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Synthesis Paper: Targeted Livestock Grazing: Prescription for Healthy Rangelands

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ABSTRACT

Targeted livestock grazing is a proven tool for manipulating rangeland vegetation, and current knowledge about targeted livestock grazing is extensive and expanding rapidly. Targeted grazing prescriptions optimize the timing, frequency, intensity, and selectivity of grazing (or browsing) in combinations that purposely exert grazing/browsing pressure on specific plant species or portions of the landscape. Targeted grazing differs from traditional grazing management in that the goal of targeted grazing is to apply defoliation or trampling to achieve specific vegetation management objectives, whereas the goal of traditional livestock grazing management is generally the production of livestock commodities. A shared aim of targeted livestock grazing and traditional grazing management is to sustain healthy soils, flora, fauna, and water resources that, in turn, can sustain natural ecological processes (e.g., nutrient cycle, water cycle, energy flow). Targeted grazing prescriptions integrate knowledge of plant ecology, livestock nutrition, and livestock foraging behavior. Livestock can be focused on target areas through fencing, herding, or supplement placement. Although practices can be developed to minimize the impact of toxins contained in target plants, the welfare of the animals used in targeted grazing must be a priority. Monitoring is needed to determine if targeted grazing is successful and to refine techniques to improve efficacy and efficiency. Examples of previous research studies and approaches are presented to highlight the ecological benefits that can be achieved when targeted grazing is applied properly. These cases include ways to suppress invasive plants and ways to enhance wildlife habitat and biodiversity. Future research should address the potential to select more adapted and effective livestock for targeted grazing and the associated animal welfare concerns with this practice. Targeted livestock grazing provides land managers a viable alternative to mechanical, chemical, and prescribed fire treatments to manipulate rangeland vegetation.

INTRODUCTION

Rangeland managers have a wide range of practices available to maintain rangeland health and productivity or restore degraded rangelands. Most of these practices fit in the categories of axe, plow, fire, cow, and gun that Leopold (1933) suggested were the keys to managing wildlife. Managers can successfully use traditional livestock grazing management, prescribed fire, mechanical interventions, and herbicide application alone or in combination to manage rangeland vegetation (Masters and Sheley, 2001; Briske et al., 2011). However, tradeoffs exist for every rangeland management practice. Mechanical treatments usually require relatively gentle terrain and are typically expensive (Herbel, 1983; DiTomaso, 2000). Herbicides can have undesirable impacts on nontarget vegetation, elicit concerns for human

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health, be expensive, and are often not feasible without cost-share programs (DiTomaso, 2000; Shepard et al., 2004; Torell et al., 2005). Prescribed fire requires specific conditions to be safely and effectively applied (Fuhlendorf and Engle, 2004), and there is a risk that it can lead to catastrophic wildfires (Yoder, 2004; Yoder et al., 2004). Targeted grazing is an alternative and/or complementary vegetation management tool. Further, targeted livestock grazing is an "environmentally friendly" alternative to traditional methods because it can be applied to extensive inaccessible areas, leaves no chemical herbicide residue, can be removed whenever necessary, and often improves biodiversity. Plus, in the process of removing plant biomass, grazing animals convert it into saleable products—meat and fiber. A survey in Ontario, Canada found that target grazing was the second most preferred method of vegetation control behind direct removal by cutting (Wagner et al., 1998).

Targeted grazing is the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals (Frost and Launchbaugh, 2003). Targeted grazing has been referred to elsewhere, especially in 20th century research literature, as *prescribed grazing*, *prescriptive grazing*, or similar terms (Walker, 1995; Frost and Launchbaugh, 2003). Targeted grazing continues to be a focus of rangeland managers and scientists. The best evidence of the value and growth of targeted grazing is the development and success of targeted grazing businesses. Entrepreneurs are paid to use livestock to control noxious weeds and other invasive plants, provide fire breaks, and for other contemporary vegetation management challenges (Frost et al., 2012). Although the field is growing, additional research and outreach are needed to ensure that targeted grazing becomes a tool that rangeland managers can readily employ to resolve land management issues. The objectives of this paper are to define the practice of "targeted grazing"; describe the information, resources, and skills it requires; and present evidence for specific ecological benefits that can be achieved when targeted livestock grazing is properly used as an element of a management plan.

ORIGIN AND USE OF THE TERM "TARGETED GRAZING"

The use of livestock grazing to accomplish defined vegetation or landscape goals has been referred to as prescribed, targeted, or conservation grazing. Currently this type of grazing management is usually referred to as *targeted grazing.* The term *conservation grazing* is also in common use but typically refers to a less intensive form of management used to maintain and increase the biodiversity of natural or seminatural ecosystems. We searched the Clarivate Analytics Web of Science database using a topic search for the terms "conservation grazing," "prescribed grazing," or "targeted grazing" to identify journal articles containing those terms. The articles are provided in Supplement 1 (available online at https://doi.org/10.1016/j.rama.2019.06.003) and were examined to ensure that the use of the term referred to livestock grazing management. Before 2006, most writings about using livestock to manage invasive plants or improve wildlife habitat referred to prescribed grazing, but the National Range and Pasture Handbook (Butler et al., 2003) used the term prescribed grazing to describe any type of planned grazing. The term *targeted grazing* came into widespread use after publication of the Targeted Grazing Handbook (Launchbaugh and Walker, 2006). Targeted grazing was used in that publication to differentiate grazing management for a specific vegetation management goals from the broader *prescribed grazing* term. The term targeted grazing was first used in a peer-reviewed journal in 1996 (Holst and Allan, 1996), but the citation is not in the Web of Science database and is not included in Figure 1. A total of 89 publications were found using one of these terms, and the earliest paper used prescribed grazing and was published in 1991. Nine of these articles used both targeted and prescribed grazing, but with one exception the second term was only used as a key word and the paper was classified for the term that was most used. Figure 1 shows that since 2010, targeted grazing has been the preferred term compared with prescribed grazing. Journal articles that used the terms prescribed, targeted, or conservation grazing were found in 51 different journals with nearly half (43%) of the articles in *Rangeland Ecology & Management,* in which the term targeted grazing was most prevalent (55%).

TARGETED GRAZING PRINCIPLES

Managers can manipulate livestock impacts to vegetation using the principles of grazing management (Vallentine, 2001): stocking rate, distribution, species of livestock, and season (or timing) of grazing. The overall intensity of defoliation or forage utilization level can be increased by increasing stocking rate (Table 1). Stocking density can also play a role on the use of targeted plants. Utsumi et al. (2010) found that utilization of one-seed juniper *(Juniper monosperma* [Englem.] Sarg.) saplings was greater at high stocking densities than low densities at similar stocking rates. Grazing can be focused or redirected by applying distribution practices such as fencing, water developments, and herding. Diet selection can be modified by changing the species of livestock (e.g., use of forbs can be increased by switching from cattle to sheep). Changing the season of grazing can affect livestock preferences for vegetation and correspondingly diet selection, which can affect the impact of defoliation on plant vigor. The grazing management principles are the same for both traditional, production-based management and targeted grazing (Table 1), but the goals and priorities differ (Frost et al., 2012). Left unchecked, livestock grazing can lead to deterioration in rangeland health and reduced livestock productivity as animals focus on preferred plants and areas near water (Vallentine, 2001). Managers use grazing management principles to prevent overuse of preferred plants and promote livestock gains and reproductive performance. Similarly, targeted grazers can use grazing management principles so that livestock can be used to increase use of undesirable plants at a time in their life cycle when they are most vulnerable to defoliation. For example, a rancher might develop a new water source to redirect grazing pressure to areas near the new water location and improve uniformity of grazing across the pasture, while implementation of targeted grazing might require temporary electric fencing or herding to focus livestock to areas with higher densities of invasive weeds.

The application of grazing management principles to targeted grazing depends on the issue being addressed (Launchbaugh and Walker, 2006). For example, species of livestock is critical for control of leafy spurge (*Euphorbia esula* L.), but timing is not as critical. Leafy spurge is not palatable to cattle, and sheep or goats must be used for control of leafy spurge. For cheatgrass (a.k.a., downy brome) (*Bromus tectorum* L.), the species of livestock is less important, but the timing of grazing is more critical. Most livestock species will consume this invasive annual grass early in the spring when it is green and growing but usually avoid it during the summer after it matures and other perennial grasses are still green and growing (Cook and Harris, 1952; Mosley, 1996).

PLANT ECOPHYSIOLOGY AND SUCCESSION CONSIDERATIONS FOR TARGETED GRAZING

The relationship between grazing animals and plants is similar to predator-prey relationships in which grazing animals are predators and plants are prey. Because plants can't run away from their predators, they use other strategies to resist grazing that Briske (1996) described as grazing avoidance or grazing tolerance. The basic difference between grazing avoidance and grazing tolerance is that avoidance mechanisms reduce the chance of a plant being grazed while tolerance mechanisms allow plants to grow more rapidly after defoliation (Briske, 1996). Understanding grazing resistance mechanisms in a target species is critical to applying targeted grazing. To achieve their landscape objectives, targeted grazers must alter the competitive interactions among plant species to favor desired plants at the expense of the undesired.

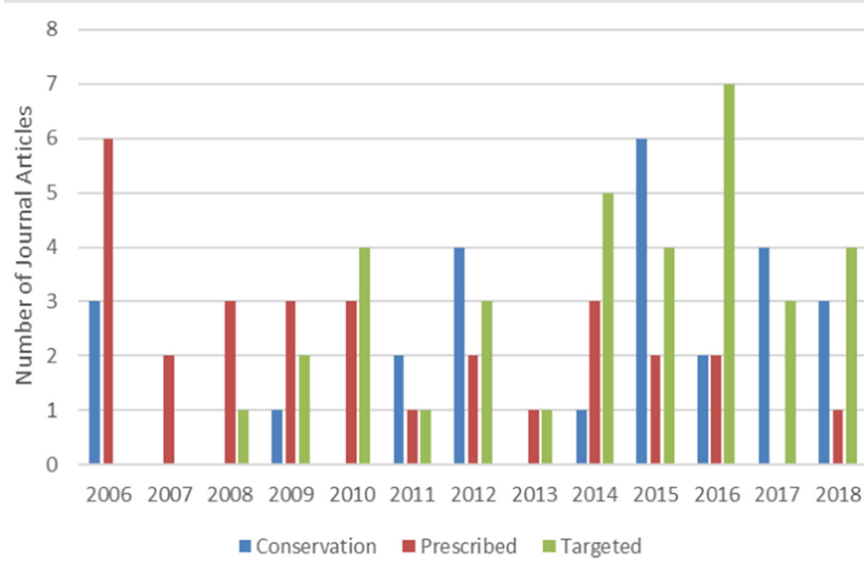

Figure 1. Annual frequency of the use of conservation grazing, prescribed grazing, or targeted grazing in peer-reviewed journal articles as determined by the literature using Web of Science. The yr 2006 includes all articles before that date with the earliest citation occurring in 1991. Supporting citations are listed in Supplemental Information 1.

Grazing avoidance is the capacity for a plant to avoid being grazed and involves mechanisms that reduce the probability and/or severity of grazing (Briske, 1996). These defense mechanisms can be divided into plant architectural attributes, mechanical deterrents, and biochemical compounds. Plant secondary compounds are biochemical compounds often used by plants to avoid herbivory (Bennett and Wallsgrove, 1994). Although recent literature has questioned the link between secondary compounds and plant defense, there is still strong evidence that secondary compounds play a major role in grazing resistance (Agrawal and Weber, 2015). Plant architectural attributes, such as plant height (Detling and Painter, 1983), as well as mechanical deterrents, such as spines or thorns (Karban et al., 1999) can reduce the probability of grazing. Finally, plant nutritive value characteristics including lignin and neutral detergent fiber can limit digestibility and reduce intake, thereby reducing the probability of being grazed.

Compensatory growth after defoliation is an often-cited attribute contributing to grazing tolerance (Briske, 1996), but other traits such as resource allocation patterns (Fornoni, 2011), meristematic number (Briske, 1996), and a high sheath-stem ratio (Cullen et al., 2006) are also important. Expression of grazing tolerance can be driven by both genetics and the environment (Damhoureyeh and Hartnett, 2002). Although presented separately here, many plant species may have developed a mixed avoidance-tolerance response to defoliation (Zheng et al., 2015).

Timing of defoliation (i.e., phenological stage) is an important factor that affects plant response. For example, mowing in the fall, when spotted knapweed (*Centaurea stoebe* L.) was flowering or in seed set, reduced its tiller densities more than mowing in spring when moisture and temperature conditions were more favorable for spotted knapweed regrowth (Rinella et al., 2001). Annual plants need to be grazed in ways to reduce their seed output. Hempy-Mayer and Pyke (2008) found that grazing treatments which defoliated cheatgrass multiple times before seeds began to mature would have the best potential for impacting seed production and reducing cheatgrass populations in successive years. Determining the most appropriate phenological stage to graze requires grazers to understand how target plants reproduce and when they are most susceptible to grazing.

Another complicating factor is the relative palatability differences between the desired and target plants. Plant palatability often changes over the course of the growing season because of advancing leaf age and senescence (Anderson, 1985; Hendrickson et al., 1997), which can shift the relative preference from maturing targeted plants to species growing intermixed with them.

Clonal plants, or plants that spread through roots and rhizomes, can be especially challenging for targeted grazers. Clonal grasses, for example, often have tiller populations containing a variety of growth stages (Hendrickson et al., 1998). The variety of phenological stages makes it difficult to graze when target plants are most vulnerable. Resource sharing among subunits of clonal plants can also propagate new growing points (Derner et al., 2012), making it difficult for a single grazing event to damage the target plant. Because clonal plants can share resources, they often have advantages in heterogeneous environments, such as grazed ecosystems (Hutchings, 1999).

Table 1
Application of grazing management principles (Vallentine, 2001) to targeted grazing and traditional grazing.

Principle	Targeted Grazing	Traditional Grazing
Stocking rate	Designed heavy use of target plants may result in moderate to heavy use of non-target plants	Low to moderate levels to help ensure plant vigor
Season of use	Timing is often a critical factor - Graze when plant secondary metabolites are low to improve palatability and/or reduce adverse post-ingestive feedback - Graze before seed set to reduce seed production - Graze when non-target plants are less palatable and/or more resistant to grazing	Timing is an important factor - Graze when plants are dormant to improve vigor - Use pasture rotation to avoid grazing at the same time each year - Limit grazing period to avoid multiple defoliations of the same plant without rest
Distribution	Livestock are usually focused with fencing or herding at high stocking densities to target vegetation.	Livestock are often dispersed using attractants to avoid heavy use and to encourage even utilization or they are rotated among pastures to avoid prolonged heavy grazing
Species, type and kind of livestock	Livestock are selected based on their preference for targeted vegetation	Livestock are usually selected based on market factors and susceptibility to predation

SHAPING AND USING ANIMAL PREFERENCE TO TARGET PLANTS

Success of targeted grazing is dependent on the use of adapted livestock. Ruminants have been classified into three groups on the basis of body size, mouth structure, and digestive capabilities: grazers, browsers, and intermediate feeders (Hofmann, 1989). These differences make some livestock species more capable of ingesting and digesting various vegetation types. For example, goats are browsers and have small, narrow mouths that readily consume leaves and small twigs of shrubs (Shipley, 1999). Goats also have relatively large livers based on their body size, which allows them to process secondary compounds more efficiently than other livestock species (Hofmann, 1989). In contrast, cattle are roughage eaters and have relatively large, broad mouths and greater relative rumen size than other livestock species, which allows them to use grasses efficiently. Although morphological and physiological differences exist between livestock species, early experiences with forages can modify both morphological and physiological characteristics of livestock's digestive systems so that they are more adapted to efficiently consume forages they were exposed to at a young age (Distel and Provenza, 1991).

Individuals vary greatly in their ability to consume and digest plants that contain large quantities of secondary compounds. Part of this variation is the inherent ability of animals to tolerate and/or process toxins, which may be inherited (Launchbaugh et al., 1999). Another determinant of diet selection is learning and experience. The palatability of forages is a result of postingestive feedback (Provenza, 1995). Livestock prefer forages that provide needed nutrients and do not contain excessive toxins and avoid plants with few nutrients and/or excessive toxin levels. Postingestive feedback is not a conscious decision, but rather a consequence of automatic processing of taste-feedback interactions (Provenza, 1996). Many weeds and invasive plants contain high levels of secondary compounds, which can limit intake of these species unless management interventions are applied (Provenza and Papachristou, 2009).

Lambs, kids, and calves learn about foods from their mother. Young animals are exposed to flavors in utero and through the milk, which can increase their likelihood of consuming the foods that their mother ate (Nolte and Provenza, 1992; Nolte et al., 1992). Exposing young livestock to the forages that managers desire to target should increase intake of those plants later in life (Wiedmeier et al., 2002). Although learning to eat foods from the mother is usually the most effective, young livestock can also learn what to eat from their peers. For example, heifers that were averted from eating larkspur (*Delphinium* spp.) started consuming this poisonous plant when they grazed with heifers that were not averted (Lane et al., 1990). In addition to learning which foods to consume, young livestock must learn how to forage. Young goats with experience eating blackbrush (*Coleogyne ramosissima* Torr.) not only consumed blackbrush more efficiently than inexperienced animals but also consumed live oak (*Quercus turbinella* Greene) more effectively (Ortega-Reyes and Provenza, 1993a, 1993b). In most cases, targeted grazers should consider raising their own female replacement animals and expose their young livestock to the forages they plan to target.

Diet training (a.k.a., diet conditioning) is another strategy that may increase livestock consumption of target plants. Diet training increased use of leafy spurge by sheep (Walker et al., 1992) and use of redberry juniper (*Juniperus pinchotii* Sudw.) by goats (Dietz et al., 2010). However, diet training did not increase cattle use of either broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton & Rusby; Ralphs and Wiedmeier, 2004) or spotted knapweed (Mosley et al., 2017b).

Supplementation with activated charcoal or polyethylene glycol (PEG) has increased livestock use of target plants. Supplementation of activated charcoal increased sheep use of big sagebrush (*Artemisia tridentata* Nutt.; Banner et al., 2000; Villalba et al., 2002) and bitterweed (*Hymenoxys odorata* DC.; Poage et al., 2000); however, activated charcoal had little to no effect on goat use of redberry juniper or Ashe juniper (*Juniperus ashei* Buchholz; Bisson et al., 2001). To date, supplementation with activated charcoal is impractical for range livestock due to difficulty finding an appropriate medium for supplementation (Poage et al., 2000). Supplementation with PEG increased goat use of one-seed juniper by sheep and goats (Utsumi et al., 2013), but PEG supplementation on rangelands is currently cost-prohibitive (Ben Salem et al., 1999). Supplemental protein and energy increased sagebrush browsing by sheep (Villalba et al., 2002; Dziba et al., 2007; Guttery, 2011), and supplemental protein increased intake of one-seed juniper by goats (Utsumi et al., 2013). However, supplemental protein-energy did not increase sheep intake of sulfur cinquefoil (Mosley et al., 2017a). Protein-supplemented cattle readily browsed big sagebrush when targeted cattle grazing was applied at a high stock density within small, 0.2-ha experimental pastures (Petersen et al., 2014) but not when targeted cattle grazing was applied at a low stock density within large, 625-ha pastures (Payne, 2018; Payne et al., 2018).

CHANGING ANIMAL USE OF LANDSCAPES

In many cases, one of the keys for effective targeted grazing is to focus the livestock in a specific area where vegetation treatments are needed. Small enclosures facilitate focusing livestock use (Kott et al., 2006). For example, managers often use temporary electric fence to construct small enclosures around patches of noxious weeds or invasive plants, which limits livestock's ability to graze nontarget plants. Small enclosures are also useful for direct defoliation in specific areas to produce fuel breaks, reducing vegetation levels under power lines, defoliating salt cedar (*Tamarix* spp.) along riparian areas, and similar treatments. Temporary fencing can be cost-effective and feasible depending on the availability of stock water. However, it may not always be feasible to construct small pens with livestock water, especially in mountainous and arid areas. In addition, enclosures should provide a variety of forages to keep animals from overingesting toxins.

Livestock grazing can be focused without fencing. Attractants can be used to lure livestock to desired areas (Bailey, 2004). Low-moisture block and other protein supplements are effective tools to attract cattle to underutilized areas (Martin and Ward, 1973; Bailey and Welling, 1999). For example, low-moisture block protein supplement was used effectively to concentrate cattle trampling and reduce dense sagebrush cover in southwestern Montana (Payne, 2018; Payne et al., 2018). Salt and mineral mixes can be effective tools to attract cattle when forages are green and growing (Pittarello et al., 2016), but protein-based low-moisture block supplements are more effective than salt when the forage is dormant (Bailey et al., 2008). Cattle grazing can be focused without fences using a combination of low-stress stockmanship and strategic supplement placement. This combination of distribution practices focused cattle grazing in underutilized areas of pastures > 2 km from water and in rugged terrain in New Mexico (Pollak, 2007; Stephenson et al., 2016) and in Arizona (Bruegger et al., 2016). Herding can also work well for focusing sheep grazing (Kott et al., 2006). Typically, whiteface sheep breeds are more suited to herding because they are usually more gregarious and have a stronger flocking instinct than blackface breeds (Olson and Launchbaugh, 2006).

High stocking densities can be created by placing relatively large numbers of livestock in small paddocks. High stocking densities may be helpful in ensuring good soil seed contact in rangeland restoration efforts (Winkel and Roundy, 1991; Mosley and Roselle, 2006), increasing mortality of undesirable shrubs through browsing and trampling (Marquardt et al., 2009), and modifying shrub structure and growth (Ganskopp et al., 2004). When livestock are spatially concentrated (high stocking densities on areas near water sources or supplements), animals can mechanically damage vegetation and impact soil structure through trampling (Warren et al., 1986; Abdel-Magid et al., 1987). Soil bulk density increases and water holding capacity and infiltration decreases after trampling, but soil structure naturally recovers after livestock exclusion (i.e., rest from grazing) through freeze-thaw and wetting and drying cycles (Drewry, 2006). Ultrahigh stocking density

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or “mob grazing” requires > 200 000 kg of cattle liveweight ha^{-1} and has been purported to increase harvest efficiency, plant productivity, plant species diversity and soil carbon (Gompert, 2010). Ultrahigh stocking densities can result in two to three times the extent of trampling compared with four pasture rotation systems (Johnson, 2012). An 8-yr study comparing mob grazing and four pasture rotation systems in Nebraska meadows did not detect any improvement in harvest efficiency, steer gain, plant productivity, species composition, ground cover, soil bulk density, and soil carbon (Johnson, 2012; Lindsey, 2016; Shropshire, 2018). Although the Nebraska studies did not support the purported benefits of ultrahigh stocking densities, further studies in other locations and vegetation types are needed.

OBSTACLES TO ADOPTION AND EFFECTIVE USE OF TARGETED GRAZING

Plant Secondary Chemistry

Plant secondary metabolites (PSMs) are a major factor driving diet selection and preferences of domestic livestock and wildlife (Kronberg and Walker, 2007). Encroaching species targeted for removal are often shrubs that maintain a competitive edge because of their PSM content. Thousands of PSM exist, representing several structural classes, and their presence and concentration in a given plant are influenced by many factors, including genetics, phenology, and a host of biotic and abiotic environmental factors. Numerous physiological (e.g., season, plant age, leaf age, plant part, regrowth) and environmental (soil properties, moisture, nutrient availability, competition, temperature, humidity, light, herbivory, microbial attack, mechanical damage, CO_2, ozone) factors affect PSM concentration (Kuokkanen et al., 2003; Llusià et al., 2006; Thines et al., 2007). Adding to this complexity is the fact that PSM concentrations vary from plant to plant, day to day, within day/diurnal cycles, and within plant (Heyworth et al., 1998; Komenda and Koppmann, 2002). Furthermore, secondary compounds can be present constitutively or induced in response to stress (e.g., herbivory or drought; Holopainen, 2004). Induced responses can occur rapidly in response to biotic stresses such as herbivory (i.e., within minutes, hours, or a few days; Kost and Heil, 2006) and are often short-lived (Faeth, 1992). Plant volatiles can even signal neighboring plants to increase defense levels before damage (Kost and Heil, 2006). Thus, for a given targeted species, the number of permutations of PSM and nutrient profiles and concentrations are infinitely large in time and space. At a larger scale, chemical variability may be driven by factors such as ecological site (i.e., soil characteristics), induction due to localized outbreaks of insects or peak populations of small mammals, and localized water pulses. This variability in PSM poses serious challenges to developing grazing prescriptions that are consistently effective. The more information available about the concentrations of these chemicals, the greater the chance of successfully implementing a targeted grazing program.

Various management options are available to increase intake of PSM-laden plants. Approaches that rely on animal genetics (e.g., selection for browsers), behavior (e.g., diet training), nutrition (e.g., supplementation, additives), and management (e.g., manipulating timing of browsing, plane of nutrition, body condition, stocking rate) (Shaw et al., 2006; Dziba et al., 2007; Papachristou et al., 2007; Frost et al., 2008; Rogosic et al., 2008; Utsumi et al., 2009; Waldron et al., 2009; Campbell et al., 2010; Utsumi et al., 2010, 2013) can be incorporated into targeted grazing programs. However, the effectiveness of these practices is influenced by variations in PSM concentrations. Conversely, understanding this variability can help to identify times and locations when a target plant is particularly vulnerable. For example, Utsumi et al. (2009) observed intake of one-seed juniper by small ruminants in the fall when PSM concentrations were highest was about half that during summer, winter, or spring. In that same study, protein supplementation increased juniper consumption by approximately twofold; however, during the fall when terpenoid concentrations were greatest, effects of protein were negligible. In a follow-up study under field conditions, Utsumi et al. (2010) observed that browsing intensity by small ruminants was greater during summer than spring and for short versus medium or tall saplings. Total terpenoid concentrations in juniper were inversely related to defoliation intensity and were lower in summer versus spring and in short versus medium or tall saplings (Estell et al., 2014). Consequently, targeted browsing of short juniper saplings during summer may be more effective than in the fall.

Seed Dispersal or Endozoochory

Endozoochory (i.e., dispersal of seeds by animals after passage through the animals' digestive system) is a valid concern when using targeted livestock grazing to suppress undesired plants. Although livestock that consume immature seed-heads of plants do not ingest viable seeds, livestock sometimes do ingest viable seeds if they consume mature seed-heads. Exposure of ingested seeds to the digestive tract of livestock significantly reduces their viability, but livestock can excrete viable seeds in their feces (Lacey et al., 1992; Wallander et al., 1995; Olson and Wallander, 2002; Frost et al., 2013). If livestock consume viable seeds of invasive or otherwise undesired plants, they should be confined in a corral before they are moved to a new area (Kott et al., 2006). Several studies indicate that livestock should remain confined for 3 or 4 d to provide sufficient time for them to excrete undesirable plant seeds (Lacey et al., 1992; Wallander et al., 1995; Olson and Wallander, 2002; Frost et al., 2013). An exception is halogeton (*Halogeton glomeratus* [M. Bieb] C.A. Mey.). Lehrer and Tisdale (1956) documented that most viable seeds of halogeton were excreted by the fourth day after consumption, but a few viable halogeton seeds were not excreted until 9 d post consumption. On the other hand, Goodman et al. (2014) reported zero germination of white locoweed (*Oxytropis sericea* Nutt.) seeds recovered from fecal pellets of sheep that had grazed infested plots for 5 d during the seed set stage.

Animal Welfare

Targeted grazing is sometimes accomplished via transient confining of animals in relatively small, fenced grazing areas (Goodman et al., 2014; Utsumi et al., 2010) or herding (Bruegger et al., 2016; Stephenson et al., 2016) to induce consumption of target (unwanted) plants that frequently contain significant concentrations of varied PSMs (see earlier). Transient confinement and, perhaps more importantly, consumption of potentially toxic feeds are management practices likely to raise concerns about animal welfare. Management of animals in targeted grazing programs usually involves modifying the expression of “natural” behaviors (Kilgour, 2012; Špinka, 2006) which are considered essential to animal welfare (Bracke and Hopster, 2006) and are a central tenet of organic animal farming (Vaarst and Alrøe, 2012). Perceived suppression of natural behaviors could pose challenges to the broad adoption of this technique, particularly among implementers seeking more natural means of managing rangeland vegetation. Ingestion of target plants containing varying levels of toxins, as is often the case in targeted grazing programs, can induce transient to chronic animal malaise (Foley et al., 1999; Estell, 2010), which, even if subclinical, could be perceived as causing unnecessary animal distress. Potential implementers of targeted grazing programs might be deterred by the risk of jeopardizing animal well-being.

Although the focus of most targeted grazing research to date has naturally been placed on measuring the efficacy of this technique to suppress unwanted plant populations (Wallace et al., 2008; Goehring et al., 2010; Utsumi et al., 2010; Mosley et al., 2016; Probo et al., 2016), researchers have recently begun quantifying the effects of target plant PSMs on animal health (Goodman et al., 2014; Arviv et al., 2016). Goodman et al. (2014), for example, tested two targeted grazing treatments to identify a prescription that would avoid alkaloid intoxication in sheep without compromising the efficacy of the targeted grazing

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treatment. They reported that by applying intermittent targeted grazing of white locoweed-infested rangeland (5 d on locoweed followed by 3 d off), subclinical symptoms of alkaloid toxicity were significantly reduced relative to sheep that grazed locoweed continuously for 25 d. Interestingly, locoweed suppression efficacy was not different among targeted grazing treatments. Alkaline phosphatase levels in plasma (an indicator of liver activity) remained within normal ranges in ewes in the intermittent targeted grazing treatment, suggesting that this prescription likely spared animals from potential adverse effects of locoweed PSMs.

PLANNING AND MONITORING

The Society for Range Management defines monitoring as “the orderly collection, analysis, and interpretation of resource data to evaluate progress toward meeting management objectives …” (SRM, 1998). Good monitoring practices and effective use of the information they produce are keys to successfully and consistently accomplishing objectives.

Successfully managing grazing animals and plant communities with targeted grazing requires 1) clear objectives (preferably measurable) for the desired plant community and soil surface characteristics being manipulated; 2) some reasonable estimate of those same characteristics at the start of the project; 3) the right species, class, and number of animals to impact vegetation in the way intended in the time available; and 4) a strategy for managing the animals in a way that will obtain the desired vegetation and/or soil surface effects. Ongoing monitoring provides feedback on the rate and direction of change in the site characteristics. All 5 of those elements (1 − 4 plus the monitoring plan) should be detailed in a targeted grazing prescription.

Monitoring is important because targeted grazing projects entail many moving parts and, therefore, a great deal of uncertainty. Animal demand; available forage; relative palatability of plants (influenced by season, stage of growth, species composition, residue levels, etc.); elapsed time during the grazing period; weather conditions; vulnerability of nontarget plants; and water quality and availability can all change continuously over time. The timeliness and appropriateness of the manager’s response to variations in these factors will influence the success of the project, and it is the combination of continuous casual observations and appropriate measurements that make such a response possible. This kind of monitoring was a component of what came to be described as “adaptive management” by Holling (1978) and Walters and Hilborn (1978). This is a management approach suited to dealing with uncertainty (i.e., situations where the best practice(s) for the intended objectives can only be approximately known in advance). In this process, management decisions are adjusted iteratively by evaluating information in a continuous feedback loop (Allen et al., 2017). Such management requires a commitment to using the feedback to change management actions and requires a plan for collecting specific feedback and a process for coupling it with management actions (“learning by doing” or “the art of range management”) (Stoddart et al., 1975; Mosley, 1985).

Sharrow and Seefeldt (2006) outlined two basic functions of monitoring in targeted grazing projects: 1) using progress toward objectives to evaluate and refine the grazing prescription (the adaptive management component) and 2) generating documentation of practices and results that may be required under grazing agreements. With respect to the first point, they emphasize the importance of selecting objectives (goals) that are clearly stated, measurable, include a timeline for completion, and are realistically achievable. Proper goal/objective selection can seem trivial, but it usually is not. For example, “Reduce target plant density” is a simple, clear goal, but by itself is not useful for making management decisions. What’s missing? The size of the desired change, the time allowed for the change to occur, the method(s) for measuring the change, and the prescription to accomplish the change. These comprise the basic elements of a monitoring plan. By identifying responsible personnel and a timeline of events, the monitoring process is complete.

There is no single, straightforward guide that covers the wide range of monitoring protocols that might be useful for the variety of targeted grazing projects that are possible. However, many good materials exist that describe monitoring practices for many common environmental and ecological objectives (Elzinga et al., 1998; Coulloudon et al., 1999; Winward, 2000; Pellant et al., 2005; Herrick et al., 2017). Modifications of these for specific circumstances and applications are continually being created and refined. University Extension programs, agricultural experiment stations, and many conservation organizations have been developing streamlined protocols of particular value for land managers and livestock operators (Lewis et al., 2000; Ward et al., 2003; Mosley et al., 2018). These resources can help livestock and land managers select appropriate monitoring methods for their specific objectives and circumstances. The goal should be to select or develop monitoring methods that can detect changes of the size anticipated and that can be completed in the time available seasonally to do the field work. This difficulty is as real for federal land management agencies as it is for conservation organizations, private landowners, and livestock operators.

APPLICATION OF TARGETED LIVESTOCK GRAZING ON RANGELANDS

It is important to recognize that targeted livestock grazing is not always the most appropriate tool to select from the vegetation management methods options. Other methods may be more practical or appropriate in some situations (Mosley, 1997). Even when targeted livestock grazing is an appropriate option, its effectiveness will depend on the skill of the person applying this technology (Table 2). Those lacking experience with targeted livestock grazing should apply targeted grazing cautiously at first and seek guidance from more experienced practitioners (Mosley, 1997). With these guiding principles in mind, opportunities abound for using targeted livestock grazing to manage rangeland vegetation. Some of the possible applications of targeted grazing are described as follows.

Suppress Undesired Plant Species

To suppress undesired plant species and increase desired ones, targeted livestock grazing should be applied when 1) targeted plants are susceptible to defoliation and relatively palatable and 2) when desired plants are less susceptible to defoliation and relatively less palatable (see Table 2). Clipping studies can efficiently and economically identify the phenotypic stages when targeted plants are susceptible to defoliation. Benzel et al. (2009), for example, hand-clipped spotted knapweed plants at seven different timings and frequencies to identify opportunities for reducing viable seed production by spotted knapweed. Similarly, Frost and Mosley (2012) hand-clipped sulfur cinquefoil (*Potentilla recta* L.) plants at seven timings and two intensities to identify potential defoliation strategies for reducing the yield and viable seed production of sulfur cinquefoil. These clipping studies were then followed with grazing experiments that examined the relative palatability of the targeted weeds and the efficacy of targeted grazing applied during the phenotypic stages identified as most promising by the clipping studies. Results of these experiments indicated that targeted grazing by sheep or cattle can suppress spotted knapweed if targeted grazing is applied when spotted knapweed is in its late bud − early flower phenotypic stage (late July) or full-flower phenotypic stage (mid-August) (Thrift et al., 2008; Surber et al., 2011; Henderson et al., 2012; Mosley et al., 2016). To suppress sulfur cinquefoil, targeted livestock grazing can be applied effectively when sulfur cinquefoil is in either its early flowering stage (late June) or late flowering − early seedset stage (mid-July) (Mosley et al., 2017a). For both spotted knapweed and sulfur cinquefoil, targeted livestock grazing was best applied

Table 2
Examples of targeted grazing applications and comparisons to alternative management

Goal of Targeted Grazing	Targeted Grazing Approach	Targeted Grazing Feasibility	Alternative Management Feasibility
Suppress undesired plants			
- Cheatgrass	Graze when green to reduce seed production	Effective if sufficient livestock are available	Herbicides are expensive
	Winter grazing can reduce cheatgrass abundance	More flexible than spring grazing and easier to apply	Seeding perennial vegetation is expensive and has low probability of success unless cheatgrass abundance is reduced
- Spotted knapweed	Graze sheep or cattle during late bud to flower stage	Can suppress spotted knapweed at a moderate cost	Herbicides are effective but expensive
- One-seed juniper	Browse saplings with goats or goats and sheep	Mortality of browsed saplings is 5 to 15%. Dependent on goat and sheep availability. Not effective on large trees	Mechanical treatments are effective but expensive
			Herbicides are effective but expensive
Enhance wildlife forage quantity and quality	Graze cattle or sheep to remove decadent vegetation	Increases use of big game and can be achieved using attractants (e.g., supplements) or minor changes in traditional grazing management	Prescribed fire is effective but has risks and moderate costs
Modify shrub structure and rejuvenate productivity	Lightly graze bitterbrush in the spring with cattle to stimulate twig growth	Cattle grazing and periodic deferment increases height and diameter of bitterbrush plants	Mechanical pruning would be impractical and expensive
Fire breaks	Graze cattle or sheep to reduce fine fuel loads	Difficult to reduce standing crop below moderate levels without fencing	Mechanical treatments are effective but expensive and may result in erosion
			Prescribed fire can be effective but has risks and moderate costs

when the targeted weed remained green during mid to late summer, but desirable grasses and forbs were largely dormant. These conditions limited potential adverse effects to desirable plants and encouraged livestock to consume the targeted weeds. Also, targeted grazing applied during mid to late summer stressed the targeted weeds when moisture was depleted and insufficient for plant recovery (Wooley et al., 2011). In addition, targeted grazing was applied before spotted knapweed or sulfur cinquefoil plants had produced viable seeds.

A targeted grazing prescription for suppressing cheatgrass was synthesized from the results of clipping studies and historical observations (Mosley, 1996). Hulbert (1955) and (Tausch et al., 1994) determined that hand-clipping cheatgrass plants twice during late spring (late April to mid-May) reduced cheatgrass plant density and biomass. Clipping occurred when cheatgrass plants were in the boot stage, before cheatgrass produced viable seeds. A subsequent study by Hempy-Mayer and Pyke (2008) also determined that clipping during the boot stage reduced cheatgrass biomass and reduced viable seed production by cheatgrass. Conclusions from the clipping studies were supported by historical observations of cheatgrass response to sheep grazing (Megee, 1938; Daubenmire, 1940), and a contemporary grazing experiment by Diamond et al. (2009) confirmed that targeted cattle grazing can suppress cheatgrass if targeted grazing is applied when cheatgrass is in the boot stage (typically April or May). In many areas cheatgrass requires a second grazing in spring because it can regrow and produce new viable seeds about 3 − 4 wk after the first defoliation (Hulbert, 1955). Cheatgrass can be suppressed by targeted livestock grazing that significantly limits its production of viable seeds for 2 or 3 consecutive yr (Daubenmire, 1940; Diamond et al., 2009). Targeted sheep or cattle grazing during late fall or winter also can be used to reduce the biomass of cheatgrass mulch, helping to suppress cheatgrass and enhancing establishment of perennial plants (Hull and Pechanec, 1947; Schmelzer et al., 2014).

Enhance Wildlife Forage Quantity and Quality

Forage quantity and quality often determine whether rangeland wildlife live or die. Targeted livestock grazing, browsing, and trampling can be used to purposely enhance forage yield, accessibility, and nutritive quality for many wildlife species (Mosley, 1994; Severson and Urness, 1994; Mosley and Brewer, 2006). For example, targeted livestock grazing, browsing, and trampling can be used to create preferred foraging habitat for northern bobwhite quail *(Colinus virginianus)* (Hernández and Guthery, 2012) and greater sage-grouse *(Centrocercus urophasianus)* (Crawford et al., 2004; Guttery, 2011; Payne, 2018; Payne et al., 2018). Targeted sheep browsing can increase the abundance and accessibility of nutritious winter browse for mule deer *(Odocoileus hemionus),* white-tailed deer *(Odocoileus virginianus),* elk *(Cervus elaphus),* and moose *(Alces alces)* (Jensen et al., 1972; Alpe et al., 1999), and targeted grazing by sheep or cattle can improve accessibility to nutritious herbaceous forage for mule deer, pronghorns *(Antilocapra americana),* and elk (Smith et al., 1979; Willms et al., 1979; Clark et al., 2000; Short and Knight, 2003; Pollak, 2007). Crane et al. (2016) demonstrated on a large landscape scale that elk in spring avoided foraging in areas not grazed by cattle during the previous summer − early fall. Rather, elk preferred to graze where cattle had grazed lightly (11 − 30% forage use) or moderately (31 − 60% forage use), and preference by elk was stronger for moderately grazed sites. Both moderate and light cattle grazing intensity had more influence on elk foraging site selection than distance to security cover, distance to roads, aspect, or slope.

Targeted grazing can also be used to modify shrub structure and increase productivity. In the absence of grazing, bitterbrush (*Purshia tridentate* [Pursh] DC) productivity can decline by 70% (Tueller and Tower, 1979). Cattle grazing can modify the structure of bitterbrush shrubs (Ganskopp et al., 1999), and light cattle grazing in the spring can rejuvenate plants and improve productivity (Ganskopp et al., 2004).

Management of vegetation diversity is critical for wildlife habitat management. For example, grassland birds inhabit a gradient of vegetative structure from heavily grazed grasslands to undisturbed tall vegetation (Derner et al., 2009). For instance, Collins et al. (1998) demonstrated that vegetation diversity of tall grass prairie can be maintained through grazing. Livestock grazing is also critical for maintaining vegetation diversity of ephemeral wetlands (Pyke and Marty, 2005). Vegetation diversity of vernal pools in California declined after 10 yr when grazing was excluded (Marty, 2015). Targeted grazing can be designed to specifically address the needs of individual species or develop diverse habitat conditions. In locations with appreciable forage regrowth, continuous grazing at low stocking densities and stocking rates can be used to create patches and diversify vegetation structure (Cid and Brizuela, 1998; Teague and Dowhower, 2003; Bailey and

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Brown, 2011). Supplements can be used to temporally create areas of heavy grazing and low vegetation levels near placement sites (Bailey and Welling, 1999). Distribution management tools such as fencing and herding, discussed earlier, can also be used to increase or decrease forage defoliation in desired areas to enhance diversity.

Fire Breaks

By focusing livestock in specific areas, managers can use targeted grazing to produce fire breaks to reduce the fuel continuity and the potential for catastrophic wildfire (see Table 2). Controlled and repeated grazing during the growing season can be used to reduce standing crop and regrowth to create firebreak strips (Taylor, 2006). Diamond et al. (2009) demonstrated that targeted cattle grazing could reduce fuel loads of cheatgrass sufficiently to reduce flame lengths and fire spread. Similarly, Bruegger et al. (2016) showed that cattle targeted grazing using low-stress herding and strategic supplement placement could reduce fuel loads sufficiently to reduce flame lengths and fire spread (Varelas, 2012). The combination of targeted grazing and prescribed fire can be an effective tool to produce firebreaks (Taylor, 2006; Diamond et al., 2012).

Integrated Management

Targeted livestock grazing can be integrated with other vegetation management options, including disking and seeding, herbicides, biological control insects, and prescribed fire. For example, cheatgrass seeds often germinate after disking, burning, or herbicide applications to control broad-leaved weeds. Targeted livestock grazing can defoliate the newly established cheatgrass plants and prevent them from producing viable seed (Mosley et al., 1999; Mosley and Roselle, 2006). After targeted livestock grazing is applied, sites can be drill- or broadcast-seeded. Another option is to broadcast seed immediately before the targeted grazing treatment and use the livestock to trample the seed into the ground (Havstad, 1994; Mosley et al., 1999), preferably with a high livestock density for a brief period when soils are moist (Mosley and Roselle, 2006).

Herbicides combined with targeted livestock grazing often suppress targeted plant species more than herbicides or targeted livestock grazing alone. To suppress leafy spurge, picloram plus 2,4-D can be applied in the fall after applying targeted livestock grazing during the summer (Lym et al., 1997). For spotted knapweed, 2,4-D can be applied in the spring to remove adult spotted knapweed plants, followed by targeted livestock grazing during summer to suppress seedling and juvenile spotted knapweed plants (Sheley et al., 2004).

Targeted livestock grazing and biological control insects complement each other, together stressing targeted plants more than either method applied alone. For example, after 4 yr of treatment, spotted knapweed plant density was 86% less in areas treated with biological control insects plus targeted sheep grazing applied during late July, versus areas treated with biological control insects alone (Mosley et al., 2016). Furthermore, combined herbivory by targeted sheep grazing and biological control insects reduced adult plant density and prevented compensatory recruitment of spotted knapweed seedlings and juvenile plants, but treatment with biological control insects alone did not. Targeted sheep grazing was timed to be compatible with the life cycles of the biological control insects.

Prescribed fire can be integrated with targeted livestock grazing to either suppress invasive plants or to alter the structural and spatial heterogeneity of vegetation to benefit wildlife. Diamond et al. (2012) combined targeted cattle grazing in May with prescribed burning in October to suppress cheatgrass. The combined targeted grazing — prescribed fire treatment was more effective than either treatment applied alone. Patch-burn grazing is another way that prescribed fire can be combined with pyric herbivory. Patch-burn grazing divides pastures into several patches using firebreaks but no cross-fences. One or two patches in each pasture are burned on a rotational basis each year, and livestock are allowed to move freely among the patches in a pasture. The most recently burned patch typically receives the greatest grazing pressure, whereas reduced grazing in unburned areas leads to greater vegetative cover. Thus, patch-burn grazing creates a mosaic of heterogeneous vegetation structure and cover (Fuhlendorf and Engle, 2004), which provides preferred habitat for many grassland birds such as mountain plover *(Charadrius montanus)*, long-billed curlew *(Numenius americanus)*, lesser prairie chicken *(Tympanuchus pallidicinctus)*, greater prairie-chicken *(Tympanuchus cupido)*, and upland sandpiper *(Bartramia longicauda)* (Derner et al., 2009; Sandercock et al., 2015; Winder et al., 2017). Patch-burn grazing also increases grassland butterfly diversity (Delaney et al., 2016).

FUTURE RESEARCH

Livestock producers, land managers, and entrepreneurs have been using the principles described in the Launchbaugh and Walker (2006) handbook for > 10 yr to apply targeted grazing. However, ongoing research is improving and refining targeted grazing practices (Figure 2). Improving managers' ability to concentrate livestock into designated areas will improve the efficacy of targeted grazing. Low-stress stockmanship developed by Bud Williams and described by Hibbard (2012) may be one potential method to focus livestock grazing, and virtual fencing (Anderson et al., 2014) is a promising technique to constrain livestock. Our understanding of secondary compounds is expanding and allowing practitioners to develop more effective targeted grazing protocols (Estell, 2010). However, the priorities for future research are animal welfare, genetic selection, and supplementation. The impact of targeted grazing on animal well-being is a critical issue that researchers have not fully considered. Consumers and other stakeholders are concerned with animal welfare (Verbeke, 2009; Lagerkvist and Hess, 2010), and some applications of targeted grazing may potentially impact animal well-being. Diet preference in sheep (Snowder et al., 2001) and goats (Waldron et al., 2009) is heritable for sagebrush and juniper, respectively, and for the latter both a physiological (Campbell et al., 2010) and genomic (Walker et al., 2019) basis has been demonstrated. The other important and exciting research area for targeted grazing is the use of supplements and pharmaceutical enhancements to minimize adverse impacts of secondary compounds on livestock. Additional research on these priority topics has great promise to increase the application of targeted grazing in the future.

Animal Welfare

Addressing potential animal welfare issues should become a priority in targeted grazing studies, particularly in those cases where the target plant species contains high concentrations of PSMs or where natural animal behavior is severely altered. Implementing targeted grazing programs at times when PSM concentrations are lowest should not only enhance chance of success (i.e., increase consumption of targeted species) but also minimize negative effects on animal well-being. The research community could anticipate obstacles to adoption of this technique by routinely addressing animal well-being in all targeted grazing studies.

Genetic Selection

A fundamental principle of targeted livestock grazing is to match the vegetation management task with the appropriate animal. Finding a good animal match is relatively easy when targeted plant species are highly palatable and located on gentle terrain. However, few good matches may be available if the vegetation management task requires livestock to consume phytotoxin-containing plants or plants growing in rugged terrain (see Figure 2). Selective breeding has great potential to mitigate phytotoxicosis in range livestock (Launchbaugh et al.,

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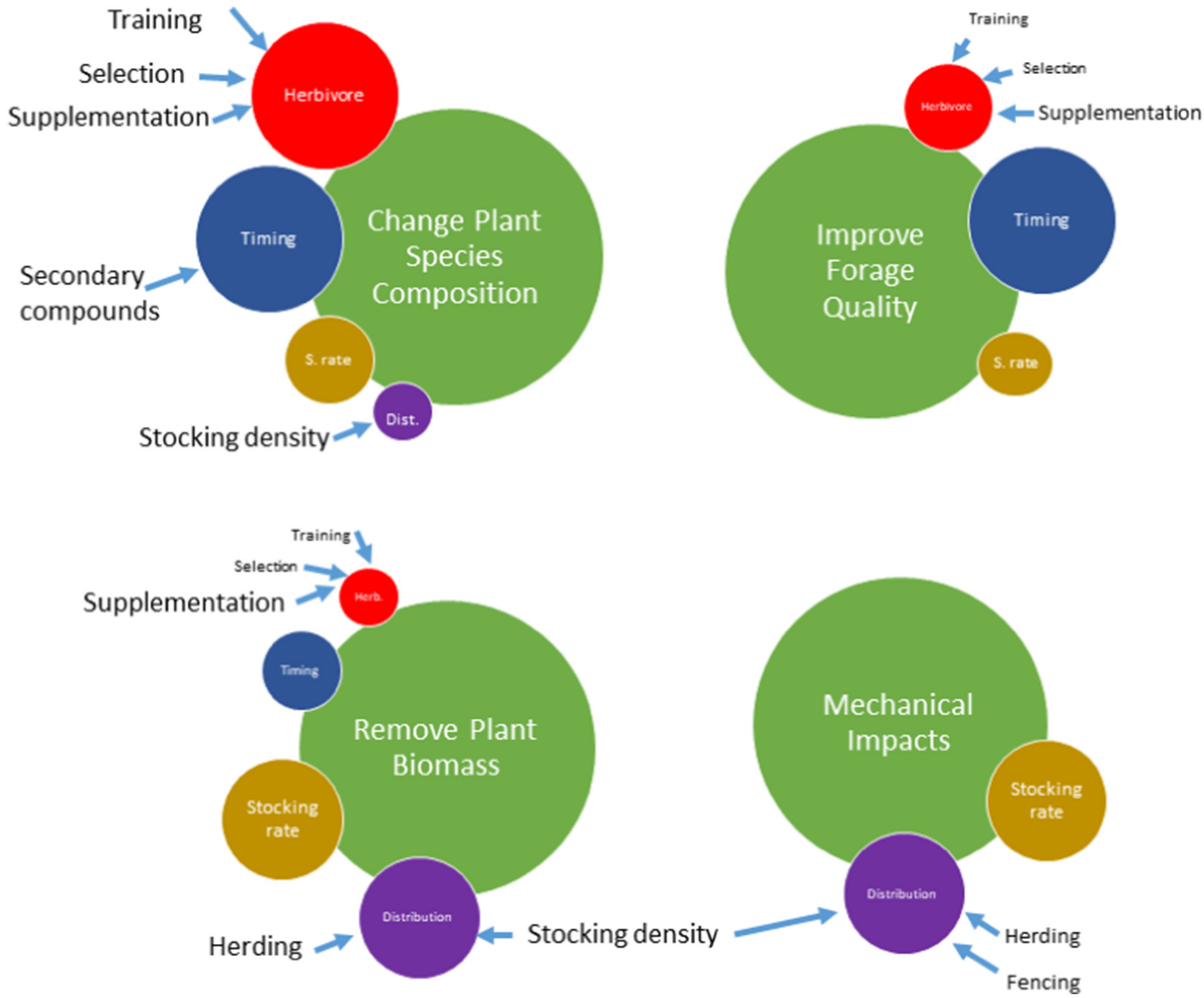

Figure 2. Grazing management tools (stocking rate, timing of grazing, species of herbivore, and distribution; Vallentine, 2001) used to achieve targeted grazing goals (change plant species composition, remove plant biomass, improve forage quality, and mechanical impacts) and ongoing research to improve the efficacy of these tools. *Arrows* show approaches to improve the efficacy of the grazing management tools and where additional research may be helpful.

1999; Campbell et al., 2010; Estell et al., 2012, 2014), and selective breeding also may be able to increase rugged terrain use by livestock (Bailey et al., 2015). Previous studies confirm the practicality and relevance of pursuing selective breeding. For example, resistance to ergot alkaloids that cause fescue toxicosis was developed by selective breeding for hepatic biotransformation enzymes in sheep (Morris et al., 1989, 1995) and cattle (Morris et al., 1998). Snowder et al. (2001) and Waldron et al. (2009) demonstrated heritable differences among individual sheep and goats in their ability to cope with phytotoxins in big sagebrush and Ashe juniper, respectively, and Cook et al. (2011) identified interindividual variation to larkspur toxicosis in cattle. Furthermore, Walker et al. (2019) found genetic markers for juniper consumption in goats divergently selected for increased or decreased juniper consumption. Ultimately it may be possible for livestock producers to identify suitable animals by submitting animal blood or hair samples for genetic testing.

Supplements and Pharmaceutical Enhancements

Several research projects have identified the value of dietary supplement to enhance detoxification and increase consumption of a targeted plant. For example, as mentioned earlier, feeding supplemental protein and polyethylene glycol may increase intake of oneseed juniper by goats (Utsumi et al., 2013) and supplementing sheep with barley and activated charcoal increased intake of big sagebrush (Banner et al., 2000). As we learn more about PSMs and physiological mechanisms of detoxification, it is likely that specific supplements will be designed to entice animals to consume target plants. In this way, individual animals will be able to consume greater amounts of target plants and fewer animals will be needed for targeted grazing projects, thereby increasing the economic and management feasibility of targeted grazing.

CONCLUSIONS

Targeted livestock grazing differs from other grazing management schemes in that its objective is to accomplish defined land management goals rather than livestock productivity. Managers use a specific kind of livestock at defined timing, intensity, duration, and location of grazing to resolve specific vegetative issues as an alternative or in combination with other practices such as herbicide applications, mechanical treatments, or prescribed burning. Like other management, targeted grazing should be approached as an adaptive process, where applications are monitored and evaluated so that the techniques can be improved and refined. Targeted grazing must overcome challenges associated with secondary compounds, endozoochory, and animal welfare. However, ongoing and future research is addressing issues that limit application of targeted grazing. Targeted livestock grazing is a valuable option in land managers' tool boxes.

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