, are well adapted to water scarcity (Kohl et al. 2013).

Temporal Ecological Variability

Common LCM approach: Modulate temporal ecological variability

LCM generally aims for a steady-state condition by modulating the ecological effects of extreme intra- and interannual variation in temperature and precipitation and associated fire and grazing patterns (Anderson 2006, Fuhlendorf et al. 2012). Of particular concern to livestock production, grasslands show more interannual variability in aboveground productivity than any other biome in North America (Knapp and Smith 2001). As described above, modulation is sought by managing for uniform production of preferred forage species over space and time. Supplemental feeding bridges periods of inadequate forage. Stock ponds and tanks reduce intra- and interannual fluctuations in availability of water that characterize intermittent prairie streams (Renwick et al. 2005). Wildlife management agencies further dampen temporal variability on LCM lands—and often on BCM lands—through game management policies that modulate natural population fluctuations (Sutherland 2001).

BCM approach: Accept high temporal ecological variability

BCM recognizes that Great Plains biodiversity depends on disturbances from drought, fire and grazing operating at multiple scales across the landscape (Knopf and Samson 1997, Anderson 2006, Fuhlendorf et al. 2012). These disturbances and other factors interact to create highly dynamic ecological conditions at the local scale and, at larger scales, a shifting mosaic of habitat diversity and ecological stability (Fuhlendorf et al. 2012).

Herbivorous Mammals

Common LCM approach: Manage for high livestock numbers and few wild herbivorous mammals

The black-tailed prairie dog, a keystone herbivore of the Great Plains, is poorly tolerated under LCM because of concerns about competition for forage (Derner et al. 2006) and now occupy 2% of their original range (Forrest 2005). Wild ungulates, especially elk and bison, are tolerated at reduced numbers or not at all on Great Plains rangelands because of forage competition, disease concerns and damage to fences, among other concerns (Freilich et al. 2003). Forage competition and social avoidance generally lead to declines in wild ungulate numbers as livestock numbers increase, particularly during periods of nutritional stress (Briske et al. 2011). Elk occupy a small fraction of their former range on the Great Plains (Laliberte and Ripple 2004). All wild populations of bison are confined to public protected areas (Aune and Wallen 2010). Commercial bison herds, increasingly common in the Great Plains, do not fulfill their native ecological role when managed according to common LCM grazing practices (Allred et al. 2011). Replacement of native herbivorous mammals by livestock simplifies herbivory patterns and reduces the diversity and abundance of prey and carcasses for predators, scavengers and decomposers.

BCM approach: Manage for natural populations of native herbivorous mammals

Restoration of two keystone species of the Great Plains, bison and black-tailed prairie dogs, to natural populations across large landscapes is central to BCM (Truett et al. 2001, Samson et al. 2004). Prairie dogs occupy a central role in prairie ecosystems as prey for specialized predators and by creating habitat heterogeneity through burrowing and herbivory (Augustine and Baker 2013). In addition to their effects as dominant grazers and the Great Plains' largest prey, bison wallowing created millions of disturbed sites and small wetlands, and bison horning and girdling of woody plants may have been a factor limiting the historic distribution of woody plants in the Great Plains (Truett et al. 2001, Gogan et al. 2010). Apart from their impact as a large grazer and browser in prairie ecosystems, elk were important in the food chain for predators, scavengers and decomposers (Beschta and Ripple 2009).

Fate of Ungulate Production

Common LCM approach: Harvest all domestic and most wild ungulate production

Under LCM nearly all surplus livestock production is removed from the landscape (Freilich et al. 2003, Towne 2000). Predation of livestock is relatively rare. An estimated 3% of livestock die annually and remain on the landscape as carcasses in the western United States (Ripple et al. 2013). Moreover, hunting in the Great Plains results in removal of a large portion of the annual production of ungulate biomass from the landscape, a practice often supported by livestock producers to reduce forage competition. Hunter kills are also, compared to natural predation, highly aggregated in time and space, resulting in distinctly different effects on scavenger communities and nutrient deposition from carcasses (Wilmers et al. 2003b, Bump et al. 2009). The combination of greatly increased biomass removal and altered carcass distribution is likely to have substantially different effects, compared to intact predator-prey conditions, on both the spatiotemporal heterogeneity of soil properties and plant communities and on populations of apex predators, scavengers and decomposers (Towne 2000, Wilmers et al. 2003b, Beschta and Ripple 2009, Bump et al. 2009).

BCM approach: Leave most ungulate production on the landscape

Under BCM most ungulate biomass remains on the land to support natural trophic level interactions. This is impractical with livestock and thus BCM emphasizes a shift from livestock to natural population levels of wild ungulates. Great Plains ungulates are important food for three apex predators—wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), and cougars (*Puma concolor*)—and numerous vertebrate and invertebrate scavengers and decomposers (Truett et al. 2001, Wilmers et al. 2003a, Carter et al. 2007). The carcass of a large ungulate, particularly bison or elk, creates a major disturbance marked by an episodic nutrient pulse, increased soil microbial activity and nematode abundance, and a succession of new plant growth that is distinct from surrounding prairie vegetation (Carter et al. 2007). Plant growth in a nutrient-rich ring around the disturbance may create positive nutrient feedback by attracting grazers whose urine and dung expand the nutrient-rich patch beyond the carcass boundary (Towne 2000). Physical and biogeochemical disturbances from a wide range of carcass sizes have significant and lasting effects on a wide range of ecological systems (see discussion by Bump et al. 2009). It therefore seems plausible that decaying ungulate carcasses contributed substantially to habitat heterogeneity in the Great Plains, an effect that was magnified during episodic bison die-offs (Knapp et al. 1999).

Apex Predators

Common LCM approach: Allow no or few apex predators

Concerns about livestock depredation and other factors resulted in the three non-human apex predators of the Great Plains—cougar, wolf, and grizzly bear—being extirpated from nearly the entire region by the early 1900s (Prugh et al. 2009). The human role as apex predator has changed in the last 150 years because humans now remove most of their preys' biomass—livestock primarily but also game animals—from the ecosystem. Only the cougar has successfully recolonized parts of its former range in the region (LaRue et al. 2012). Extirpation of cougars, wolves and (or) grizzly bears in the western United States appears to have resulted in higher populations and altered feeding behavior of ungulates, increased browsing that caused rapid declines in shrubs and trees and other changes in native plant communities, and a shift toward alternative ecosystem states (Beschta and Ripple 2009). As noted above, substitution of human hunting and other anthropogenic causes of ungulate mortality for predation by apex predations can affect consumer and plant communities in multiple ways (Wilmers et al. 2003b, Bump et al. 2009). Mesopredator population increases following eradication of big predators (mesopredator release) have diverse cascading effects through the food chain that can result in large changes in animal and plant populations and habitats (Prugh et al. 2009, Ripple et al. 2013). Evidence from diverse ecosystems demonstrates the multiple pathways by which the absence of apex predators leads to trophic downgrading and major ecosystem change (Estes et al. 2011).

BCM approach: Manage for natural populations of apex predators

The goal of BCM is to restore populations of cougars, wolves and grizzly bears to ecologically effective levels.

Wolves were more widely found across upland prairies as they followed bison herds, whereas cougars and grizzly bears were more confined to riverine areas, badlands and the region's isolated mountain ranges. These apex predators appear to have exerted strong top-down effects on biodiversity in western North America (Beschta and Ripple 2009, Ripple et al. 2013). Rather than the command-and-control role that prevails across the Great Plains, BCM includes humans as one apex predator among four to be considered in restoring and conserving biodiversity.

Size of Management Units

Common LCM approach: Create relatively small management units

Management units for LCM are generally measured in thousands to, at most, tens of thousands of hectares, the general range of ranch sizes in the Great Plains. Cooperation among adjacent landowners to create larger management units is rare. Fences usually divide property boundaries and fragment habitat. Neighboring livestock managers generally manage for similar ecological conditions, thereby reducing habitat complexity and mosaics at larger scales. Lack of large-scale management goals, planning, and action results in inattention to large-scale ecological patterns and processes (Samson et al. 2004, Fuhlendorf et al. 2012). NRCS reinforces this by focusing on individual management units or ranches with no protocol or program for measuring conservation effects at larger spatial scales (Bestelmeyer et al. 2011).

BCM approach: Create relatively large management units

Large management units of several hundred thousand hectares or more are required to support viable populations of large and wide-ranging species and for large-scale ecological processes such as pyric herbivory and stream flows. Large units more readily incorporate habitat complexity and accommodate disturbances that interact with complex landscapes and form multi-scaled habitat mosaics (Fuhlendorf et al. 2012). Large units enable unified management planning and action across landscape scales relevant to these large-scale ecological factors (Samson et al. 2004).

A Trophic Level View of LCM and BCM

LCM practices generally address all major trophic levels to maximize livestock productivity and profitability (Figure 2). LCM practices 1–6 are mostly aimed at primary productivity—how to get the most out of forage production across space and time. LCM practice 7 focuses on maximizing the allocation of primary production to livestock as primary consumers by eliminating or reducing native herbivorous mammals, particularly grazers, that compete for forage. Although LCM practice 8 greatly alters the ungulate assemblage of primary consumers, it is chiefly aimed at allocating secondary production to human use rather than to predators, scavengers and decomposers. Under LCM practice 9, secondary and tertiary consumers—specifically, predators capable of preying on livestock—are, to the extent practical, extirpated or reduced in number to avoid livestock loss. The relatively small size of LCM management units places constraints on ecological patterns and processes across all three trophic levels.

Economic Trade-Offs between LCM and BCM

Economic trade-offs between BCM practices and LCM practices have not been well studied and are highly sensitive to the ecological and socioeconomic conditions of an area. A detailed assessment of these trade-offs is beyond the scope of this paper, but we offer some general observations.

Of the ten BCM practices, we believe that five—managing for native vegetation and topoedaphic conditions, heterogeneous grazing, patch fires, contiguous landscapes and larger management units—will often have modest effects (negative or positive) on production and income for the livestock enterprise. Patch fires coupled with heterogeneous grazing (pyric herbivory) appear to have no discernible effect on livestock productivity (Fuhlendorf and Engle 2004, Fuhlendorf et al. 2013, Limb et al. 2011). Continuous grazing across large management units is equal to or superior to traditional rest-rotation grazing systems (Briske et al. 2008) and thus fencing, except perhaps perimeter fencing, is unnecessary, thereby greatly reducing habitat fragmentation as well as landowner costs. Production benefits of introduced non-native plants seem marginal or questionable (Willms et al. 2009). Similarly, control of invasive woody plants both reduces habitat fragmentation and benefits livestock production (Bidwell et al. 1996). We see no a priori reason that managing at larger spatial scales negatively affects cattle production.

Native herbivores may have a facilitative or competitive effect on livestock production. At low densities, for example, elk grazing of dead grass and sage-brush in winter may increase grass productivity in spring. As elk numbers increase, however, a threshold is reached and elk herbivory becomes competitive with cattle (Hobbs et al. 1996, Weisberg et al. 2002). Cattle and bison exhibit considerable dietary overlap (Plumb and Dodd 1993, Hartnett et al. 2007) and therefore above relatively low population levels we expect their relationship to be competitive. Effects of prairie dogs on livestock production are complex and, depending on site conditions such as rainfall amounts, may be facilitative or competitive (Derner et al. 2006, Augustine and Springer 2013). When competitive, the cost of prairie dog control may exceed reduced revenues from livestock production (Breland et al. n.d.).

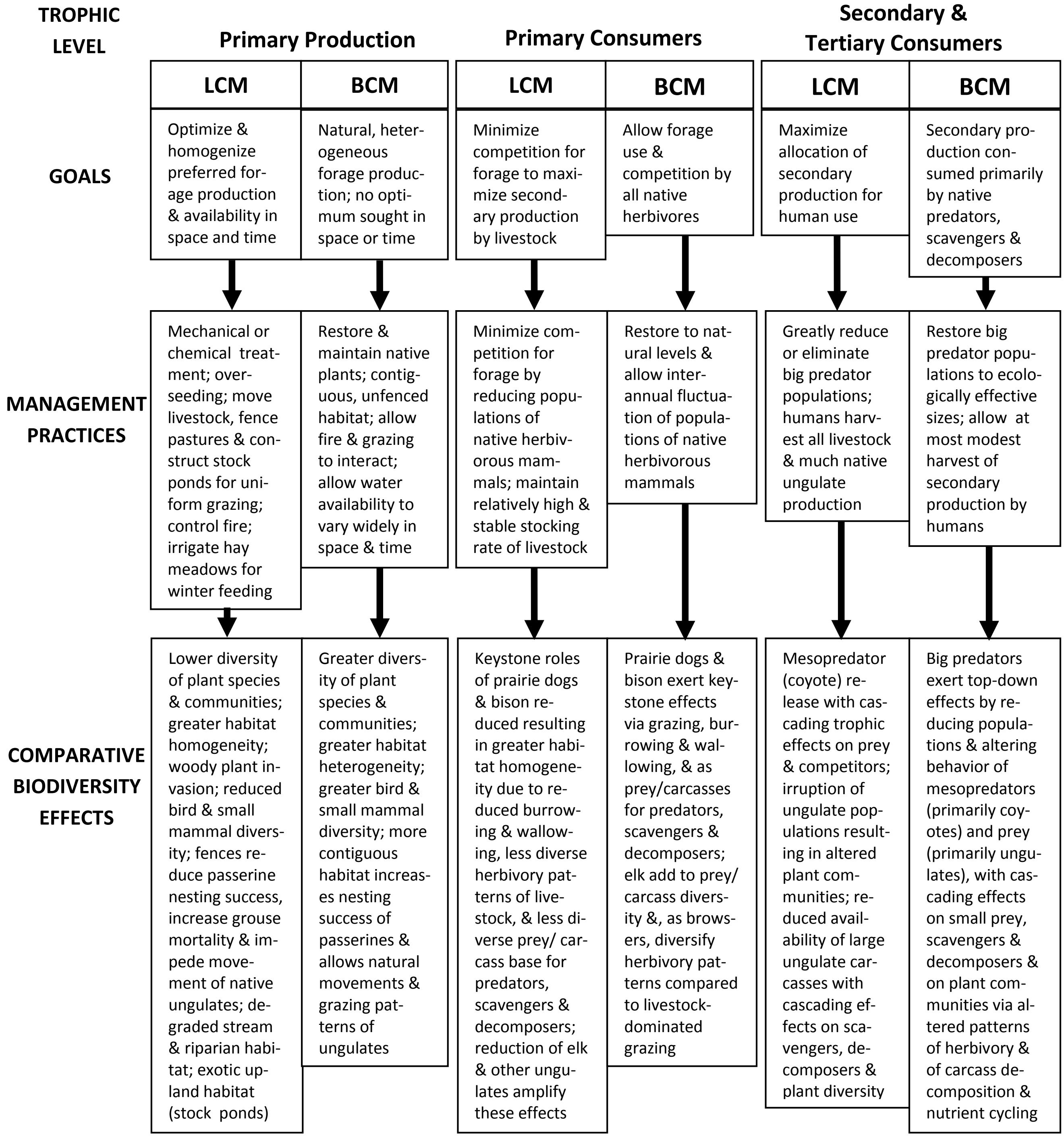

Figure 2. Comparison, by trophic level, of LCM and BCM goals, common management practices and examples of resulting effects on biodiversity.

Reduction of artificial water sources will often reduce livestock productivity as forage areas become too distant from water for use (Holecheck et al. 2011). More generally, allowing large intra- and interannual spatial and temporal variation in water availability and forage production that characterize Great Plains rangelands and can be expected to reduce production and profitability from livestock operations.

Wolves, cougar, and grizzly bears co-exist with livestock in many areas. However, large populations of these predators may result in predation on livestock and alter livestock behavior in ways that reduce productivity, depending on the predator's experience, whether the livestock are cattle, sheep or bison, the abundance of alternative prey, livestock herding techniques, and other factors (Musiani et al. 2003, 2005, LaPorte et al. 2010). These costs to the livestock industry are relatively small but they can be important to individual producers (Muhly and Musiani 2009, Rashford et al. 2010).

Tanaka et al. (2011:412) concluded that "When considering only forage value or livestock production from rangelands as the primary benefit, many conservation practices will not show a favorable benefit-to-cost ratio for conservation programs." For the majority of Great Plains landowners, however, including Indian tribes, traditional and nontraditional private owners, nonprofit organizations and government agencies, the importance of livestock profitability varies widely relative to other biodiversity-dependent, monetary and non-monetary values of the land. Increasingly, landowners can generate revenues from ecotourism, fee hunting, conservation easements, green labeling, habitat conservation, carbon sequestration and other ecosystem services, revenues that can compensate for reduced income from livestock (Havstad et al. 2007, Goldstein et al. 2011). Moreover, aesthetic, spiritual and other non-monetary motivations based on conservation interests and "doing the right thing" strongly influence landowner management decisions (Chouinard et al. 2008).

Discussion

Partial or even complete transition from the ten LCM to the ten BCM practices is in large part ecologically feasible on Great Plains rangelands. Restoration of natural stream hydrology poses the biggest challenge in some areas because of the intensity of infrastructure and landscape engineering at both small and large scales. Reversing the spread of some introduced forage species, such as smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pretensis*), may be equally challenging (Ellis-Felege et al. 2013). Proper sequencing is important for some management changes. For example, the creation of large management units needs to precede restoration of species with large area requirements such as apex predators and of large-scale processes such as pyric herbivory. Wolf restoration, as a check on population growth of coyotes and their effects on prey, may need to precede the accumulation of large ungulate carcasses across the landscape (Ripple et al. 2013). Overall, however, the ecological obstacles to biodiversity restoration of the region's rangelands are highly surmountable.

We expect changes underway in land ownership to favor an ongoing management shift toward biodiversity values on western rangelands, including the Great Plains. An increasing number of individual and corporate buyers are seeking natural-amenity and investment values from the land (Havstad et al. 2007, Hodur et al. 2012, Sorice et al. 2012), livestock profits are often of secondary importance in ranch valuation and purchase decisions (Torell et al. 2005), and new rangeland owners show greater interest in, and financial capacity for investing in conservation practices (Gosnell et al. 2006, 2007, Sorice et al. 2012). Growing public interest in how public lands are managed is leading public agencies to give increasing attention to biodiversity conservation. Public and nonprofit entities are buying lands in areas of high biodiversity value for the creation and expansion of protected areas (APR 2013, Parks Canada 2013, TNC 2013). American Prairie Reserve (APR) has adopted our management framework for setting management goals and evaluating progress on 111,000 ha of rangelands, including both APR-owned lands and leased public lands, being converted from LCM to BCM.

Livestock production will dominate land use of Great Plains rangelands for the foreseeable future. Thus our emphasis is on the transition "toward," rather than "to" BCM. The framework, however, serves either purpose, and combined with socioeconomic trends, points to the feasibility of making major gains in restoring Great Plains biodiversity over the next two decades. To realize these gains and to improve our proposed framework, we need much more research and long-term monitoring of how management changes outlined here affect livestock production, biodiversity targets, revenues and costs, and non-monetary values derived from rangelands.

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