Livestock Management for Coexistence with Large Carnivores, Healthy Land and Productive Ranches

Ranchers can apply many of the same management approaches that work for land health and livestock production to prevent conflicts with large carnivores.

A white paper

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Abstract

Livestock – large carnivore coexistence practitioners can be more effective by expanding from a direct focus on carnivores and predation-prevention tools to the broader social-ecological context of ranches and rural communities, especially livestock management. Ranchers can apply many of the same approaches that work for rangeland health and livestock production to reduce conflicts with large carnivores. This paper synthesizes evidence from the rangeland, wildlife, and animal sciences into a cohesive argument: modeling livestock management after the grazing patterns and reproductive cycles of wild ungulates in the presence of their predators can improve rangeland health and livestock production—and increase the ability of ranching operations to coexist with native carnivores. The central anti-predator behavior of wild grazing animals is to form large, dense herds that then move around the landscape to seek fresh forage, avoid fouled areas, and escape predators. They also have their young in short, synchronized birthing seasons (predator satiation). Grazing management involving high stocking density and frequent movement, such as rotational grazing and herding with low-stress livestock handling, can improve rangeland health and livestock production, by managing the distribution of grazing across time, space, and plant species. Short calving seasons can increase livestock production and reduce labor inputs, especially when timed to coincide with peak availability of forage quality. Such livestock management approaches based on anti-predator behaviors of wild ungulates may directly and synergistically reduce predation risk—while simultaneously establishing a management context in which other predation-prevention practices and tools can be used more effectively.

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Can modeling livestock management after the grazing patterns and reproductive cycles of wild ungulates in the presence of their predators improve rangeland health and livestock production, and increase the ability of ranching operations to coexist with native carnivores? Evidence in the rangeland, wildlife, and animal science fields suggests so, but it has never been synthesized into a cohesive argument. Livestock-carnivore coexistence in the context of an ecologically and economically thriving ranching sector requires integrating knowledge of rangelands, livestock, and wildlife, as well as the perspectives of their respective fields of study and management (Breck et al. 2012).

The vast landscapes that support large herds of grazing animals and their predators, known as rangelands, are the quintessential landscapes of the American West. Most of these grasslands, shrublands, savannas, and woodlands provide habitat for both wildlife and livestock, and are part of someone's ranch or public-land grazing allotment (USDA-NRCS 2003; USDA-FS 2014; USDI-BLM 2015). In North America, these are the lands that provide much of the habitat for animals like bison, deer, elk, and pronghorn—and in turn for wolves, coyotes, grizzly bears, and mountain lions. This is also where those carnivores come into conflict with livestock and humans. Livestock-carnivore conflicts are a concern for many ranchers in the region (Muhly and Musiani 2009; Sommers et al. 2010) and a substantial source of carnivore mortality (Gunther et al. 2004; Musiani et al. 2005; Schwartz et al. 2006) and social polarization (Clark et al. 2005; Woodroffe et al. 2005).

North American large carnivores are mostly habitat generalists, able to live anywhere from desert to mountains, as long as prey is sufficiently abundant and conflict with humans is not excessive. Habitat includes both the resources and the *conditions* for a species' persistence. In the Northern Rockies, the large national parks and wilderness areas are relatively "secure" habitat for large carnivores, in the sense that they can serve as refugia from human persecution. In between these protected areas are the expanses of working landscapes, dominated by native vegetation, and supporting prey animals. The working landscapes may or may not be *available* habitat for carnivores, depending on human activities and tolerance; thus these lands provide important opportunities for carnivore conservation.

Overall, most carnivores are opportunistic, and the number of livestock losses to predators is low relative to other sources of mortality. Most bears and wolves remain focused on wild prey, even when livestock are nearby (Fritts et al. 1992; Oakleaf et al. 2003). But some individual predators do switch their focus to livestock (Morehouse and Boyce 2011), and if they do they are often removed by management agencies. Non-targeted lethal predator control is often ineffective at reducing livestock losses, partly because it can shift the age structure of the population to younger, less-experienced, and more transient individuals, and partly because removal of individuals not focused on livestock opens up a place for other individuals that may be or become focused on livestock (Treves and Naughton-Treves 2005; Robinson et al. 2008). One recent study found that wolf control could actually contribute to increased predation on livestock in certain circumstances (Wielgus and Peebles 2014). With proactive management we cannot expect to prevent all depredations by preventing predators from switching from wild prey to livestock, but we may be able to keep them to a lower, opportunistic level while also generating benefits to rangeland and to people.

Conservation strategies that separate or exclude people from nature are insufficient to build resilience in social-ecological systems or foster harmonious coexistence between humans and wildlife; they may also generate conflict between people (Treves 2008). Conservation efforts that recognize humans as a part of nature are likely to be more effective than those that do not, as human activities and decisions now affect all ecosystems. Broad stakeholder engagement and input is now recognized by many as essential to lasting and robust conservation outcomes (Peterson et al. 2010) and is necessary in human-wildlife conflict work since conflict reduction is largely voluntary. Ultimately, building social carrying capacity for wildlife requires reconciling the often deep-rooted conflicts between people manifested in these issues (Madden and McQuinn 2014). Though not the focus of this paper, the need for relationship in this work cannot be overstated, as it relies on landowner collaboration often with outside parties.

Developing human tolerance for carnivores is a complex endeavor that includes preventing or mitigating livestock depredations. Ideally developing tolerance, or better yet appreciation of carnivores occurs as part of a broader cultural evolution towards resilience in social-ecological systems. Much of this takes the form of working with the ranching community to improve rangeland health—the proper functioning of ecological processes—and thus the capacity of the land to produce biological diversity and ecosystem services, including forage for both wildlife and livestock. Ranchers generally seek a rural quality of life, including connection with the land, and to earn a living directly from the land and livestock; they have a vested interest in the health of their livestock and the grazing lands on which they operate. While largely utilitarian, these goals broadly align with conservation goals as they both rely on land health.

Much of the work done to reduce carnivore-livestock conflict has focused on keeping carnivores physically separated from humans and livestock, and on developing tools to manage the carnivores, such as human presence, guard dogs, and mechanical tools (Shivik et al. 2003; Shivik 2004, 2006; Clark et al. 2005; Woodroffe et al. 2005). Coexistence practitioners can become more effective by shifting their focus from the wild animals to the domestic animals, which, after all, are much more manageable. Moreover, only within certain livestock management contexts can tools be applied effectively (Shivik 2004).

Livestock grazing management has been an important specialization within rangeland science and management. In the management realm, rangeland conservationists and progressive ranchers have advocated and applied grazing management "systems" such as rotational grazing, a broad category where livestock are concentrated and moved through a series of pastures or paddocks, rather than scattered over most of the landscape (as distinguished from continuous or season-long grazing, rotational rest, or rotational deferment). Rotational grazing or similar approaches are generally adapted to specific landscapes and usually managed adaptively (Sayre 2000; White 2008; Barnes and Hild 2013; Teague et al. 2013), and are often applied in the broader framework of Holistic Management (Dagget 1995; Stinner et al. 1997; Savory with Butterfield 1999; Montagne and Orchard 2000; Howell 2008). Progressive livestock management practices such as green-grass calving, rotational grazing, and herding using low-stress livestock handling, are partly based on the patterns of wild ungulate herds, and are collectively called "the New Ranch" (Sayre 2000; White 2008) and "ranching in nature's image" (Howell 2008). These practices have been reported to facilitate improved rangeland health, livestock production, and ranch profitability, but are still in the early-adoption phase represented by the most progressive managers (Stinner et al. 1997; Provenza 2008; Barnes 2011; Barnes and Hild 2013).

In rangeland science, classical grazing studies, generally at small scales and with rigidly applied grazing schedules, found little or no advantage to rotational over season-long grazing (Briske et al. 2008, 2011)—in apparent contrast to the experience of many rangeland managers. At larger scales, incorporating complexity and adaptive management, rotational grazing can be used to improve rangeland health and grazing capacity (Norton 1998, 2003; Teague et al. 2013). The range profession is now moving the discussion beyond the old debate, to the strategic management of grazing across space and time, in the context of complex creative systems (as shown in a recent special issue of *Rangelands*; Barnes and Hild 2013). The range science field's more general focus on plant-herbivore interactions has been only minimally extended to herbivore-carnivore interactions. Such an extension, this paper argues, has paradigm-shifting importance for livestock-carnivore coexistence.

This paper synthesizes evidence from the rangeland, wildlife, and animal sciences into a cohesive argument: *Livestock management modeled after the grazing patterns and reproductive cycles of wild ungulates in the presence of their predators can—while maintaining or improving rangeland health and livestock production—directly and synergistically reduce predation, while establishing a management context in which other predation-prevention practices and tools can be used more effectively.*

Livestock Management as Context for Livestock-Carnivore Coexistence

As a sub-field within wildlife conservation, coexistence is inherently bottom-up, practical, science-based, and collaborative, rather than top-down and regulatory; yet practitioners have historically emphasized approaches that keep carnivores physically separated from humans and livestock (Robel et al. 1981; Shivik et al. 2003; Shivik 2004, 2006; Clark et al. 2005). The emphasis on carnivores rather than management context is due to several factors. The coexistence field arose after North American large carnivore populations were decimated, the social-ecological system of the western range including land tenure patterns was established, and the overall wildlife management systems based on the North American Model were in place. It is probably also partly because of the artificial separation between the rangeland and wildlife disciplines; wildlife professionals are often unfamiliar with livestock grazing management, and rangeland professionals are often untrained in carnivore biology and predator-prey interactions. Wildlife biologists and conservationists have generally dominated the livestock-carnivore coexistence field, more than rangeland ecologists or managers.

Arguably, the most pragmatic strategies are those that address multiple goals, in this context including rangeland health, well-managed grazing, and wildlife habitat availability. The effects of livestock grazing on the land can be positive or negative depending on how the grazing is managed. Rangelands evolved with grazing by large ungulates (Stuart Hill and Mentis 1982; Frank et al. 1998). However, the replacement of free-ranging wild herbivores with livestock managed by humans has led to degradation of some rangelands while others have remained resilient, depending on the intensity and distribution of grazing across space and time (Milchunas and Lauenroth 1993; Vavra et al. 1994). However one views grazing and its impacts, most rangelands are valuable for livestock production, and thus will likely continue to be used for livestock grazing into the foreseeable future.

Very little existing science has directly examined linkages between livestock management and predation. In Montana and Idaho, wolf depredation on cattle is correlated with pastures that are larger, have larger herds, and have more overlap with wild prey and predators (all of which are confounded; Bradley and Pletscher 2005). In the Rocky Mountains of the northern U.S. and Alberta, Canada, wolf predation of livestock peaks during the summer grazing season when livestock are most spread out; another depredation season coincides with calving season in the U.S. (Musiani et al. 2005). Based on this seasonal trend, the authors suggested that preventative approaches focus on animal husbandry, but they did not suggest specific methods. Yearlong grazing and calving, as well as very small groups of cattle, were associated with higher depredation rates in a case study of two ranches in the Mogollon Mountains of Arizona – New Mexico, but causality could not be conclusively established (Kluever et al. 2008; Breck et al. 2011, 2012). Several authors have said that livestock management might be related to predation without clearly showing how (Linnell et al. 1996; Merrigi and Lovari 1996; Ciucci and Boitani 1998; Rasmussen 1999; Mech et al. 2000; Fritts et al. 2003; Musiani et al. 2005). In many cases livestock nutrition or health may be an ultimate cause of losses, masked by predation as a proximate cause (Cozza et al. 1996). A meta-analysis of 28 human-predator-prey conflict studies from around the world found that husbandry level, in general terms of fenced pastures, frequency of humans spending time with livestock, and night penning, increased with both land productivity and predator density, but the studies in their analysis were insufficient to establish correlation between husbandry and actual livestock losses (Graham et al. 2005). Other studies have found that fine-scale livestock husbandry practices specifically focused on preventing predation, such as night penning and human presence around corralled animals, can be effective (Robel et al. 1981; Ogada et al. 2003; Woodroffe et al. 2007).

The patterns of behavior of wild herbivores in the presence of carnivores suggest some ways to manage domestic herbivores, especially the way they are distributed across space and time. Generally, wild grazing animals tend to form large, dense herds that then move around the landscape to seek fresh forage, avoid fouled areas, and escape predators. They also tend to have their young in short, synchronized birthing seasons—swamping potential predators. Following a brief review of how livestock management practices based on these patterns have been shown to facilitate improved rangeland health, livestock production, and ranch profitability, this paper argues that these approaches may directly and synergistically reduce predation while establishing a management context in which other predation-prevention practices and tools can be used more effectively.

Grazing Management: Distribution of Livestock on the Landscape

Rangelands have evolved with grazing by large ungulates since the late Mesozoic Era, with grasslands supporting more animal biomass and herbivory than other ecosystems (Stuart Hill and Mentis 1982; McNaughton et al. 1989; Frank et al. 1998). However, the replacement of free-ranging wild herbivores with livestock managed by humans has led to degradation of some rangelands while others have remained resilient. Domesticated livestock have become sedentary as humans restricted their movements across landscapes, suppressed periodic fire, and eliminated large predators—leading to the removal of periodic grazing and rest (Milchunas and Lauenroth 1993; National Research Council 1994; Vavra et al. 1994).

On most of the world's rangelands outside of North America, fences are relatively rare and often cost-prohibitive, and livestock are herded daily (Coughenour 1991; Turner et al. 2005). Pastoralists essentially live with their livestock. Nomadic and transhumant herders who operate over great distances often camp with or near their livestock, while more sedentary livestock operations often involve returning the animals to the relative safety of a village, camp, or other headquarters at night. In Africa, where livestock cultures evolved with large carnivores, livestock are night-penned in kraals intended to protect the livestock from lions and other predators; some of these kraals are mobile.

Grazing management that involves bunching livestock into a single cohesive herd, keeping that herd in a limited portion of the landscape at any one time and moving the herd across the landscape over time, rather than scattering the animals across the entire landscape, has the potential not only to improve land health, increase biodiversity and grazing capacity by changing diet selection patterns (Norton 1998, 2003; Barnes et al. 2008; Barnes and Hild 2013; Teague et al. 2013), but also to help domestic herds re-learn their natural anti-predator behaviors. The link between grazing management and anti-predator behavior has been hypothesized (Coughenour 1991; Savory with Butterfield 1999), but has never been tested scientifically. Following is a brief review of the principles of grazing management for rangeland health and livestock production, an argument for extension of those principles to reducing losses to potential predators, and a brief overview of the essential practices.

Grazing Management for Rangeland Health

The effects of livestock grazing on land health (soil stability, hydrologic function, and biotic integrity: Pellant et al. 2005) can be positive or negative—depending on the specific context and how the grazing is managed (Milchunas and Lauenroth 1993; Vavra et al. 1994). The task of grazing management is to manage the overall intensity of grazing, the distribution of grazing across time, space, and plant species, so as to minimize repeated or over-grazing of desirable plants, while optimizing the proportion of the plant biomass available for grazing (Norton 1998, 2003; Teague et al. 2013; Barnes and Hild 2013).

To maintain rangeland health, forage demand must not exceed forage supply; yet, in the western U.S., most grazing problems are with distribution rather than absolute overstocking relative to forage mass. Both wild and domestic grazing animals tend to select preferred areas and plants (Senft et al. 1987; Bailey et al. 1996), which can lead to degradation (Milchunas and Lauenroth 1993; Vavra et al. 1994), especially in the case of livestock under less-intensive management regimes such as continuous grazing (Coughenour 1991). Expansion of degraded patches has occurred even in rested pastures (Fuls and Bosch 1991). Reductions in stocking rate alone (Kellner and Bosch 1992) at best only reduce the extent of heavily grazed patches (Hormay 1956; Morris and Tainton 1991; O'Connor 1992; Norton 1998, 2003; Provenza 2008; Teague et al. 2004, 2011).

Ideally, livestock grazing is managed such that animals use the entire ranch or allotment over the course of a grazing cycle, without repeatedly grazing the more desirable plants in preferred areas. A well-planned rotation can even out grazing across landscapes and shift selection to a wider variety of plants (Norton 1998, 2003; Barnes et al. 2008; Teague et al. 2013). The main guidelines are to incorporate diversity in pasture layouts, leave sufficient residual standing cover at the end of each grazing period, allow sufficient time between grazing periods that the preferred plants are re-grown before they are re-grazed, and vary the time of year that a pasture is grazed. In practice, this generally means relatively short grazing periods, with non-grazing periods long enough for plant recovery. On arid and semiarid rangelands, the ideal recovery period may be somewhat longer than a year. To accomplish all of this generally requires concentrating herds at relatively high stocking density (Steffens et al. 2009, 2013; Teague et al. 2013).

Many ranches have noted improvements in rangeland health after intensifying management, with rotational grazing (Sayre 2000; White 2008), especially when in the context of Holistic Management (Dagget 1995; Stinner et al. 1997; Savory with Butterfield 1999; Montagne and Orchard 2000; Howell 2008). These claims are borne out by recent case studies of creatively planned and adaptively managed rotational grazing on full-scale ranches, which have tended to show results opposite to small-scale grazing studies; with the most responsive variables tending to be soil parameters, ground cover, and species composition.

One study in particular measured soil health parameters on adjacent ranches in Texas. On ranches with rotational grazing compared to adjacent ranches stocked continuously at the same stocking rate, many soil health parameters improved: soil aggregate stability, soil penetration resistance, soil organic matter, cation exchange capacity, fungal/bacterial ratio, water-holding capacity, and nutrient availability were all higher, and sediment loss was lower (Teague et al. 2011).

With rotational grazing, compared to less-intensive management regimes, live plant cover increased, and bare ground decreased, and plant species composition and diversity improved, at multiple ranches in the tall-grass prairie of Texas (Teague and Dowhower 2003; Teague et al. 2004; Teague et al. 2011), the short-grass prairie of Colorado (Grissom and Steffens 2013), the southern Rocky Mountains of Colorado (Barnes and Howell 2013), the Pampas of Argentina (Jacobo et al. 2006), and semiarid New South Wales, Australia (Earl and Jones 1996). In short-grass prairie, rotational grazing initially failed when recovery periods were short and inflexible; but when recovery periods were lengthened based on plant growth processes, rangeland health improved, particularly in a shift from warm-season to cool-season grasses (Grissom and Steffens 2013). In the Southern Rockies, holistically planned, strategically managed rotational grazing redistributed grazing pressure from riparian areas to previously unpalatable bunchgrasses on steep slopes (Barnes and Howell 2013).

Grazing Management for Livestock Production

Livestock production is a function of the stocking rate relative to the grazing capacity for a particular place and time. Grazing capacity is not static but depends on forage mass, livestock species and type, grazing season, the distribution of grazing across the landscape and plant species, performance goals, and management (Heitschmidt and Taylor 1991; Teague et al. 2013). In practice, the maximum stocking rate is never desirable, as maximizing any single output of a system leads to loss of resilience (Walker and Salt 2006). The optimum stocking rate is somewhere between the rate that maximizes production per animal and the rate that maximizes production per area (Jones and Sandland 1974; Frasier and Steffens 2013).

Grazing management "systems," e.g., rotational deferment and rest, were originally developed based on the needs of rangeland plants, with less focus on livestock needs; rotational grazing, depending on the particulars of grazing frequency, intensity, and selectivity, is more suited than other "systems" to livestock nutritional needs (Kothmann 1980, 1984; Malecheck 1984). Stocking rate is generally more important than grazing "system" for livestock production (Hart et al. 1988, 1993; Bryant et al. 1989; Heitschmidt et al. 1990; McCollum et al. 1999). However, rotational grazing can be used to manage the stocking rate at a finer scale, effectively increasing forage availability (Norton 1998, 2003; Steffens et al. 2009; Barnes et al. 2011; Norton et al. 2013).

Grazing management can increase forage availability by increasing the proportion of the land area or the proportion of plant species contributing to the forage base (Norton 1998, 2003; Teague et al. 2013). Grazing is spatially uneven, especially under less-intensive management such as season-long grazing in large pastures (Coughenour 1991). Preferred areas and plants tend to be grazed repeatedly and excessively, at a higher effective stocking rate than the whole pasture (Ring et al. 1985; O'Connor 1992; Kellner and Bosch 1992), while ungrazed plants become unpalatable (Willms et al. 1988). Smaller pastures, higher stocking density, and shorter grazing periods—the hallmarks of rotational grazing—can make utilization more even across a grazing management unit (Norton 1998; Norton et al. 2013). As animals remove the higher-quality plants at the beginning of a grazing period, the proportion of forage that animals can consume and still meet their requirements decreases; thus short grazing periods increase the proportion of forage that animals can consume for a given level of performance (Norton 2003; Steffens et al. 2009; Barnes et al. 2011; Teague et al. 2013), an effect magnified by high stocking density (Peterson et al. 2013). Increases in grazing capacity due to pasture size and layout combined with strategic grazing management have been shown in southern Utah (Barnes et al. 2008), eastern Colorado (Grissom and Steffens 2013), and western Colorado, where grazing was redistributed from riparian areas to steep slopes, and to typically unpalatable and previously ungrazed plants, increasing grazing capacity by a factor of about 1.5 (Barnes and Howell 2013).

Ranch profitability depends on many factors, including stocking rate, and the variable cost of production, which can respectively be increased and decreased with grazing management (Frasier and Steffens 2013). Many ranchers have claimed higher profitability with creatively managed rotational grazing, especially in the context of Holistic Management, which includes financial planning as well as land and grazing planning (Dagget 1995; Savory with Butterfield 1999; Montagne and Orchard 2000; Sayre 2000; White 2008). The peer-reviewed literature contains very little economic data, as experiments generally are not conducted in real markets and can only make inference for profitability from changes in grazing capacity or stocking rates. A survey of 25 Holistic

Management practitioners in the US, who were presumably practicing rotational grazing, found that 80% perceived increased profitability (Stinner et al. 1997). At Rancho Largo, under strategically planned rotational grazing but only after recovery periods were adapted to plant recovery rates, profitability increased as measured by gross margin per head, total gross margin, and return to management (Grissom and Steffens 2013). A ranch in south Texas simultaneously reduced excessive stocking rates, minimized supplemental feeding, and implemented rotational grazing, collectively leading to increased profits both per head and per acre (Ortega-S. et al. 2013). The economics of grazing management is clearly a pivotal question and an important topic for future research.

Grazing Management for Coexistence with Carnivores

Herd formation most likely evolved in response to predation pressure; increasing group size (aggregation) is considered a passive anti-predator behavior, and may reduce the indirect costs or risk effects of active anti-predator behaviors (Creel 2011). The advantage of increased group size can be produced by several interacting mechanisms (Elgar 1989; Lima and Dill 1990; Roberts 1996; Creel 2011): the task of scanning may be spread over more individuals, reducing the individual need for vigilance (the detection or "many-eyes" hypothesis: Dimond and Lazarus 1974; Lima 1995; Roberts 1996); a predator may be less likely to find vulnerable individuals (the predator confusion effect: Milinski and Heller 1978; Jeschke and Tollrian 2007; Ioannou et al. 2008); and an individual reduces its risk of being taken (the "selfish herd" or dilution effect: Hamilton 1971; Olson et al. 2013), even if the overall herd risk is not reduced (Creel 2011), and especially when the herd also avoids encounters (attack-abatement effect: Turner and Pitcher 1986). Many North American wild ungulates aggregate in response to predation risk (Mech and Peterson 2003; Creel 2011), including pronghorn (Kitchen 1974; Berger 1978), mountain goats (Holroyd 1967), bighorn sheep (Berger 1978), caribou (Bergerud et al. 1984), mule deer and elk (Lingle 2001; Laporte et al. 2010), in some cases white-tailed deer (Nelson and Mech 1981) and moose (Molvar and Bowyer 1994). Elk may dilute their individual risk in large herds, but reduce the wolf encounter rate in smaller herds (Hebblewhite and Pletscher 2002). Mule deer are more likely than white-tailed deer to form large groups and stand their ground against a predator; mule deer in smaller groups are more likely to be attacked by coyotes (Lingle 2001). Muskox group size appears to be a tradeoff between individual predation risk and foraging efficiency, and directly related to wolf density (Heard 1992). African wildebeest increase group size in response to lions (Hunter and Skinner 1997), a behavior that theoretically stabilizes this and possibly many predator-prey interactions (Fryxell et al. 2007).

Large herds must move around the landscape to reduce predation risk (Fryxell et al. 1988; Seip 1991; Carbyn 1997; Mech and Peterson 2003), as well as to seek fresh forage and avoid fouled areas (Savory with Butterfield 1999; Provenza 2003). Wild herds such as bison are commonly thought to have massed in huge, dense herds, and conceptually this is part of the basis for rotational grazing (Coughenour 1991; Savory with Butterfield 1999). Observations of nineteenth-century wild bison suggest a more nuanced picture: animals would spread out in smaller groups, which were likely extended families, but would form large, dense herds under predation pressure (Hornaday 1889; Mayer and Roth 1958). Larger, mobile groups, particularly when comprised of extended families, provide health benefits, protection from predators, and enable knowledge of landscapes to be passed among generations. Movement can mitigate trade-offs between grazing within the group, and grazing outside the group, which ensures better nutrition but exposes animals to predators. Such social organization in mobile multigenerational family groups may lead to patterns approximating rotational grazing without fences (Provenza 2003; Shaw 2012).

Cervids, more than large bovines, are the primary prey of North American large carnivores (Mech 1970; Peterson and Ciucci 2003). For example, elk are usually wolves' primary prey wherever they are abundant, often followed closely by deer (Peterson and Ciucci 2003), such as in the U.S. and southern Canadian Rocky Mountains (Carbyn 1983; Weaver 1994; Kunkel et al. 1999; Smith et al. 2000*a*), or red deer in Europe (Kudaktin 1978; Okarma et al. 1995). In an encounter with wolves, large cervid prey are most vulnerable when isolated (Lingle 2001; Mech and Peterson 2003), and when wolves can instigate running rather than standing ground, triggering the rush and chase (Mech 1970, 1984; Gray 1987; Carbyn et al. 1993; MacNulty 2002; MacNulty et al. 2007). Generally, large carnivores kill fewer bovines such as bison or muskoxen than cervids such as elk or deer (Okarma et al. 1995; Smith et al. 2000*a*; Mech and Peterson 2003; Peterson and Ciucci 2003). Bison and muskoxen usually stand their ground against wolves, and when they do, wolves usually do not kill them (Smith et al. 2000*a*; Peterson and Ciucci 2003). They often keep their calves in the middle of the herd (Peterson and Ciucci 2003). Among Yellowstone bison, isolated individuals are slightly more likely to run from and be killed by wolves (Smith et al. 2000*a*).

The American slang term for cattle of "slow elk" (popularly attributed to Native Americans and rustlers) is ironic, considering that cervids, not large bovines, are the primary prey. When cattle exhibit behaviors similar to smaller cervids, such as smaller group sizes and flight from predators, it seems they are more likely to be killed. Cattle apparently exhibit less anti-predator behavior than elk (Kluever et al. 2008; Laporte et al. 2010; Breck et al. 2012), although the natural behavior of cattle is probably more like that of bison or muskox, to which they are closely related and similar in size. However, livestock producers have generally bred herds and trained individual animals not to behave this way, largely unintentionally. This happens in many ways, not least of which are scattering animals across large areas, creating general handling stress, or only gathering animals into a herd for occasional husbandry practices (Cote 2004; Hibbard 2012). Behaviorists call this negative reinforcement, essentially teaching the animals to avoid bunching and pairing—the very behaviors that would protect them. Modern cattle, in a behavioral sense, have indeed become those "slow elk."

In western North America, riparian areas and valley bottoms are often where prey animals are most vulnerable (Wilson et al. 2005, 2006), and they tend to be over-selected by cattle, especially under less-intensive management. In Yellowstone following wolf recovery, there is more evidence for trophic cascades involving vegetation release from wildlife grazing pressure in riparian areas (Ripple and Beschta 2003) than on uplands (Kauffman et al. 2010). A greater and faster vegetation response to reduced wildlife grazing in riparian areas than uplands is not surprising, considering that in livestock grazing management, both rest and intensification of rotations to even out distribution often result in faster and greater benefit to riparian areas than uplands (e.g., Butler 2000; Barnes and Howell 2013).

Livestock are most vulnerable to predation when scattered over large areas, as they generally are on conventionally managed rangelands. Larger pastures with more cattle, and more overlap with wild prey and predators, are more likely to generate depredations (Bradley and Pletscher 2005). The spatial dispersion of livestock is probably an underlying explanation for the wolf depredation season that corresponds with the summer grazing season in the U.S. Northern Rockies and Alberta (Musiani et al. 2005). Scattered individuals are more likely to run from predators, increasing their vulnerability. Intensifying grazing management such that livestock are bunched into a single cohesive herd, keeping that herd in a limited portion of the landscape at any one time, and moving the herd across the landscape over time—e.g., rotational grazing—has the potential to reduce predation losses similar to the group size effect in wild prey. A herd at relatively high stocking density maximizes the probability that the entire herd will detect a predator while reducing the individual need for vigilance (Carbyn and Trottier 1987; Kluever et al. 2008; Laporte et al. 2010; Breck et al. 2012), may promote mothers remaining paired with young, and likely facilitates active anti-predator behaviors such as standing ground and defending young. Individuals naive to predators may not exhibit these behaviors, but they have not been completely lost in domestication (Laporte et al. 2010); a dense and socially cohesive herd will likely facilitate group-learning of these behaviors. Finally, the ability to move livestock between distinct areas of a grazing management unit within a grazing season can reduce the livestock-carnivore encounter rate by allowing a reduction in the spatial overlap between livestock and wild prey, and avoidance of seasonally high-risk areas, e.g., wolf den and rendezvous sites (Oakleaf et al. 2003; Bradley and Pletscher 2005; Breck et al. 2011, 2012; Nelson et al. 2012).

Grazing Management: Ends and Means

The management that seems most likely to simultaneously maintain or improve rangeland health and livestock production, while also minimizing conflicts with large carnivores, is that which keeps livestock at high density and moving across the landscape over time. The *grazing management*, the overall strategy for affecting plant-herbivore-carnivore interactions, is of primary importance. This management can be accomplished to varying degrees with *facilitating practices*: cross-fencing for grazing "systems" especially rotational grazing, herding, strategic placement of supplements, rotating access to water sources, and patch burning. These are means to an end, and to be effective, must be used creatively and adaptively, based on ecological and behavioral processes, rather than methodically (Provenza et al. 2013; Steffens et al. 2013). The concepts may seem simple, but applying them is always complex, and every new management approach or tool has a learning curve (Provenza 2003, 2008). To accomplish the general goals of grazing management as described above for rangeland health, livestock production, and minimizing predation losses, the facilitating practices that are the most effective are rotational grazing, provided that there are enough pastures and they are small enough; and herding, if done in a way that achieves the same benefits as rotational grazing.

Rotational grazing, the planned movement of a single herd of livestock through a series of pastures within a grazing season, is a category that includes many variations, whether calendar-based or timed according to plant growth rates (including short-duration, time-control, cell, and management-intensive grazing; but distinguished from rotational deferment or rest). For rotational grazing to be effective, the non-grazing interval must be long enough for full plant recovery, and the grazing period should be short enough to minimize grazing of regrowth; which often takes about 8 to 10 pastures per herd (Steffens et al. 2013). More pastures per herd may have additional benefits through increased stocking density (Norton 1998, 2003; Steffens et al. 2009, 2013; Teague et al. 2013).

Cross-fencing to facilitate rotational grazing can be done cheaply with wildlife-friendly electric fence. Permanent electric (high-tensile) fencing is cheaper than barbed-wire fencing, and is less of a barrier to wildlife. Temporary electric fencing is cheaper yet, and its portability facilitates adaptive management. It is generally the most wildlife-friendly type of fence because it can be removed immediately after the grazing period. All types of fence, especially temporary electric, are susceptible to damage by wild ungulates.

Herding (the tending of livestock by herders on the range) generally implies controlling livestock movement without fences, or on a finer scale within a larger pasture. Open herding within a large management unit, such as from preferred (e.g., riparian) or sensitive areas to areas where more utilization is desired, can be effective range management (Williams 1954; Skovlin 1957; Butler 2000; Bailey et al. 2008), but may not maintain sufficient stocking density to prevent predation. Close herding (at high stocking density) through the management unit over the course of a season, if preventing repeat grazing of preferred plants, can be considered functionally equivalent to rotational grazing without physically bounded pastures (Meuret and Provenza 2014). Where grazing management is to be accomplished by herding rather than fencing, superior methods such as low-stress livestock handling, and skill level, become essential (Cote 2004; Bailey and

Stephenson 2013).

Low-stress livestock handling (LSLH) is a livestock-centered, behaviorally-correct, psychologically-oriented, ethical and humane method of working livestock, as developed by Bud Williams (Williams 1990; Smith 1998; Cote 2004; Hibbard 2012). A skilled rider can get the animals to want to go where he or she wants them to go, so that they go willingly and remain in that location longer. Operationally, LSLH means handling cattle with pressure and release, rather than force or reliance on fear; thus it is fundamentally different from conventional handling. It is counter-intuitive for most people and thus has not been widely adopted. In reality, conventional handling and LSLH can be considered a continuum with many handlers somewhere in the middle and closer to one or the other at various times. LSLH is part of the suite of skills referred to as *stockmanship,* which make intensified livestock management on rangeland feasible (Hibbard 2012).

Herd Management: Breeding Cycle

It is essential that livestock be locally adapted, in terms of species, breed, type, and age class, as well as health, and that animals not performing in their environment be culled from the herd, as many progressive producers are now doing (Provenza 2008; Barnes 2011). Where that environment includes potential predators, livestock must be able to avoid or survive encounters as much as possible. As for any prey species, maximizing survivability depends on minimizing predation risk at the most vulnerable stage in the life cycle of the species. The most vulnerable age class of herbivores is young-of-the-year, especially the very young, for both wild ungulates (Mech 1970; Mech and Peterson 2003; Peterson and Ciucci 2003) and livestock (Fritts et al. 1992; Oakleaf et al. 2003; Kluever et al. 2008; Breck et al. 2011); not surprisingly, calving and lambing pastures are conflict hotspots (Wilson et al. 2005, 2006).

Wild herbivores generally employ a strategy of predator satiation or swamping through synchronized birthing seasons, which maximize the adults' collective defense of young, reduce predators' ability to identify and kill otherwise vulnerable individuals, and produce many more young than predators can kill, maximizing the proportion of young that grow beyond the most vulnerable size (Bergerud 1971; Schaller 1972; Rutberg 1987; Adams et al. 1996; Adams and Dale 1998; Kunkel and Mech 1994). Shortening livestock calving seasons may reduce the likelihood of predators switching their focus from wildlife to livestock (Breck et al. 2011). The only study to assess the effects of duration and timing of calving on vulnerability was based on an analysis of wolf depredations on cattle in the Northern Rockies: in a sample of 14 depredated and 23 non-depredated calving pastures, neither duration nor timing was significant (Bradley and Pletscher 2005); but the range of practices applied may not have been sufficient to detect an effect as most ranches practiced winter to early spring, rather than late spring calving (E. Bradley, personal communication, Aug. 2014), reducing the likelihood of very short calving seasons.

The effect of timing of calving on vulnerability is likely case-specific and may be masked by other factors (e.g., herd and pasture size; Bradley and Pletscher 2005). Many ranchers may have the ability to calve in low elevations where large carnivores are less common (Breck et al. 2012), or where livestock can be kept on feed in small pastures close to ranch headquarters (Musiani et al. 2005). This may only be practical with winter to early spring calving for ranchers who use higher elevation rangelands with higher carnivore density beginning in late spring to early summer. However, winter to early spring calving may increase spatial overlap with elk and thus wolves (Bradley and Pletscher 2005). Winter calving may reduce losses to bears, which typically emerge from hibernation in March and April.

Thus, where large carnivores cannot be seasonally avoided, changing calving season from what is currently considered conventional for cattle (January-April) to May-June, to coincide with wild ungulate calving season (when the snow is gone and the grass is green) may reduce losses in some cases. When the calving seasons are distinct and consecutive, predators can focus on livestock from the onset of calving to late spring, and then switch to wild calves and fawns. If all wild and domestic calves are born simultaneously, predators are more likely to remain focused on wild ones. On mountainous ranges, this is especially likely if the wild ungulates have already begun their upward seasonal migration, with the predators following them, such that livestock and wild ungulates are geographically separated (by elevation).

For cattle, late-spring or early-summer calving contributes to a shorter calving season, and more efficient use of forage in general, because it matches the physiological cycle of the cow to the forage cycle of the range (Valentine 1990:130-136; Adams et al. 1996). In the Rocky Mountains, where the forage base is mostly cool season grasses, the peak of forage growth is usually June or July, and the lowest availability of quality forage is of course during the winter, especially late winter as forage is consumed. The cow's nutrient requirements are lowest during the second trimester of pregnancy (after weaning), and highest in early lactation. Timing peak demand with peak availability, and thus also minimum demand with minimum availability, decreases the need for supplemental feeding and may increase the proportion of cows that breed back in successive years (Deutscher et al. 1991; Clark et al. 1997; Stockton et al. 2007). Timing calving to peak forage quality means that cows will have been grazing freshly growing forage for at least a month prior to calving, likely improving cow body condition and reducing calving problems. When the cycles of reproduction and forage availability are matched, cows are more likely to be in better condition all year, come into first postpartum estrus sooner, and breed successfully on the first attempt, allowing for a shorter breeding season and therefore a shorter calving season.

These factors may translate into higher profits for green-grass calving. Later-born calves are younger at weaning, but may grow faster than their winter- or early-spring-born counterparts (compensatory gain), so that they are not much smaller by fall weaning time. Because the forage and cattle cycles are better matched, and because the calves are smaller, late calving allows more total cows and calves on the same forage base. A higher number of smaller calves are more profitable than fewer, larger calves if the total weight of weaned calves is similar (Clark et al. 1997; Stockton et al. 2007).

Coexistence: Expanding Focus From Tools to Management

Effective coexistence work requires not only expanding the focus from carnivores to livestock but also expanding the focus from facilitating practices, or tools (Shivik et al. 2003; Shivik 2004, 2006), to developing management contexts in which those tools can be used more effectively (Breck et al. 2012). Facilitating practices that can directly influence the management context in which livestock-carnivore interactions occur are preventative, and thus more important than smaller-scale non-lethal tools applied reactively. Whether preventative or reactive, practices or tools that can be applied creatively and adaptively are more likely to be effective. For example, range riders or herders and livestock guarding animals are "tools" with inherent adaptability, but their effectiveness depends on the context in which they work.

Many of the tools that have been developed for deterring predators are repellants that produce disruptive or aversive stimuli, and which must be selective and targeted in application (Shivik et al. 2003; Shivik 2004, 2006). What these tools all have in common is that they are focused on the predators and have limited adaptability and therefore limited efficacy. They are effective in the short term, much like a scarecrow or a fake owl in the garden. Over-reliance on them can create stimulus-resistant predators, as predators can become habituated to or learn their way around the tool (Shivik 2004, 2006).

Perhaps most importantly, none of the predation-prevention tools, including range riders and livestock guarding animals, are very effective when livestock are scattered over large areas (Shivik 2004), as is often the case on conventionally managed rangelands. Neither riders nor guarding animals can prevent isolated or distant animals from encountering or being killed by predators. Disruptive stimuli, especially those that do not require a human presence (e.g., fladry, motion-sensitive lights, or radio-activated guard [RAG] boxes; Shivik 2004, 2006) still need to be in close association with the livestock, and as such are rarely used on conventionally managed rangelands. Concentrating livestock at high stocking density (e.g., by rotational grazing or herding) creates a context in which all of the other tools are more effective, by reducing the spatial scale at any one time to a manageable level. Those other tools can then be applied when and where they are appropriate, on a scale that facilitates their effectiveness (Shivik 2004).

Coexistence practitioners and wildlife advocates should be careful not to overstate the potential of non-lethal tools to deter carnivores from interacting with or killing livestock, especially in the context of conventional management. Non-lethal tools are limited by cost as well as landscape and management context, and mechanical disruptive stimuli are also limited in length of time of efficacy (Shivik 2004, 2006). Over-focusing on the potential of the tools or claiming that they provide absolute solutions undermines practitioners' credibility, and takes the focus off the most effective (albeit more difficult) strategy: livestock management. Following is an explanation of how the effectiveness of range riders, livestock guarding animals, and fladry (as an example of a mechanical tool) depend on management context, and how a mechanical tool is limited by over-use.

Range Riders

Range riders or herders are potentially the most important of the preventative "tools" because humans are inherently creative and adaptive, and riders can serve as much more than a human presence. Only humans can simultaneously create the context in which livestock-carnivore interactions occur, adapt to predator behavior, reduce the probability of interactions resulting in depredations, and potentially "train" predators to associate livestock with humans and thus maintain distance. Nevertheless, range riding to prevent predation has not been well studied. Riders' efficacy likely varies widely and is probably heavily dependent on the landscape and management context (e.g., pasture size and stocking density) as well as what the riders actually do—e.g., actively herding and tending livestock (the original meaning of a "range rider") and simultaneously serving as human presence, versus covering a larger area looking for and responding to predators and carcasses (e.g., Breck et al. 2011). Riders need to be able to see most or all of the livestock in a short time to reliably respond to a predator presence.

Livestock Guarding Animals

Livestock guarding animals—livestock guarding dogs (LGDs), donkeys, and llamas—have all been used to reduce predation on livestock by wild and feral carnivores, but are more likely to be successful in some situations than others. Overall, LGDs are the most effective, especially when used in combination with other methods (Andelt 1996, 2004; Smith et al. 2000*b*). LGDs do not herd livestock, and operate more or less independently of a herder (Smith et al. 2000*b*). Scientific research on protection of cattle, or guarding against large carnivores (bears, wolves, and mountain lions) remains limited (Gehring et al. 2010; Urbigkit and Urbigkit 2010).

Landscape and livestock management context seem to affect the effectiveness of LGDs. No studies have directly examined the link between grazing management and LGD effectiveness, but there is evidence in the studies that suggests such a link, especially when the studies are considered together. For example, Coppinger et al. (1988) found that the only situation where LGDs were ineffective was where sheep were scattered widely rather than flocked (herded) and producers spent minimal time with the flock. They attributed this primarily to the amount of human presence.

However, this could just as well be attributed to the absolute size of the pasture ("open range") and the dispersion of livestock within it (low stocking density). Andelt and Hopper (2000) found that LGDs were more effective on "open range" than "fenced pastures" but this may reflect low predation rates in the latter. In contrast to most studies, Hansen and Smith (1999) suggested that LGDs were more effective in fenced pastures than open range in Norway; in this case the difference observed may reflect small pasture size and high stocking density rather than pastureland as a land type.

Overall, it appears that the effectiveness of LGDs is highest when livestock are at high density in a relatively small area (which is also herding animals' instinctive anti-predator behavior). Where livestock are spread out over the landscape, whether a single dispersed herd, or in the case of several small herds near each other, LGDs are likely to be less effective (Gehring et al. 2010). In the latter case, roaming behavior is problematic and the total number of LGDs needed on the landscape may be unmanageable.

Fladry

Fladry is an example of a mechanical tool that can be effective to exclude wolves, especially if electrified (Lance et al. 2010), on small spatial and short time scales (Shivik 2006), such as around a small attractant (e.g., a carcass) or around the outside of a permanently-fenced calving or lambing pasture (Musiani et al. 2003)—or a small pasture in a grazing rotation. Fladry is a disruptive stimuli (primary repellant), in that is serves as a visual barrier; if electrified, it may also serve as an aversive stimuli (secondary repellant) by shocking wolves when they attempt to cross (Shivik 2006; Lance et al. 2010). As a mechanical tool it is not inherently adaptive, other than that it can be moved. But there are practical limitations to using or moving it often. Fladry requires about an order of magnitude more labor than a single-wire temporary electric fence (such as is used for livestock) to set up and maintain, partly because it is bulkier and heavier than polywire, requires larger spools, and requires about twice as many posts for the same length (Lance et al. 2010; Primm and Robinson 2012). It also needs to be set and maintained at the proper height in a more exacting way. Wolves can find any hole in the line of flags, including a spot too low or too high, thus allowing wolves inside the enclosure. Such an incident may desensitize the wolves to fladry, a process also facilitated by excessive use of fladry at any one place or time (Musiani et al. 2003; Shivik et al. 2003; Shivik 2006). Fladry can be effective for up to ~60 days (Musiani et al. 2003). A wolf desensitized to fladry may be more likely to kill livestock not otherwise protected, and to be killed in response. Thus an inappropriate use of fladry is potentially worse than none at all. There are similar issues of scale and desensitization with all mechanical tools.

Synthesis and Implications

The primary habitat needs of North American large carnivores are sufficient wild prey and human tolerance. Developing human tolerance, let alone appreciation, for carnivores includes preventing or mitigating livestock depredations while reducing human conflict over wildlife and natural resources in general. Coexistence of livestock and large carnivores in the context of resilient ranching requires synthesizing the rangeland, wildlife and animal science fields. The coexistence field will be more holistic and effective by expanding from a direct focus on carnivores and predation-prevention tools to the context of livestock management and the broader social-ecological systems of ranches and rural communities (Fritts et al. 2003; Clark et al. 2005; Shivik 2006; Breck et al. 2012; Mattson et al. 2013; Barnes 2015). Much of this takes the form of conservationists working with the ranching community to improve land health—the proper functioning of ecological processes—and thus the capacity of the land to produce biological diversity and ecosystem services, including forage for both wildlife and livestock.

This paper synthesizes the relevant rangeland and wildlife literature, and argues for specific livestock and grazing management approaches that work for rangeland health, livestock production, and coexistence with large carnivores. Wildlife biologists have suggested that livestock husbandry may influence livestock-carnivore interactions in a general sense (Fritts et al. 2003; Shivik 2004, 2006; Graham et al. 2005; Musiani et al. 2005; Breck et al. 2012). Progressive livestock management practices such as strategically planned and creatively managed rotational grazing, herding using low-stress livestock handling, and synchronized green-grass calving are intended to meet the needs of both plant communities and livestock, and are partly based on the patterns of wild ungulate herds. These practices have been reported to facilitate improved rangeland health, livestock production, and ranch profitability, but they have not been widely adopted. Progressive rangeland managers who use these methods, especially in Holistic Management, have suggested that they may also reduce predation losses (Savory with Butterfield 1999; Howell 2008), but this has never been scientifically tested. The range science community has debated the merits of grazing management, especially rotational grazing, for decades. Small-scale trials of rigidly applied rotational grazing have shown little benefit (Heady 1961, 1980; Briske et al. 2008, 2011); but full-scale studies have shown that rotations can benefit land and livestock if they are strategically planned and creatively managed (Norton 1998, 2003; Barnes and Hild 2013; Teague et al. 2013).

This paper began with the question: *Can modeling livestock management after the grazing patterns and reproductive cycles of wild ungulates in the presence of their predators improve rangeland health and livestock production, and increase the ability of ranching operations to coexist with native carnivores?* Evidence in behavioral ecology, predator-prey interactions, and grazing management science suggests so, but until now existing scientific evidence has never been integrated into a cohesive argument in terms of applied plant-herbivore-carnivore interactions. That evidence, reviewed here, suggests an overall hypothesis for research and management: *Livestock management, specifically rotational grazing, herding with low-stress livestock handling, and synchronized calving in short seasons, in some cases corresponding with those of wild ungulates, can—while maintaining or improving rangeland health and livestock production—directly and synergistically reduce predation, while establishing a management context in which other predation-prevention practices and tools can be used more effectively.*

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