Targeted Grazing: Plant and Animal Interactions

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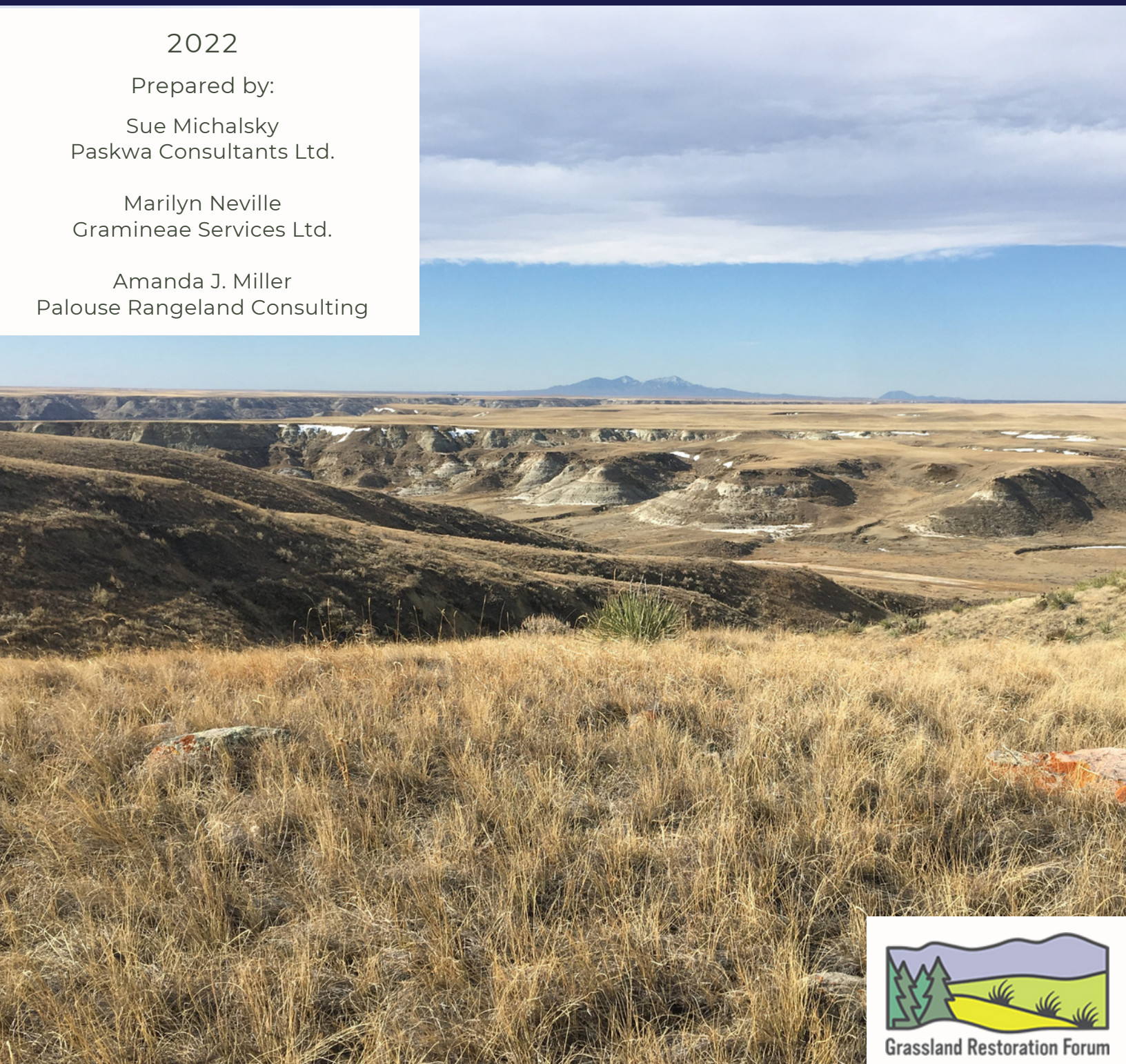

Grassland Restoration Forum

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This report is developed using primarily western methods, concepts, and theories. The principles and practices of rangeland science are widely accepted by professionals around the world, forming the international body of the Society for Range Management. When braided together, modern western science and traditional ecological knowledge can provide the basis for ecological and cultural reconciliation. We would like to pay respect to the Blackfoot people past, present and future while recognizing and respecting their cultural heritage, beliefs, and relationship to the land.

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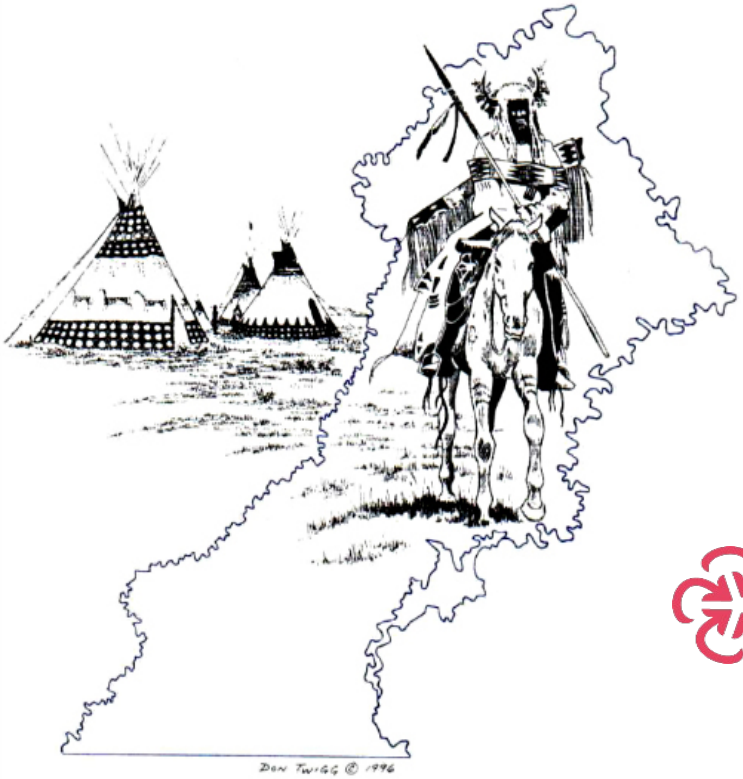

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Executive Summary

Targeted grazing uses livestock timing, frequency, intensity, and selectivity to apply herbivory pressure on target plant species or portions of the landscape to reach specific vegetation objectives. Although a simple concept, it is more complex in practice and relies on an understanding of several different interacting factors, including the interactions between plants and herbivores. This report delves into the details of plant-herbivore interactions, and the various considerations that should be taken into account when developing a targeted grazing prescription.

When developing a targeted grazing prescription it is critical to match the livestock species with the target plant or application by considering grazing preference, toxicity implications, and palatability of target and off-target plants. Livestock are categorized into major functional feeding groups that include bulk feeders such as cows (select grass dominated diets), intermediate feeders such as sheep (select grasses, forbs, and shrubs), and selective feeders such as goats (select forbs and shrubs). Each feeding type and livestock species has traits that can be beneficial in targeted grazing applications, as well as limitations that must be recognised.

Livestock Type	Habitat Selection	Forage Preference	Toxicity Considerations
Bulk Feeders / Grazers	Flatter areas closer to water resources	Grasses	More susceptible to toxicity effects
Intermediate Feeders	Steeper slopes further from water	Grasses, forbs, shrubs	Moderately susceptible to toxicity effects
Selective Feeders / Browsers	Steeper slopes further from water	Forbs and shrubs	Less susceptible to toxicity effects
Monogastric Omnivores	Shady areas close to water	All forages	Moderately susceptible to toxicity effects

Although animals will largely select within their feeding categories, they can and will make use of plants across categories. Forage selectivity is influenced by a suite of factors, including maternal influence, social learning, individual experience, class and kind of animal, and even breed can play a role.

Toxicity and palatability are also key considerations when developing targeted grazing prescriptions. Target plants are often not palatable and have toxicity concerns that affect both the efficacy of the treatment and impact animal health. The toxicity, palatability, suitable livestock species, best timing and frequency of grazing, and other key grazing prescription considerations are defined for a large suite of plants of interest, categorized as annuals, biennials, perennial forbs and grasses, and woody vegetation. These include invasive species of concern such as spotted knapweed and downy brome, and native species such as western snowberry and wolf willow.

Although these concepts provide guidance, it is important to consider that target plants have a variety of traits such as palatability, toxicity, and reproductive strategies that are related and interact with grazing livestock. Choosing the timing, intensity, and duration of grazing that most affects the target plant, facilitates grazing of the target plant, maintains the health of the livestock, and enhances the desirable vegetation on the site is a complex task as optimizing for one factor often results in negative outcomes for another.

Table of Contents

Executive Summary 2
Introduction 6
Goals 7
Livestock Overview 7
Livestock Forage Adaptability 10
Livestock and Habitat Selection 10
Livestock Suitability for Vegetation Management in Natural Landscapes 11
Forage Selectivity 12
Maternal Influence 12
Social Learning 13
Individuality and Individual Experience 14
Class and Kind 14
Breed 15
Targeted Grazing Principles 16
Stocking Rate 17
Distribution 17
Species of Livestock 18
Timing of Grazing 18
Comparison to Traditional Grazing 21
Animal Productivity and Gains 22
Palatability 23
Toxicity 24
Toxicity Exposure 27
Additional Forages and Supplementation 29
Toxicity, Body Condition, and Gains 29
Livestock Developmental Stage and Toxicity 30
Reproduction 30
Introducing New Foods 31
Training 32
Animal Welfare 32
Knowledge Gaps 33
Summary 33
References 35

Appendix 1: Anatomy and Digestive System Comparisons 52
Appendix 2: Livestock Profiles 53
Appendix 3: Plant Profiles 60

Table of Tables

Table 1. Functional feeding groups and their forage preferences. 9
Table 2. Livestock suitability summary. 11
Table 3. Plant species susceptibility to grazing by growth stage. 20
Table 4. Targeted grazing principles in contrast to traditional grazing 21
Table 5. Plant palatability – toxicity interactions. 26
Table 6. Susceptibility of livestock species to plant toxicity. 28
Table 7. Comparison of anatomy and digestive systems of browsers and grazers 52

Table of Figures

Figure 1. Vegetation – livestock interactions. 6
Figure 2. Functional feeding groups and their associated livestock types. 8
Figure 3. Livestock forage continuum. 10
Figure 4. Simplified palatability and postingestive feedback pathway 23

Introduction

Prescriptive grazing is the targeted application of grazing using timing, frequency, intensity, and selectivity to apply herbivory pressure on target plant species or portions of the landscape. Livestock pressure is focused on areas/plants of interest through the use of distribution tools such as herding, supplement placement, and fencing to both trample and/or defoliate plants/areas of interest to achieve vegetation objectives (Bailey et al., 2019; Rinella & Bellows, 2016). Developing successful prescribed grazing prescriptions requires an in-depth understanding of site and plant ecology, specific plant response, herbivore diet, nutrition and behaviour, animal husbandry, and plant-herbivore interactions (Bailey et al., 2019; Launchbaugh & Walker, 2006; Rinella & Bellows, 2016). It is important to understand that these factors do not operate independently and interactions between them must be considered when developing a grazing prescription.

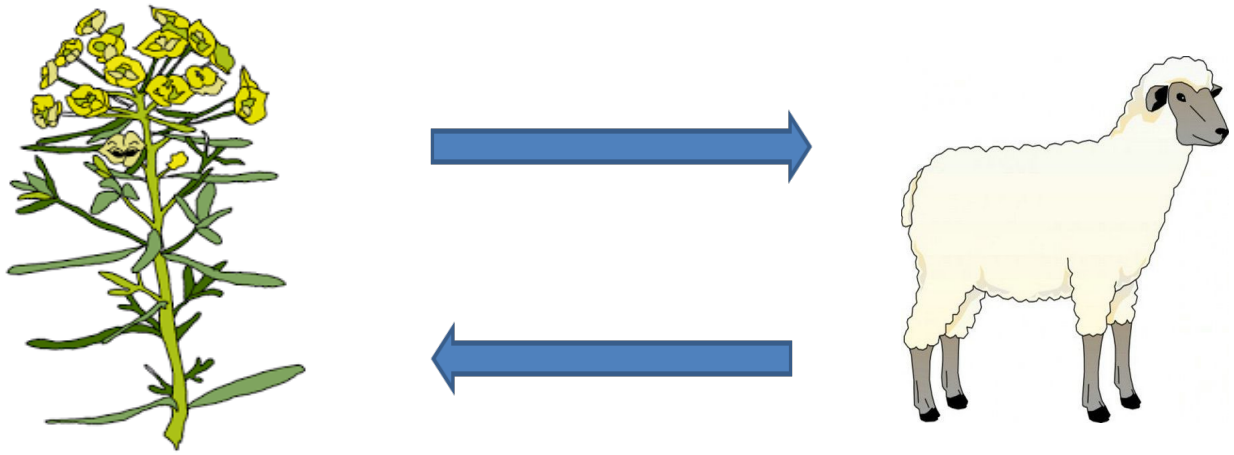

Figure 1. Vegetation – livestock interactions.

The goal of a grazing prescription for targeted grazing is to manipulate patterns of defoliation and disturbance to place an undesirable plant at a competitive disadvantage relative to other vegetation in the community. This is accomplished by grazing the target plant species when it is most vulnerable, at an intensity that harms the target plant species, and at a time when the target plant is least toxic to the livestock species used for grazing.

Targeted grazing principles are used to manipulate livestock impacts, and are defined by Bailey et al. (2019) as:

1. Stocking rate
2. Distribution
3. Species of livestock
4. Season (timing) of grazing

Altering any of these principles will impact the grazing treatment, and with the right background knowledge decisions can be made to refine the treatment based on these principles to best accomplish the desired goal(s). Many of the plant species land managers seek to control through targeted grazing

are generally less palatable and less nutritious that the desirable plants on a given site, and some contain compounds that are toxic to livestock (Becker and Miller 2009). When preparing a targeted grazing prescription, land managers need to consider and balance the timing of grazing when a plant species is most susceptible to stress from grazing with the timing of when a plant species is least toxic and/or most palatable (Frost and Launchbaugh 2003). These considerations are sometimes in conflict. This section will address the specific livestock considerations necessary to support successful targeted grazing prescriptions in natural landscapes.

A successful grazing prescription should:

- ✓ Cause significant damage to the target plant.
- ✓ Limit irreparable damage to the desirable components of the plant community.
- ✓ Limit negative impacts to animal health and welfare
- ✓ Be consistent with other goals for the site.
- ✓ Be integrated with other control methods as part of an overall strategy.

Goals

It is important to establish clear goals and desired outcomes to ensure that the grazing treatment is purposeful and beneficial. This is critical to success and supports positive outcomes and working relationships.

Prescribed Grazing Case Study: Kainai Nation (*Káínawa*)

After a decade of increasing leafy spurge infestations with losses of native grasslands, traditional foods, and medicines, Blood Tribe Lands partnered with Robert Finck of Creekside Goat Company to utilize goats for a targeted grazing program to control leafy spurge. The goals of the project are to reduce leafy spurge cover and prevent its spread, while subsequently protecting and enhancing traditional foods and medicines.

'With the spread of leafy spurge into the grasslands we realized we were losing our native medicinal plants and plants used for traditional native food and food security."

Nathan Mistaken Chief

Additionally, it is important to implement an effective monitoring program to determine whether goals are being met, timing and efficacy of treatments is still appropriate, or if restoration actions are necessary (Bailey et al., 2019; Frost et al., 2012) Recommended monitoring protocols for targeted grazing projects in western Canada are defined by Michalsky & Neville (2021) and provide well-defined monitoring protocols to support goals.

Livestock Overview

Herbivores have unique grazing strategies that are a function of mouth size and design, digestive system, and overall size (Nader et al., 2007). Grazing livestock are broadly classified into three functional groups based on their feeding habits; these include grazers (bulk feeders), browsers (selective feeders), and intermediate feeders (Holechek et al., 2011). Monogastric omnivores are in addition to these categories and refer to swine.

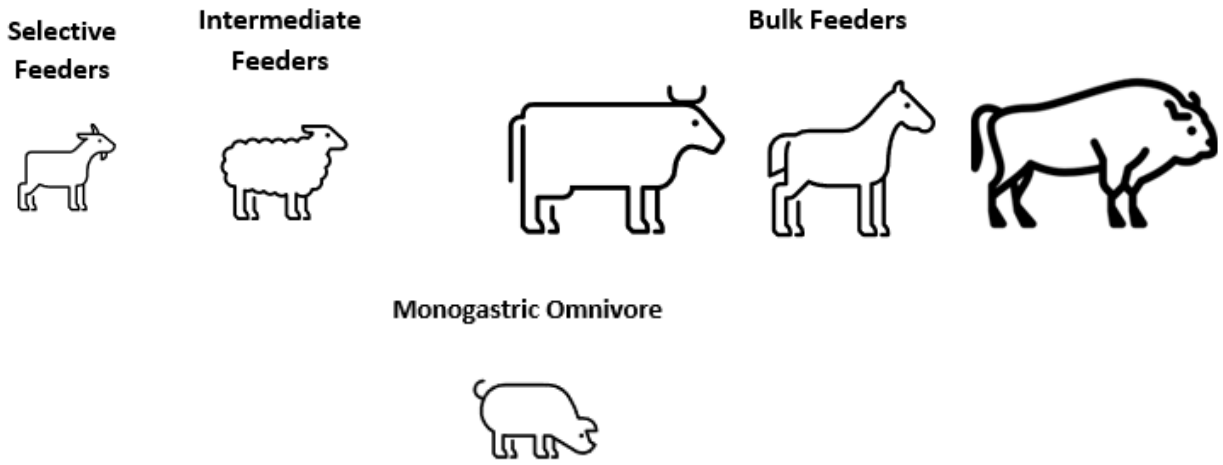

Figure 2. Functional feeding groups and their associated livestock types.

Bulk feeders, also known as 'grazers', include cattle, bison or *Iinnii*[1], and horses. Their diets are grass dominated, although they will eat both forbs and shrubs. Grazers will often avoid shrubs as they lack the digestive mechanisms able to mitigate toxicity often associated with shrubs (Austin et al., 1989; Holechek et al., 2011). Morphologically grazers tend to be larger in size, have a broader muzzle width, less dexterity of mouthparts as they exhibit reduced selectivity when foraging, and have a larger omasum than ruminants in other functional feeding groups (Codron et al., 2007; Janis, 1995). They have a higher daily forage intake than other feeding groups (partially due to their large size), consume large amounts of relatively low quality forage, and are more susceptible to toxicity effects than selective and intermediate feeders (Hofmann, 1989; Holechek et al., 2011). The bulk feeders we are most familiar with, horses and cattle, have different dental anatomy, where horses have both top and bottom incisors and can graze very close to the ground relative to cattle which have bottom incisors and a hard upper palate, resulting in a less effective grazing pattern with more standing vegetation generally left behind (Rook et al., 2004).

Bison and cattle have relatively similar dental anatomy and diets (91% dietary overlap), but graminoids tend to make up a higher proportion of diet in bison than cattle (Plumb & Dodd, 1994; van Vuren & Bray, 1983). Although bison select largely for graminoid plant species when foraging, they exhibit horning and rubbing behaviour on shrubs and trees (specifically aromatic species such as sagebrush and juniper) that can result in large-scale mortality (up to 80%) of those species in pastures grazed by bison (Coppedge & Shaw, 1997; Edwards, 1978; Painter & Ripple, 2012). This activity is theorized to be linked to rut, shedding, or the use of aromatic substances for insect repellent properties, or some combination of these different factors (Coppedge & Shaw, 1997).

Selective feeders are also referred to as 'browsers' and include goats. They select primarily for forbs and shrubs (Holechek et al., 2011). Browsers tend to be smaller in size, have narrow muzzles for selective feeding, and large salivary glands (Codron et al., 2007; Hanley, 1982; Janis, 1995). Narrow muzzles and dextrous mouthparts allow browsers to select the portions of plants that have lower levels of volatile oils to mitigate toxicity, in addition to other adaptations that mitigate toxicity effects (Codron et al.,

[1] The Buffalo: A Treaty of Cooperation, Renewal and Restoration (https://www.buffalotreaty.com/treaty).

2007; Hanley, 1982; Janis, 1995). Browsers also tend to have softer and more delicate mouth tissues than grazers. Goats also chew forage more thoroughly than larger ruminants, which when combined with their tannin binding salivary proteins results in reduced impacts of toxins and toxic effects (Robbins et al., 1991; Schmitt et al., 2020). Goats have the ability to degrade tannins through gut flora and enzymes that convert potentially harmful metabolites into waste, and also have large livers relative to their body mass allowing them to effectively process secondary compounds, and further supporting their ability to mitigate toxicity effects (Miller et al., 1995).

Intermediate feeders include sheep. They are adapted to both browsing and grazing and will make use of grasses, forbs, and shrubs (Hofmann, 1989; Holechek et al., 2011). Intermediate feeders are opportunistic, and can forage between the extremes of selective feeders and bulk feeders, adapting their feeding habits to whichever forage resources are available (Codron et al., 2007; Hofmann, 1989; Holechek et al., 2011). Short-term and seasonal dietary shifts are common with intermediate feeders, where their forage selection is associated with shifts in forage quality (Hofmann, 1989). Intermediate feeders are less susceptible to toxicity effects than bulk feeders, but more susceptible than selective feeders (Codron et al., 2007; Holechek et al., 2011).

Grazers, intermediate feeders, and selective feeders generally refer to ruminate feeding types, but within the context of targeted grazing there is another category that must be considered: **monogastric omnivores**, referring to swine specifically. Swine are highly adaptable and will feed on almost any forages or foodstuffs available, and root through the earth which can pull out plant roots and crowns (Lyons et al., 1999). However, swine have different nutritional requirements than ruminants, with a specifically high requirement for the amino acid lysine, and cannot survive on plant-based forages alone (Cromwell, 2016).

It is interesting to note that body size plays a foundation role in livestock selectivity, smaller animals generally have higher energy requirements and select for higher quality, energy-dense foods, while larger animals can better extract nutrition from lower-quality foods due to the fact that they retain them in their digestive tract for longer (Ferrer-Cazcarra & Petit, 1995; Illius & Gordon, 1993; Lazo & Soriguer, 1993).

Matching livestock species with the target plant species or vegetation/landscape goal is a critical step in developing a successful targeted grazing prescription. Consideration must be given to grazing preferences, toxicity, palatability, and the experience levels of herds and individual animals to match suitable livestock to the landscape and target plants (Olson & Launchbaugh, 2006). Table 1 provides a broad overview of forage preferences of each functional group, and the morphological and physiological adaptations of selective feeders and grazers are detailed in Appendix 1: Anatomy and Digestive System Comparisons.

Table 1. Functional feeding groups and their forage preferences.

Functional Group	Forage Preference
Bulk Feeders / Grazers	Grasses
Intermediate Feeders	Grasses, forbs, shrubs
Selective Feeders / Browsers	Forbs and shrubs
Monogastric Omnivores	All forages

Although there is flexibility in an individual animal's foraging preferences, the broad categorization of browsers, intermediate feeders, and grazers can provide a good starting point for developing grazing prescriptions (Taylor, 2006).

Livestock Forage Adaptability

Although herbivores generally forage within the feeding categories summarized in Table 1 there is a wide range of adaptability where herbivores can and will make use of plants across these broad categories depending on available forages, representing a continuum of forage use across livestock types rather than neatly categorized groups (Gordon, 2003; Meuret & Provenza, 2015; Provenza et al., 2003).

'Plants and animals aren't machines and genes aren't destiny.'
- Meuret & Provenza

Animals classified as grazers have been shown to thrive on browse-based diets, while browsers have also shown instances where they live primarily on graminoid-based diets, indicating that managed grazing has the potential to impact livestock foraging behaviour, creating flexibility and adaptability in forage selection, instilling behaviours beneficial for prescribed grazing across a variety of forage types (Meuret & Provenza, 2015; Provenza, 2003b). Even bison, who show a very strong selective preference for graminoids, will select for up to 20% shrubs in some cases (Plumb & Dodd, 1994).

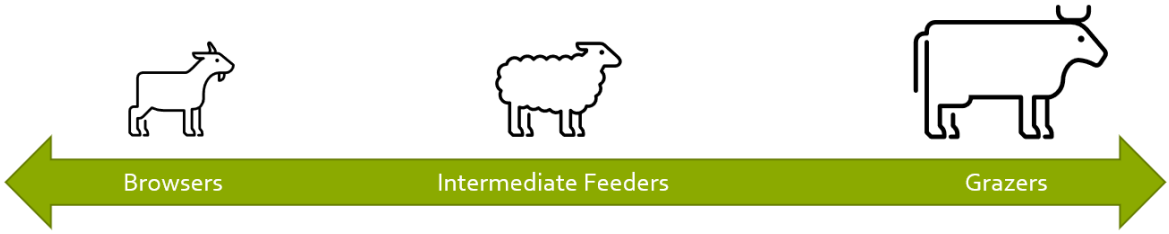

Figure 3. Livestock forage continuum.

In real-life application, a ranch in eastern Montana implemented intensive targeted grazing to address invasive species, and during that time cattle began to forage on generally unpalatable shrubs that have toxic compounds (snowberry and sagebrush) and learned to self-regulate toxic effects by simultaneously utilizing palatable (Provenza et al., 2003). However, these changes in management that result in a requirement for animals to learn new behaviour and foraging patterns are often associated with decreases in performance (body weight, condition, and conception rates) for a short period of time, often between 1 to 3 years (Provenza, 2003a).

Livestock and Habitat Selection

In addition to differing forage and diet preferences, livestock types also demonstrate varying preferences across habitat types (Walker et al., 2006).

Cattle prefer to utilize flatter areas close to water resources, preferentially using primary range areas within 1.5km of water and salt resources and avoiding slopes of over 30% (Alberta Government, 2015; Ganskopp & Vavra, 1987; Kaufmann et al., 2013; Launchbaugh & Howery, 2005). Cattle will overuse these primary range areas if management tools and strategies are not used to improve distribution.

Similar to cattle horses have been found to prefer flatter areas closer to water, and also show an avoidance of closed canopy forests, selecting for open grasslands and/or cutblocks (Girard et al., 2013). As with cattle, horses will overuse these areas if distribution tools/strategies are not implemented.

Bison also prefer gentle terrain close to water, however relative to cattle they are more heat and drought tolerant, and will spend less time at watering sources and in riparian areas (Boyce et al., 2022; Fuhlendorf et al., 2010; Kohl et al., 2013; Larter, 1988; van Vuren, 1983). Bison tend to use areas of higher elevation, but avoid steeper slopes and roads (Kohl et al., 2013). Bison habitat use is dynamic across a seasonal cycle, and in winter bison will use steeper slopes to take advantage of stockpiled forage (Plumb & Dodd, 1994; Ranglack & du Toit, 2015).

Both sheep and goats will use steeper slopes, dispersing further from water sources, sometimes travelling through areas of abundant forages along the way, and tend to bed down in open upland areas (Burritt & Frost, 2006; Launchbaugh & Howery, 2005).

In addition to these broad preferences, the pattern of use of an individual animal across a landscape is influenced by plant community, topography, wind, shade, relationships between herbivores, predator interactions, and supplement placement (Meuret & Provenza, 2015; Teague et al., 2013). This can result in preferential use of areas that have to be addressed through the use of distribution tools (eg. fencing, herding, salting, etc.) to effectively target grazing pressure. However, skilled livestock managers may be able to train animals to more effectively use areas that perhaps are less desirable for certain types of livestock, and these adaptations and learnings can be leveraged in targeted grazing applications (Launchbaugh & Howery, 2005).

Livestock Suitability for Vegetation Management in Natural Landscapes

When developing a targeted grazing prescription it is critical to match the livestock species with the target plant or application by considering grazing preference, toxicity implications, and palatability of target and off-target plants (Olson & Launchbaugh, 2006). Each feeding type and livestock species has traits that can be beneficial in targeted grazing applications, as well as limitations that must be recognised, these broad considerations are identified in Table 2.

Table 2. Livestock suitability summary.

Livestock Type	Habitat Selection	Forage Preference	Toxicity Considerations
Bulk Feeders / Grazers	Flatter areas closer to water resources	Grasses	More susceptible to toxicity effects
Intermediate Feeders	Steeper slopes further from water	Grasses, forbs, shrubs	Moderately susceptible to toxicity effects
Selective Feeders / Browsers	Steeper slopes further from water	Forbs and shrubs	Less susceptible to toxicity effects
Monogastric Omnivores	Shady areas close to water	All forages	Moderately susceptible to toxicity effects

Swine are generally not suggested as a suitable species for targeted grazing as they represent a public relations challenge due to issues with manure odours, and there is a risk associated with escaped swine contributing to the rapidly evolving invasive feral pig problem currently facing several provinces (Aschim & Brook, 2019).

Bison can be used in intensive management situations such as targeted grazing applications if they are used to that type of management, and are being managed by individuals familiar with bison behaviour and handling. Bison have strong instincts and require specialized skills to ensure the safety of both animals and handlers, and there should not be the expectation that bison unfamiliar with intensive management, or humans unfamiliar with specialized bison handling skills can easily adapt to targeted grazing applications. (Canadian Bison Association, 2022; Spencer, 2022).

Forage Selectivity

Selectivity is influenced by a host of complex and interacting intrinsic and external factors, from broad-scale morphological differences described in the 'Livestock Overview' section, learned behaviours from their mothers and herd mates, plant availability and toxicity, individual nutrient needs and ability to process toxic compounds via postingestive feedback (Glasser et al., 2009; Provenza et al., 2003).

As animals begin to grow and develop their selectivity is influenced by several factors, and learning plays a key role in determining and animal's selectivity (Provenza et al., 2003; Provenza, 1995). The experience of individual animals and herds is an important consideration in targeted grazing applications, where animals with experience have the ability to eat a large variety of forages with differing levels of nutrition and toxins and an ability to self-regulate, while naive animals will only eat forages that they are familiar with (Provenza, 2003b). Experienced animals will eat a variety of forages with toxic compounds and varying nutrient levels, even in cases where there are nutritious alternatives. An animal's individual experiences combined with current environmental conditions and social dynamics within a herd all work together to influence selectivity (Howery et al., 1998).

Maternal Influence

Young animals are taught foraging strategies including what to eat, where to go, and the motor skills necessary to consume different plants from their mothers (Howery et al., 1996; Mirza & Provenza, 1990; Luis Ortega-Reyes & Provenza, 1993). In fact, forage preferences of individual animals beings to develop in utero via exposure from the mother's diet (Simitzis et al., 2008). In utero exposure can result in selection of even bitter or strong flavoured plants that foraging livestock would otherwise avoid (Nolte et al., 1992). This exposure underlays changes in form and function, where the digestive tract development and its subsequent performance are enhanced when animals eat food types they have been exposed to as part of their mother's diet (Ortega-Reyes et al., 1992). This exposure and flavour preference continues to develop through suckling where animals are exposed to flavours in milk (Nolte & Provenza, 1992a), and in the initial introductions to solid forages (Nolte & Provenza, 1992b).

Aside from passing along an acquired taste for certain flavours, mother animals pass down learned patterns of behaviour to select for invasive species, 'unpalatable' species, and strategies for how to manage toxicity (Provenza et al., 2003). As young animals move away from milk-dominated diets and begin to forage they learn by observing their mother, and the foods that she chooses lay the foundation for the young animal's forage selectivity (Burritt & Frost, 2006).

(Green et al., 1984) found that lambs that had been fed wheat, a very nutritious food source, with their mothers would eat almost 10 times more wheat than lambs with exposure to wheat without their mother's presence, and this relationship was still evident even three years after the first experience with wheat and no additional exposure. Lambs will also consume more of a novel food with their mother than if they are with a dry ewe (Thorhallsdottir et al., 1990). This highlights the long-lasting impact of the

maternal role in diet selection, where flavours introduced early in life and experienced with their mother persist as preference over time (Nolte & Provenza, 1992b). However, as strong as this role is, animals still won't eat food that makes them sick, even if their mother has a strong preference for it (Provenza et al., 1993). Unsurprising as this may be to any parent, as animals begin to age the mother's influence begins to wane, as was proven in a study by (Mirza & Provenza, 1990) who found that mother ewes had more influence novel food acceptance in lambs at 6 weeks of age than at 12 weeks. It's been postulated that the weaning period is a sensitive time to learn about new foods, and may be a period of easy acceptance of novel foods (Provenza & Balph, 1988).

Early learning and experience from the mother animal also plays an important role in grazing distribution, (Howery et al., 1998) found that young animals tend to use the same home range as the cow that they nursed on, whether it was the natural mother or a foster.

The feeding behaviours and distribution/movement patterns an animal learns at a young age are repeated throughout an animal's life and appear to be more persistent than behaviours learned or acquired later in life (Launchbaugh & Howery, 2005; Provenza & Balph, 1988).

Social Learning

Although maternal lessons are critical in developing foraging behaviours, other adult animals and peers will also influence foraging behaviours and habitat selection/dispersal (Howery et al., 1998). Social learning can have substantial impacts on forage selectivity and adaptation to varied environments, which is why animals of the same species are found in different environments and can survive and thrive on radically different diets (Provenza, 2003a; Provenza et al., 2003). Research has shown that when herds are created using mother animals with distinctly different dietary habits their offspring will show preference to the diets of their dams, but in successive generations diets become more alike between individuals through the influence of peers (Biquand & Biquand-Guyot, 1992).

Experienced animals within the herd setting can help facilitate selection of new target plants by naive animals who observe and then replicate the grazing behaviour (Davison et al., 2006). Social learning is not only limited to forage selection, but also habitat use and distribution, where lead individuals will select foraging areas and facilitate use of various parts of pastures (Bailey, 1995). Animals encourage each other to try larger quantities of novel forages and different environments, and animals will roam over a larger area and variety of terrain when foraging together than alone (Provenza et al., 2003; Thorhallsdottir et al., 1990). Adults also learn from their young or other young because of the innate curiosity of young animals to try novel foods, a study found that lambs taught mature ewes to eat Douglas fir seedlings over a 4-year period while grazing in tree plantations (Provenza, 2003a).

Social dominance also plays a role in both forage and habitat selection, where dominant animals influence selection (Bailey, 1995; Bailey et al., 1996; Sato, 1982). This can be used to the advantage of targeted grazing practitioners, who can use dominate experienced animals with desirable foraging tendencies to influence naïve animals to reach desired objectives.

Animals tend to become more reluctant to try new and novel foods as they age (Squibb et al., 1990), but social learning can play an important role in aiding naive animals to try novel foods in targeted grazing applications.

Individuality and Individual Experience

Individuality and individual experience have significant influence on dietary preferences of each specific animal. Animals of the same age, sex, breed, lifecycle stage, and experience will still show variation in dietary preference (Scott & Provenza, 1999). Individuals all have unique sensory and physical abilities, dental structure, and organ size/function, and these differences affect both an animal's capacity to metabolize nutrients and toxins, as well as their innate foraging capabilities (Burritt & Frost, 2006). Genetics play a role in individual dietary preference and habitat selection, and may be somewhat heritable (Bailey et al., 2004, 2015, 2006; Ellis et al., 2005; Jackson, 2012; Snowder et al., 2001), although other research has indicated that genetics may not influence diet and habitat selection significantly (Moore, 2018).

Experience is a key driver in the use of novel forages, past experiences allow animals to effectively self-regulate and optimize nutritional intake and reduce energy use both in foraging behaviour and in toxic compound mitigation. Animals with experience with foods with toxic compounds will use them exponentially more than animals with no experience, even in cases where toxins are at low enough quantities that they result in no negative effects (Villalba et al., 2004). Early life experiences have persistent effects on animal distribution and their willingness to use certain types of foraging habitats (Howery et al., 1998). Animals with experience in specific types of habitats will be better suited to targeted grazing applications in those same types of landscapes and may be less suited to grazing in radically different environments even if target plants are the same. For example, goats raised in shrub dominated landscapes in Texas were found to perform better in shrubby ranges in Southern Utah when compared to goats reared in grass pastures (Villalba et al., 2004). It is not necessarily a successful strategy to take animals into substantially different environments and expect that they will be able to effectively fulfill a targeted grazing prescription. As an example, animals raised in a feedlot or corral situation could not be expected to quickly and easily adapt to living and grazing in remote open range situations, and conversely animals raised on rugged open range may have difficulty adjusting to busy urban environments (Frost et al., 2012).

As experience is the primary factor impacting the efficacy and self-regulating abilities of livestock in targeted grazing applications, it is key to match animals with experience with both target plants and landscapes/habitats whenever possible.

Class and Kind

Consistent with the foundational effect of body size on diet selection, females and younger animals (smaller in body size) generally show higher degrees of selectivity than males or older animals (Ferrer-Cazcarra & Petit, 1995; Illius & Gordon, 1993; Lazo & Soriguer, 1993). Age can have substantial affects on diet selection, nutritional requirements, and the ability of an animal to tolerate toxic secondary compounds (Grings et al., 2001). Mature animals generally require less foodstuffs than younger animals as their metabolic requirements change with age, and will spend less time foraging, while young growing animals have higher nutritional requirements for crude protein and energy specifically, and will spend longer foraging and eat more in general (Grings et al., 2001). Younger animals are also more apt to try novel foods, consume less palatable foods, and retry foods that may have made them sick previously in an effort to meet their higher nutritional needs (Ralphs & Provenza, 1999).

Older animals have an additional factor that affects their dietary selection – tooth wear. As herbivores age their teeth begin to wear down, which impacts overall grazing efficacy and selectivity, leading older animals to begin to select for forages with higher concentrations of nutrients (Mellado et al., 2005).

Nutritional needs also change dramatically across different life stages and play a substantial role in diet selection (Burritt & Frost, 2006). Females that are gestating or lactating have higher nutritional requirements than males or nonlactating females, while nonlactating adult animals exhibit reduced selectivity since they have the ability to consume a wider array of plants to meet lower nutritional needs (Nader et al., 2007). Ferrer-Cazcarra & Petit (1995) found that calves exhibited a higher degree of selectivity than mature dry cows, while Lazo & Soriguer (1993) found that small and medium-sized animals (sub-adults and some small adult females) were more selective than adult males, and when forage availability decreased they subsequently altered foraging behaviour to ensure intake of preferred foods by increasing travel while foraging. Some target plant species, such as leafy spurge, have high nutrient content and can support animals during reproductive life stages, however not all target plants are highly nutritious so care must be taken when matching animals to specific plants and objectives (Fay, 1991).

In cases where low quality forages are the target plant(s) or plant community the use of castrated males may be desirable as they don't need to maintain body condition for breeding, and can recovery lost weight much more rapidly than even nonlactating females (Burritt & Frost, 2006).

Foraging behaviour differences between males and females, and the various developmental stages across an animal's lifecycle are well established and should be considered when selecting the right animals to achieve goals in targeted grazing prescriptions.

Breed

Different breeds of livestock species can differ substantially in their size, which can impact nutritional requirements and digestive ability, with subsequent impacts on forage selectivity (Illius & Gordon, 1993; Launchbaugh et al., 1997). Selective breeding also appears to have influenced the type of terrain used by various breeds of livestock for effective foraging (Burritt & Frost, 2006). Livestock breeds are also generally adapted to different climates they were developed in, for example European cattle breeds (*Bos taurus*) are better adapted to cooler climates, while zebu or African cattle breeds (*Bos indicus*) are better suited to hot humid climates, and sheep/goats are largely better adapted for desert climates (Holechek et al., 2011). Sheep and goat breeds have some general differences as well, where those that were heavily selected for fibre or growth (eg. Angora and Boer goats) have historically been less exposed to environmental extremes via intensive management, while other breeds (Spanish and Damascus goats) had less historic management and subsequently will include less palatable and nutrient-rich forages in their diets (Riddle et al., 1996). Although these general concepts are well-established, there are only small number of studies that investigate direct breed comparisons.

Cattle breeds developed in rugged terrain are associated with more uniform use of steep slopes and mountainous topography than breeds developed in areas with flatter topography based on work by Bailey et al. who found that Tarentaise cows used steeper slopes at greater distances from water than Hereford cows (Bailey, Kress, Anderson, Boss, & Davis., 2001; Bailey, Kress, Anderson, Boss, & Miller, 2001). Meuse-Rhine-Yssel steers have been found to select for more digestible herbage than Hereford steers, likely as a result of higher body maintenance requirements as they were less mature (Wallis de

Vries, 1994). VanWagoner et al. (2006) found that Piedmontese-sired cows ventured further from water horizontally and vertically than other breed mixes (Angus) with similar findings to Bailey et al. (2001) where cows sired from breeds originating from mountainous regions appeared to use rugged terrain more uniformly than those sired by bulls whose breed originates in areas with gentler terrain. Additional studies have noted that Gertrudis cows walk further on a daily basis than Hereford cows in spring and summer (Herbel & Nelson, 1966), while Brahman cows were found to walk further than Brangus or Angus cows in another study (Russell et al., 2012).

Larger Latxa dairy ewes have been found to select a higher digestibility diet than smaller Gallega ewes in a study by Osoro et al., (1999), and similar observations were made in perennial ryegrass-white clover swards with the same sheep breeds, although breed effects on selectivity were small (Osoro et al., 2002). Sheep breed has also been linked with a difference in browse consumption, where Barbado blackbelly sheep consume significantly more browse than other sheep breeds (Warren et al., 1984). Dwyer & Lawrence (2000) found that Scottish Blackface ewes used upland pastures more than Suffolk ewes, and that this behaviour persisted in their lambs as they matured.

Damascus goats were found to select for tannin-rich shrubs twice as often as Mamber or Boer goats, despite the presence of abundant other forages that were low in tannins and palatable (Glasser et al., 2008), and along the same vein Glasser et al. (2009) found that Mamber does were able to teach avoidance of toxic high-tannin foods to their natural or fostered offspring, while Damascus does had no impact on preference.

Even within breed genotype can have impacts on grazing behaviour. Cid et al. (1997) found that small genotype Aberdeen Angus steers were more selective with their grazing behaviour than larger Angus genotypes. A study by Bailey et al. (2015) indicated that grazing behaviour was a heritable trait across various breeds of cattle, where two genetic markers found on different chromosomes accounted for 24% and 23% of the variation in use of higher elevations and steep slopes in rangelands with variable topography. These genetic markers are linked to a gene associated with locomotion, motivation, and spatial memory.

Despite these research findings, across species, it appears that learned behaviours are largely more dominant than genetics in determining forage and habitat preference and avoidance (Glasser et al., 2009; Howery et al., 1998; Moore, 2018).

Targeted Grazing Principles

Targeted grazing principles that can be adjusted to impact grazing treatment outcomes include (Bailey et al., 2019):

1. Stocking rate
2. Distribution
3. Species of livestock
4. Season (timing) of grazing

Understanding the impact of these principles on livestock behaviour and outcomes will support the development of successful targeted grazing prescriptions. Different grazing management systems address these principles in different ways and result in altered foraging dynamics that may or may not support targeted grazing objectives (Provenza et al., 2003).

Stocking Rate

The stocking rate, ie. the intensity and duration of a grazing period, impacts the utilization of the vegetation resources, and may have positive or negative implications depending on the desired outcomes of the grazing treatment (Nader et al., 2007).

Increasing stocking rate will increase the overall amount of forage utilisation, and also impacts the use of target plants (Bailey et al., 2019). Grazing under higher stock densities tends to reduce livestock selectivity due to reduced grazing choice, and animals will begin to graze less preferred or undesirable plants (Davison et al., 2006; Utsumi et al., 2010). Using higher stock densities can increase the utilization rate of target plants (often undesirable due to palatability and/or toxicity issues) and help ensure that invasive species do not gain a competitive advantage over the more palatable plants (Hart et al., 1991; Provenza et al., 2003). Animals that are repeatedly pressured through high stocking densities to eat all the plants available in an area are more likely to learn to eat mixtures of toxic and nutritious plants in ways to mitigate toxicity, and these learned adaptations of forage mixtures to mitigate toxicity are beneficial in targeted grazing applications (Provenza et al., 2003). Research out of California found that even with minimal use of distribution practices goats will use less palatable plant species and parts under high stocking rates (Spurlock et al., 1980). However, high stocking rates and grazing intensities may also increase the risk of livestock losses or health issues if greater amounts of toxic plants are ingested (Pfister et al. 2002).

During long duration grazing periods with lower livestock numbers animals will preferentially select the most desirable plants/forages first, and move on to for less palatable forages once desirable plants have been overused (Nader et al., 2007). This can result in outcomes contrary to invasive species management and provide a competitive advantage for less desirable plants, and highlights what an important consideration stocking rate is in targeted grazing prescriptions.

Some tips to consider when prescribing stocking rates for a targeted grazing program include:

Tips:

- Low grazing intensities can be used to take advantage of an animal's dietary preferences in sparse infestations of palatable plants.
- High grazing intensities can be used to achieve even use of vegetation in situations of dense infestations or less palatable target plants.
- Remove animals before 60% of the desirable plant foliage is grazed to avoid impacts to non-target plants.
- Consumption of target plants should significantly exceed consumption of desirable plants.
- Repeated grazing within a growing season over several years can be the best method to control some plants.

Distribution

Distribution practices can be used to focus or direct grazing pressure, and the use of various distribution tools and practices can be an important component of targeted grazing prescriptions (Bailey et al., 2019). Commonly used practices and tools include; fencing, water development, salt/mineral supplement placement, access and trail development, and riding or herding (Holechek et al., 2011). A brief overview of each practice is outlined below:

Fencing: Fencing is an effective but logistically complicated and/or expensive solution to alter livestock behaviour in support of targeted grazing prescriptions (Holechek et al., 2011). Either temporary or permanent fencing may be needed for passive management approaches, where animals are contained to the treatment area to focus on the target species or area. Targeted grazing applications may require additional fencing needs such as portable panels to support night penning, or electric net fencing for smaller more curious animals prone to escape (ie. goats).

There are some disadvantages to establishing permanent fencing for targeted grazing treatments, largely cost, but also the maintenance requirements, the fact that it may not be necessary or desirable to maintain long term in some situations, and potential disruptions to wildlife movement.

Water: Water is a critical requirement for livestock, and greatly influences their habitat selection (Holechek et al., 2011). Water developments are effective tools to influence and enhance distribution and can assist with focusing animal pressure into target areas if strategically placed.

Salt/Mineral: Placing attractants such as salt and mineral blocks in target areas will encourage their use. These supplements also provide benefit by supporting the metabolization of toxic compounds that may be associated with target plants (Banner et al., 2000; Villalba et al., 2002).

Riding/Herding: Herding can improve distribution by moving animals into target areas or focusing them on target plants. This method often requires constant attention in targeted grazing prescriptions and full employment of attentive and well-trained herders or riders (Kott et al., 2016). Herding may be used to develop new patterns of grazing behaviour by introducing animals into new areas and using herding to condition them to desired distribution and foraging patterns is often successful (Meuret & Provenza, 2015).

Access and Trail Development: Providing trails or access routes through natural barriers (eg. dense forest or rough topography) can facilitate livestock movement and direct grazing pressure (Holechek et al., 2011).

Species of Livestock

Described in detail in the 'Livestock Overview' portion of this report, target plant selection can be adjusted by using different species of livestock.

Timing of Grazing

Timing of grazing, also referred to as 'season of use', impacts livestock preference and forage selectivity (including which specific plants are consumed), while stage of growth affects physiological status and associated nutritional value of plants (Bailey et al., 2019; Nader et al., 2007). Grazing target plants during the periods of time when they are palatable (either has higher nutrient levels or low levels of toxins) is an important consideration as well, targeted grazing strategies may be more or less effective depending on whether or not grazing occurs during these windows (Campbell & Taylor, 2006).

Studies of intensive grazing by sheep in Idaho bunchgrass/sagebrush communities found that sheep selected for sagebrush in the fall when it had lower levels of terpenes (Bray et al., 1991; Personius et al., 1987) and bunchgrasses in the spring when sagebrush had higher levels of terpenes, illustrating that season of use is a factor in selectivity (Taylor, 1994).

Timing of grazing is critical to control of all plant species. For example, leafy spurge (*Euphorbia esula*) has a longer window of time where grazing is an effective control method than cheatgrass (*Bromus tectorum*) which has a short window of opportunity for effective grazing impact when it is green and growing during early spring (Cook & Harris, 1952; Mosley & Roselle, 2006). Timing grazing can be tricky as the time of year that various growth stages occur will vary from year to year based on climatic variables such as date of the last frost, temperature, and spring moisture.

An understanding of the plant communities and/or target plants can support effective timing of grazing treatments. Table 3 outlines the best stage of growth to impact targeted plant species for some of the commonly targeted plants in our area. Some general considerations can be used as guidelines for timing of grazing based on plant type.

Annuals

Annual plants, such as Downy brome, depend solely on seed for reproduction and are best controlled during the seedling and early vegetative stages.

Biennials

Biennials, such as sweet clover, live for two years and generally do not produce seed until the second year. They are easier to control while still in the rosette stage (first year of growth).

Perennial Forbs and Grasses

Perennial forbs, such as leafy spurge, are usually best controlled during the early bud stage, about two weeks before flowering. Perennial grasses, such as Kentucky bluegrass are best controlled during the seedling and early vegetative stages.

The goal of targeted grazing is often to reduce production of seed and extent of cover of the target plant species without harming the associated desirable vegetation. With many target plant species, it may be necessary to use a twice-over grazing regime wherein the plant is grazed in early growth stages and then again in the flowering stage or when new shoots have emerged (Launchbaugh 2012; Davidson et al. 2007; DeBruijn and Bork 2006; Beck et al. 1998; Lajeunesse et al. 1999; Mosley et al. 1999; Olsen and Wallander 2001). For example, a single graze of Kentucky bluegrass has been shown to increase the cover of that species relative to sites that were not grazed. A twice-over grazing system reduces the cover of Kentucky bluegrass relative to sites that were not grazed (Beck et al. 1998). A twice-over grazing regime helps balance the differences in timing of palatability and susceptibility to grazing. However, twice-over grazing systems can also have negative impacts on desirable vegetation. Palatable decreaser species may decline with a second grazing event (Moss et al. 2008; Beck et al. 1998).

Woody Vegetation

Palatable brush species are most sensitive to heavy grazing pressure in early spring, when stem and leaf growth is rapid. Protein and phosphorus levels are highest and stem hardness is lowest at this time. Few of these palatable species can withstand grazing in spring in excess of about 35% use of new stems and leaves (Moss et al. 2008). Heavy grazing in spring and early summer can be used to reduce palatable brush and to promote the production of grasses and other forages on range and pasture lands.

Best control of palatable tree species, such as trembling aspen, occurs when trees are in full leaf and the terminal leaf has just emerged (late May or June). When the terminal leaf has broken bud or is in full leaf, the tree is at its lowest level of root reserves. Leaves of woody species such as aspen and saskatoon

have the highest protein and nutrient levels in June and these levels decline as the growing season progresses (Moss et al. 2008).

Native poplars, willows, silverberry, snowberry, saskatoon, wild cherries, wild roses, wild raspberry, wild gooseberry, and similar species all re-sprout after burning, mowing, or dozing. There is evidence that these species may be susceptible to late season grazing (August) the year after a burning, mowing, or dozing event (Fitzgerald and Bailey 1984; AFGA 2011). The timing of an effective late season graze would occur once the plant has set bud for the following year, but before it has replenished its root reserves.

Note that it may take several years of grazing treatment of woody vegetation before actual changes in the forage supply become available to livestock.

Table 3. Plant species susceptibility to grazing by growth stage.

Plant Susceptibility to Grazing							
N/A=NOT APPLICABLE L = LOW M=MODERATE H=HIGH	SEEDLING	VEGETATIVE	BUD	FLOWERING	SEED SET	HARDENING	DORMANCY
ANNUALS							
Downy and Japanese Brome (*Bromus tectorum, Bromus japonicus)*	M	H	H	L	L	n/a	n/a
Kochia (*Bassia scoparia*)	H	H	M	L	L	L	L
BIENNIALS							
Sweetclover (*Melilotus officinalis*)	H	H	M	L	L	L	L
PERENNIAL GRASSES & FORBS							
Kentucky Bluegrass (*Poa pratensis*)	H	H	M	M	L	L	L
Canada thistle (*Cirsium arvense*)	H	H	M	L	L	L	L
Common Burdock (*Arctium minus*)	M	M	H	M	L	L	L
Common Tansy (*Tanacetum vulgare*)	H	H	H	M	L	L	L
Diffuse Knapweed (*Centaurea diffusa*)	M	H	H	M	L	L	L
Hoary Cress (*Lepidium draba*)	M	M	M	L	L	L	L
Hound's-tongue (*Cynoglossum officinale*)	M	H	H	M	L	L	L
Leafy Spurge (*Euphorbia esula*)	M	H	H	H	L	L	L
Oxeye Daisy (*Leucanthemum vulgare*)	H	H	H	M	L	L	L
Purple Loosestrife (*Lythrum salicaria*)	H	H	M	M	L	L	L
Russian Knapweed (*Rhaponticum repens*)	H	H	H	H	M	L	L

Spotted Knapweed (*Centaurea stoebe*)	M	M	H	H	M	L	L
WOODY VEGETATION							
Chokecherry (*Prunus virginiana* or *Pakkii'p*)	H	H	M	L	L	L	L
Greasewood (*Sarcobatus spp.*)	H	H	M	L	L	L	L
Saskatoon (*Amelanchier alnifolia* or *Okonokee*)	H	H	M	L	L	L	L
Silverberry / Wolfwillow (*Elaeagnus commutata* or *Misisaimi'soyiis*)	H	H	M	M	L	L	L
Western Snowberry (*Symphoricarpos occidentalis*)	H	H	M	L	L	H	L
Willows (*Salix spp.* or *Otsipiis*)	H	H	M	L	L	H	L
Trembling Aspen (*Populus tremuloides,* or *A'kĺĺtoyi*)	H	H	M	L	L	H	L

Comparison to Traditional Grazing

The goals and priorities of targeted grazing and traditional grazing strategies differ, with targeted grazing applications using livestock behaviour to increase the use of undesirable plants at their most vulnerable periods, in comparison to traditional grazing which aims to promote livestock gains while maintaining the productivity of plant communities (Bailey et al., 2019). These differences are contrasted below in Table 4.

Table 4. Targeted grazing principles in contrast to traditional grazing. Adapted from Vallentine (2001) and Bailey et al. (2019).

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
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 of Livestock	Livestock are selected based on their preference for targeted vegetation	Livestock selected due to market factors and predation considerations
Timing of Grazing	Timing is often a critical factor • Graze when plant secondary metabolites are low to improve palatability and/or reduce adverse postingestive feedback • Graze when target plants are least resistant (most susceptible) to grazing • Graze before seed set to reduce seed production	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

Principle	Targeted Grazing	Traditional Grazing
	• More than one grazing event per year may be necessary • Graze when non-target plants are less palatable and/or more resistant to grazing	

Different grazing systems influence foraging behaviour, where continuous grazing systems under low stock densities encourages animals to be more selective and reduce the variety of forages consumed, while shorter duration grazing at higher stock densities will reduce selectivity and increase the variety of forages consumed Provenza et al. (2003). Traditional grazing management strategies may have inadvertently trained generations of livestock to use preferred forages and habitats selectively – 'eat the best and leave the rest' as coined by Provenza (2003b) of Utah State University.

The management intensity of the targeted grazing prescriptions should be matched with the economic constraints or realities of both the land and livestock managers. There are some factors that increase cost and/or reduce animal performance and can have negative implications to the productivity of either livestock or the land base. These are defined by Launchbaugh & Walker (2006) and include:

1. High grazing pressure to induce consumption of a target plant
2. Close proximity to urban areas in areas with overlapping and conflicting uses

Targeted grazing in these situations can be expensive either in terms of infrastructure/oversight or animal production, and in practice targeted grazing practitioners make decisions based on the best use of existing ecological, social, and economic conditions by linking principles with an understanding of process and the ability to be flexible in response to change (Meuret & Provenza, 2015).

Animal Productivity and Gains

Short and long-term impacts on livestock gains have been associated with implemented targeted grazing prescriptions. Increasing management intensity is associated with reduced gains and livestock production as animals are either subject to high levels of grazing pressure that result in reduced forage intake or increased intake of toxic compounds (and subsequent reduced gains/condition due to energetically expensive toxin metabolization) or stress from grazing in high-conflict areas, such as urban grazing environments with multiple land uses that may be in conflict with livestock production such as off-leash dogs (Launchbaugh & Walker, 2006).

A ranch in eastern Montana moved to an intensive targeted grazing approach to manage weedy species, and this shift was associated with a short term reduction in weaning weights while cattle adapted to the new grazing regime (dropping from over 500lbs to 350lbs) which rebounded to over 500lbs in year three (Provenza et al., 2003). This indicates that there may be short-term impacts on gains and other performance indicators (condition and conception rates) while animals adapt to changes in diet and learn new behaviours as a component of targeted grazing treatments, but they do not appear to be long-term (Provenza, 2003a).

Other work has shown that supplementation is necessary to ensure productivity gains in targeted grazing applications, which affects profitability if sale of meat products is a component of the operation (Hintze et al., 2021).

In other cases where herds are well-experienced in targeted grazing applications there may be little to no impact on animal productivity as a result of these treatments.

Palatability

Palatability is a complex concept and process. It is an integration of odour, taste, and texture with postingestive (feedback from the gut to brain allowing for animals to sense the toxic or nutritional effects of food) effects of toxins and nutrients (Provenza, 1995; Provenza et al., 2003). Palatability is driven by flavour, a result of sensory effects in the mouth and nose responding to the taste (sweet, salty, bitter, sour), smell, and feeling (astringency, pain) of whatever has been ingested, in combination with internal postingestive feedback (Provenza et al., 2003). This flavour-postingestive feedback interaction allows animals to effectively differentiate among different types of foods and determine their utility relative to the animal's nutritional state (Pfister et al., 1997; Provenza et al., 2003).

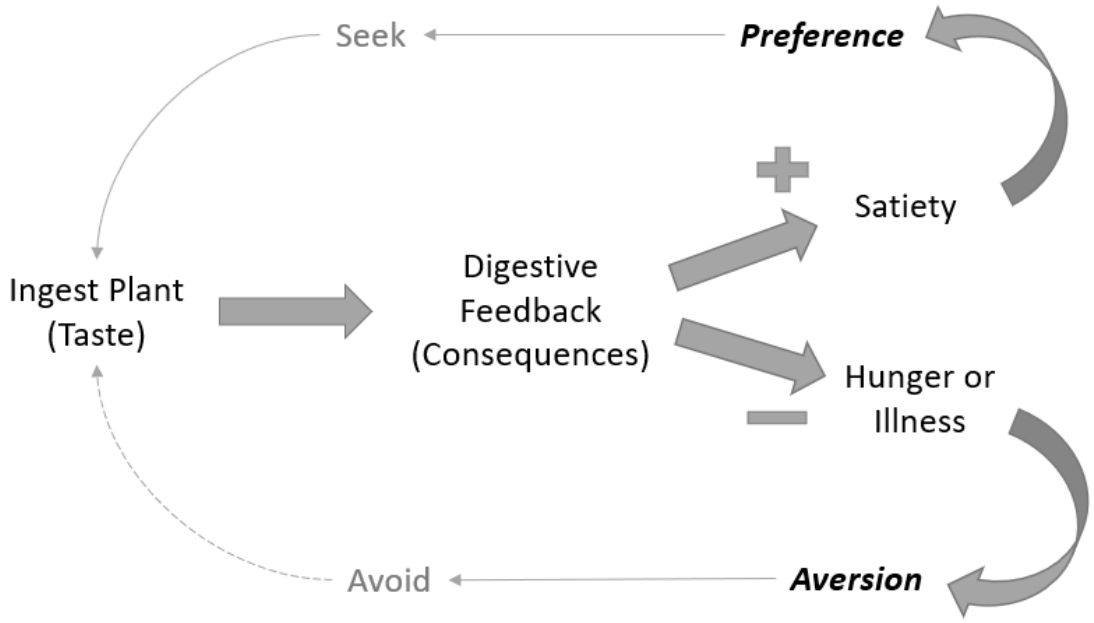

Figure 4. Simplified palatability and postingestive feedback pathway. Adapted from Launchbaugh & Howery (2005).

This relationship is not solely built on whether flavours are inherently 'good' or 'bad', but the combination of flavour and postingestive feedback, where animals begin to experience comfort/satiety and preference for a plant that provides nutrients as desired (palatable), or conversely experience discomfort when they ingest plants that have inadequate nutrients or toxic compounds (unpalatable) (Burritt & Frost, 2006). Learning via postingestive feedback happens automatically, and research has shown that it can change food preferences even when animals are anesthetized, Provenza et al. (1994) found that sheep fed a nutrition-rich food followed by a toxin dose while they were anesthetized developed an aversion to the food via this negative feedback even though they were asleep.

Put simply, if it tastes good it's likely helping to meet an animal's current nutritional needs, and if it tastes bad it's either not providing nutritional benefit or is of detriment.

However, this relationship is not static in time or space. The palatability of certain plants changes over time, as concentrations of toxins change or as lignification increases, or in space where it is dependent on which plant community they are present in and the relative palatability of the plants around them (Meuret & Provenza, 2015; Provenza et al., 2003).

To add complexity to the palatability concept, aversions to certain plants or forages can also occur when animals eat the same food/forage too often or in large amounts, resulting in 'grazing weariness' and a decline in the comparative palatability and preference of a certain food type, and is considered a transient food aversion (Meuret & Provenza, 2015; Provenza et al., 2003). This decrease in preference is accelerated, persists longer, and is stronger when the food/forage in question is either nutrient deficient or toxic, and is not adequate relative to the animal's nutritional needs (Early & Provenza, 1998; Ralphs & Provenza, 1999; Villalba et al., 2011).

Combined, these factors affecting palatability lead to a cyclic pattern of intake of different forages, which helps ensure that toxic effects are mediated and nutritional requirements are met, while making use of available forage resources (Provenza et al., 2003). This also highlights the importance of providing additional forages as a component of targeted grazing prescriptions, which is further detailed in the 'Additional Forages and Supplementation' section.

Toxicity

Toxic compounds co-evolved with grazing disturbance and are a defensive mechanism against herbivory that deter grazing and represent a major factor in the diet selection of grazing animals (K. Launchbaugh & Walker, 2006). Some plant species are generally considered toxic while others are not, but even within a species the level of toxicity can fluctuate depending on the time of day, the season, or environmental conditions of the area where it is growing (Meuret & Provenza, 2015). Changes in toxic concentrations in plant tissue change over the grazing season, between years, and between populations of the same plant, and even slight changes in these concentrations can result in toxicity concerns for livestock (Ralphs et al., 1997). These influence the interactions between animals and plants, affecting intake and selection and limiting how much of one particular plant species can be consumed, subsequently spreading grazing pressure across the plant community (Nader et al., 2007; Provenza, 2003b). Many weedy plants that are targeted in these grazing applications have higher levels of toxins, along with higher levels of nutrients.

The most common toxic compounds and agents present in plants include alkaloids, furanocoumarins, glycosides, nitrates, oxalates/oxalic acid, tannins, and terpenes, summarized in brief below.

> **Alkaloids** are organic compounds with bitter tastes that are largely irritating to gastrointestinal tract, and central nervous system, and can cause a variety of symptoms including nausea, diarrhea, muscular weakness, and death (Lord & Roberts, 1987). They are the strongest toxic substance in plants, are generally distributed throughout the entire plant and often remain potent after maturity or if a plant freezes (Holechek et al., 2011). Toxicity is often acute, but if non-lethal amounts are consumed then animals usually recover shortly.
>
> **Furanocoumarins** are organic chemical compounds produced by plants that have negative impacts on liver function and cause inflammation of skin and mucus membranes when exposed to light, resulting in painful blisters, dermatitis, and light sensitivity (Drever & Hunter, 1970;

Gucker, 2009; Morton, 1975; Tiley et al., 1996). Symptoms may also include inflammation around the mouth, eyes, ears, nostrils, udders, and genitals, and ongoing hypersensitivity to sunlight (Buttenschon & Nielsen, 2007; Page et al., 2006). Bare, unpigmented skin is the most susceptible to furanocoumarins, and animals with dark pigmentation and thick pelts are less susceptible (Buttenschon & Nielsen, 2007; Nielsen et al., 2007; Quinn et al., 2014).

Glycosides contain glucose and are not toxic themselves, but form toxic substances as they break down either from events such as wilting, freezing, crushing, or digestion (Holechek et al., 2011). Glycoside concentrations vary over time, and are often higher in younger plants (especially when growing rapidly in cooler weather), when drought-stressed or if they have been exposed to freezing temperatures (Stegelmeier, 2021). Normally safe forages can accumulate toxic levels of glycosides under these types of growing conditions. Symptoms include nervousness, muscle tremors, convulsions, rapid respiration, and often rapid death (Lord & Roberts, 1987).

Nitrates in are often found in high levels in weedy plants, and when digested is reduces to nitrite, which bonds with hemoglobin to form methemoglobin, which is unable to carry oxygen within the bloodstream, ultimately leading to asphyxiation (Holechek et al., 2011; Lord & Roberts, 1987). Ruminants are sensitive to nitrate poisoning as they are able to quickly reduce nitrates to nitrite, while higher levels are required to be toxic in monogastric animals (Stegelmeier, 2021). Nitrate accumulation occurs in areas with nitrogen-rich soils, drought or frost stress, and some herbicides (such as 2,4-D) which cause accumulation of excess nitrates (Holechek et al., 2011; Stegelmeier, 2021). Symptoms include trembling, rapid breathing, staggering, brown discoloured blood, cyanotic mucus membranes, and death. Chronic nitrate accumulation results in poor milk production, abortion, and poor growth.

Oxalates in soluble forms bind calcium and other trace minerals within the body, leading to an inability of the body to metabolize the compound, which forms an insoluble salt that precipitates in the kidneys and causes kidney failure (Rahman et al., 2013). Ruminants are more tolerant than non-ruminants as rumen bacteria work to degrade oxalate into carbon dioxide and formic acid, which are harmless (Allison et al., 1977). Symptoms include weakness, muscle tremors, and death (Holechek et al., 2011; Rahman et al., 2013).

Tannins are a common toxic compound used as a defence mechanism in many plant species; they decrease palatability, nutrient availability, feed intake, and suppresses enzymatic activity (Barry & Duncan, 1984; Du Toit et al., 1990; Jones et al., 1994; Makkar, 2003). At high levels tannins can damage the liver, kidneys, and epithelium of the digestive tract (Bryant et al., 1991; Reed, 1995).

Terpenes are the aromatic compounds that provide the scent associated with many plants (eg. sagebrush, lavender, orange peel, pine, etc.) and are toxic to livestock when consumed in too high of concentrations (Dziba et al., 2006; Johnson et al., 1976). Symptoms include nervousness, rapid breathing, drowsiness, convulsions, lack of coordination, and loss of consciousness (Dziba et al., 2006).

Herbivores have developed a suite of physiological, anatomical, and behavioural adaptations to mitigate these defence mechanisms, where different adaptations are found in different species, and sometimes

even across different breeds of a given species (Glasser et al., 2009; Makkar, 2003; Pritz et al., 1997; Squires, 1982). Understanding these adaptations is important when developing targeted grazing prescriptions. Table 5 outlines the interactions between toxicity and palatability of some of the commonly targeted plant species in our region.

Ruminants (cattle, sheep, goats) and monogastric animals (horses and pigs) differ in their sensitivity to toxic compounds, for example glycosides are more hazardous to ruminants as their digestive process rapidly releases the toxic compounds relative to monogastric animals, whereas alkaloids are more toxic to monogastric animals (Majak et al., 2008). Additionally, individual tolerances play a substantial role in an animal's ability to metabolize toxins. Practically every research trial on plant toxicity has revealed individual animals who have the ability to consume what would be a lethal dose of toxins to another animal without any ill effects (Keeler et al., 1988). Although there are practices identified below that can minimize the impact of toxic compounds on livestock the welfare of the animals should be the primary concern (Bailey et al., 2019).

Table 5. Plant palatability – toxicity interactions.

Plant Palatability - Toxicity Considerations			
	Generally Palatable to Livestock	**Generally Unpalatable to Livestock**	**Palatable at Certain Stages of Plant Growth**
Always Toxic	Greasewood *(toxicity increases with maturity of foliage)* Kochia *(toxic only when it comprises at least 50% of diet)* Purple loosestrife (*conflicting data on toxicity) (low to moderately palatable to goats)*	Absinth Wormwood Tall buttercup Common Hound's-tongue Blueweed Leafy Spurge	Chokecherry *(new foliage is palatable)* Tall Larkspur *(new growth is highly palatable)* Canada thistle *(poisoning is rare – low risk) (palatable to goats, sheep, and cattle especially in early growth stages)* Common mallow *(mildly toxic, especially to horses)* Hoary cress *(mildly toxic) (palatable to sheep and goats in early stages of growth)* Wild Caraway *(toxic to horses, palatable to other livestock species in spring before bolting)*
Toxic Only at Certain Times	Saskatoon *(early growth through flowering)*		
Not Toxic	Sweet Clover Kentucky bluegrass Most Willows	Common Tansy *(conflicting data on toxicity; may be toxic to horses and cattle in large quantities) (not palatable to cattle and horses, but somewhat more palatable to sheep and goats)*	Downy and Japanese Brome *(palatable in vegetative stage)* *Green foxtail (most palatable in early growth stages)*

	Burdock *(conflicting data on toxicity) (most palatable to sheep)* Oxeye Daisy (most palatable to sheep and goats)	Russian Knapweed *(not palatable to cattle and horses, but palatable to sheep and goats)* Scentless chamomile Western Snowberry *(not palatable to cattle, but palatable to sheep and goats in early growth stages)* Wolfwillow/Silverberry *(unpalatable to cattle, but palatable to sheep and goats)*	*Field scabious (palatable prior to bolting but unpalatable once mature)* Spotted and Diffuse knapweed *(most palatable in early growth stages) (most palatable to goats and sheep)* Trembling aspen *(most palatable in early growth stages) (highly palatable to sheep)*

Toxicity Exposure

Experiences and exposures to toxic compounds early in life can result in changes in animal behaviour and their responses to both the physical stresses from toxic compounds and interestingly enough how well animals are able to cope with larger stressors, including changes in their environment (Francis et al., 1999).

Early exposure to toxic compounds in young animals has shown variable results, in some cases it is linked with increased ability of the liver to process toxins, and in other cases is associated with liver damage dependent on the specific toxin and its associated dose (Distel & Provenza, 1991; Pritz et al., 1997).

Research results on toxicity of plant species to different livestock species is highly variable and sometimes conflicting. Many differences in levels of toxicity in a plant species are dependent upon the growth stage in which it is grazed. However, most studies do not control for prior exposure or learned behaviour. Table 6 shows the susceptibility of different livestock species to toxicity of some of the commonly targeted plant species in our region.

Table 6. Susceptibility of livestock species to plant toxicity.

Plant Toxicity Considerations for Livestock Species				
Plant Species Level of Toxicity (L=Low M=Moderate H=High)	**Sheep**	**Goats**	**Cattle**	**Other**
Common Burdock (*Arctium minus*)	**L**	**L**	**L**	**M (horses)**
Canada thistle (*Cirsium arvense*)	**L**	**L**	**L**	**M (horses)**
Chokecherry (*Prunus virginiana* or *Pakkii'p*)	**H**	**H**	**H**	**N/A**
Common Tansy (*Tanacetum vulgare*)	**L**	**L**	**Conflicting information – may be highly toxic**	**Conflicting information on horses – may be highly toxic**
Diffuse Knapweed (*Centaurea diffusa*)	**L**	**L**	**L**	**M (horses)**
Greasewood (*Sarcobatus spp.*)	**M (lambs) L (adults)**	**N/A**	**M (calves) L (adults)**	**N/A**
Hoary Cress (*Lepidium draba*)	**L**	**L**	**M**	**N/A**
Hound's-tongue (*Cynoglossum officinale*)	**M**	**L**	**H**	**H (horses, pigs)**
Kochia (*Bassia scoparia*)	**H**	**M**	**H**	**H (horses)**
Leafy Spurge (*Euphorbia esula*)	**M**	**M**	**H**	**H (horses)**
Russian Knapweed (*Rhaponticum repens*)	**M (lactating ewes)**	**L**	**M**	**M (horses)**
Scotch broom (*Cytisus scoparius*)	**M**	**L**	**M**	**M (horses)**
Spotted Knapweed (*Centaurea stoebe*)	**L**	**L**	**M**	**M**
Sweetclover (*Melilotus officinalis*)	**L**	**L**	**M**	**N/A**
Saskatoon (*Amelanchier alnifolia* or *Okonokee*)	**M**	**M**	**M**	**L (Horses)**
Tall buttercup (*Ranunculus acris*)	**M**	**M**	**H**	**M (horses)**
Water Hemlock (*Cicuta spp.)*	**H**	**H**	**H**	**H (all livestock)**

Some toxic plant species are considered too toxic to livestock and grazing as a control option is not recommended. The risk of death might be too high, or the type of toxin may produce symptoms that acutely harm the animal. These plant species include all water hemlocks (*Cicuta spp.)*, tall buttercup (*Ranunculus acris*) (DiToamso, 1999), and possibly Hound's-tongue (*Cynoglossum officinale*).

Additional Forages and Supplementation

When grazing animals have the ability to freely select forages they are rarely poisoned by toxic plants/compounds as they are able to self-regulate through postingestive feedback and can select for additional forages without toxic compounds, allowing their body to effectively process ingested toxins without significant negative effects (Provenza, 2003b; Provenza et al., 2003).

In targeted grazing situations where animals are focused on plants that may contain toxins, additional forages may be necessary to maintain animal health and welfare. This is dependent on characteristics and objectives relative to target plants, the target area, and non-target plants. Additional forage resources will allow livestock to manage toxicity levels as they adjust to consuming target plants containing toxic compounds. Additional forage resources may include non-target plants in treatment areas if the use of significant amounts of non-target plants is acceptable, or supplemental forages such as hay. Supplemental forages may require a designated feeding area to address potential off-target impacts. Providing supplemental feed may also increase the intake of less preferred plants (eg. weedy species with toxic compounds) and support an effective grazing prescription (Davison et al., 2006).

Different toxic compounds are metabolized in different ways, and providing a variety of forages can help prevent negative effects of toxicity while providing a wide array of nutrients to support animal health (Provenza & Villalba, 2010). Ensuring that animals have a mix of forages available in time and space is important to ensure that the nutritional needs of the animals are met while mitigating the potential negative impacts of toxicity (Meuret & Provenza, 2015).

Not only is a variety of forages important but providing additional supplements (eg. salt, mineral, protein, or other foodstuffs such as grain) can support the metabolization of toxic compounds (Banner et al., 2000; Villalba et al., 2002). Supporting this through supplementation increases the intake of less preferred plants the same manner as providing additional forages, where faster rates of metabolization/elimination allow livestock to ingest higher levels of toxic compounds without negative effects (Provenza et al., 2003).

It is important to note that animals will learn to avoid and regulate a plant only if the toxin present causes nausea, they can't learn to avoid plants that cause issues such as neurological problems, birth defects, respiratory failure, or chronic liver disease (Provenza et al., 1992).

Toxicity, Body Condition, and Gains

Current body condition and implications of toxic plants/compounds on livestock gains are important consideration in targeted grazing applications where target or non-target plants may have toxicity considerations. Animal condition impacts foraging behaviour and the tolerance of a specific animal to plant toxins. Processing toxic compounds is an energy intensive process, with subsequent effects on livestock body condition and weight gain. The general mechanism of detoxification includes the conversion of toxic lipophilic compounds into water-soluble compounds which are then excreted as waste products. This process requires energy, proteins, and water, and reduces the amount of protein and energy that can be put towards livestock maintenance and production/gain. (Foley et al., 1995; Illius & Jessop, 1995; Provenza, 2003b)

If an animal is in low body condition it will have a lower tolerance to plant toxins, and less ability to metabolize toxic compounds (Foley et al., 1995; Illius & Jessop, 1995). Toxic compounds are generally processed by the liver, and a large healthy liver supports this process. In scenarios where animals are in

low body condition and potentially under nutritional stress (either from lack of available forage or the prolonged energetically expensive metabolization of toxic compounds), liver mass may be reduced. Supplementing with additional feed, protein, and minerals can help enhance liver function and support the animal's ability to process toxic compounds (Olson & Launchbaugh, 2006).

Unfortunately, selectivity is decreased when animals are hungry, which can lead to situations where animals with low body condition and reduced tolerance to toxins will ingest amounts of toxins that their body may not be able to effectively process due to their physiological state (Arnold & Birrell, 1977; Newman et al., 1994; Sibbald & Kerr, 1994). As examples, goats with low body condition scores were found to consume four times as much redberry juniper than goats with average condition (Frost et al., 2008), and cattle in poor condition were found to select for lupine in advance of and in larger quantities than average condition cattle (Lopez Ortiz, 2002). This indicates that monitoring body condition is an important consideration in the application of targeted grazing prescriptions to prevent animals from reaching low body conditions where they may be more apt to overconsume toxic plants.

Supplements and additional forage can mitigate the impacts of toxicity on livestock gains, a study by Provenza et al. (2003) found that sheep fed supplemental protein and energy spent more time feeding on the target plant (sagebrush) and lost 37% less weight in comparison to sheep that did not receive supplements. Supplementation with polyethylene glycol has also been found to support increase intake of shrubs that contain tannins, as polyethylene glycol binds to tannins and mitigates their negative impacts (Silanikove et al., 1994; Titus et al., 2001).

Livestock Developmental Stage and Toxicity

Animals have differing nutritional requirements based on their developmental and/or reproductive stage, and their intake is driven by their physiological state. Animals can eat below their nutritional needs for a short period by using body fat and protein stores, but the length of time that this deficit can be sustained varies depending on their lifecycle stage. Growing animals and lactating females have higher nutrient requirements than nonlactating adult animals, and are generally not recommended for targeted grazing prescriptions as sustained periods of energy and/or protein deficits are more likely to negative impacts on them. (Nader et al., 2007)

Reproduction

In conventional livestock production systems reproductive efficiency is often the most critical economic consideration (James et al., 1992). In some specialized targeted grazing operations reproduction may not be a key consideration, but in others the maintaining the reproductive capacity of the herd and individual animals may still be a primary objective. To ensure that producers are not surprised by potential unintended consequences of targeted grazing on reproductive efficiency it is important to understand the potential impacts.

There are a number of different factors that may impact reproduction, and the two that are of primary concern relative to targeted grazing applications are 1) impact of toxic substances, and 2) impact of low body condition on reproductive success (James et al., 1989, 1992; Panter et al., 1989).

There are various impacts of toxic substances on reproductive success, toxic plant compounds may interfere with libido, estrus, the development of sex cells (eggs and sperm), cause abnormal mating

behaviour, abortion, birth defects, increase the postpartum interval, or impact the survival of offspring (James et al., 1992).

Many of the plants that affect reproductive success also have other significant impacts on the mother animal (eg. lesions, sickness, and/or fatality) that make the presence of detrimental toxic compounds apparent, however there are some toxins that may be undetected until reproductive failure occurs, or birth defects become apparent, both many months after exposure to toxins (Stegelmeier et al., 2020).

As an example, locoweeds contain an alkaloid that results in well-documented clinical signs when ingested in toxic amounts by livestock, primarily a staggering gait, lack of coordination, weight loss, and a vacant staring gaze, giving the animal a 'crazy' look (hence 'loco'weed) (Cook et al., 2009). Aside from these clinical signs locoweeds also negatively affect many aspects of reproduction in livestock, even if not consumed at levels that result in clinical signs described above, and reproductive failure may be the initial sign of toxicity issues (Cook et al., 2009; James et al., 1992; Stegelmeier et al., 2020). At lower levels locoweed will cause declines in libido, male fertility, fertilization, delay placentation, and result in offspring with birth deformities, low vigour, and mental delay (Cook et al., 2009). Silky lupine also produces alkaloids that have neurotoxic effects in livestock, with ingestion of 1.0-1.5 pounds per day resulting in toxic effects to cattle (Majak et al., 2008; USDA ARS, 1993). In addition to direct toxicity, a more common indirect effect is birth defects (skeletal abnormalities, cleft palates) in calves if ingested during early gestation, particularly if repeated ingestion occurs between the 40th and 70th days of gestation, with some reports that this risk may continue up to the 120th day in cattle (Majak et al., 2008).

Aside from direct effects of toxins on reproductive efficiency, there may be indirect effects on offspring vigour and survival rates when toxic compounds are processed and excreted in the dam's milk supply (Cook et al., 2009; James et al., 1992). This is beneficial for the mother animal as excreting toxins via milk is a significant pathway for eliminating these compounds from the body (Panter & James, 1990). However, this has the potential for significant negative effects on offspring who may begin to rapidly exhibit the effects of these toxins (Cook et al., 2009; James et al., 1992), or develop long-term complications, for example calves nursing from cows grazing in areas with significant locoweed components developed congestive heart failure (James et al., 1986). This is important to keep in mind as milk is the sole source of nourishment when animals are very young, and their health and well-being is at risk if toxic plants are consumed and subsequent toxins excreted into the milk (James et al., 1992).

Low body condition interferes with an animal entering estrus and delays conception or birth, and in severe cases may result in abortion in gestating animals (Mellado et al., 2004; Wathes et al., 2014). This can be managed by ensuring that animals receive adequate nutrition, which is a cornerstone of animal husbandry.

An understanding of the toxic plants on site and their potential impacts on livestock is critical to avoiding reproductive issues.

Introducing New Foods

It's likely become apparent that there a host of different factors and their varied interactions that impact the success of targeted grazing prescriptions. Strategies exist to facilitate the use of novel forages and plants and are well synthesized by (Burritt & Frost, 2006), and have been adapted in the list below:

- Introduce target plants or feed to mothers with young to support acceptance of novel food
- Introduce plants slowly. Don't force a single plant diet on a naïve animal for extended periods, especially if the plant is high in nutrients or toxins. The animal and their organs, especially the liver and rumen needed for digestion and metabolization of toxins, need time to become accustomed to these changes.
- The first experience is critical. If an animal becomes sick from the first few exposures to a novel food, they are not likely to select for it again.
- Persuasion or encouragement to eat novel foods can be effective, offering novel foods early in the morning when animals are hungry and providing by access to familiar foods can support the adoption of novel foods in the diet
- Placing animals familiar with target plants with those naïve to them will support social learning and increased intake of novel plants
- If animals are provided novel foods in a familiar location, they are more likely to try them
- Putting familiar or appealing flavours (eg. molasses) on novel foods may increase acceptance

These strategies can all support acceptance of novel foods but must be balanced with animal health and welfare implications. Eating too much of a new food in too short of a time can result in negative impacts from too high concentrations of nutrients or toxins (Burritt & Frost, 2006).

Training

Sometimes a grazing prescription can be correct, but the project fails because the livestock will not eat the targeted plant species. This is a common problem when livestock is brought in from a different region or if the livestock has not learned to eat the target plant species (Moss et al., 2008). The livestock may not know the plant species is potential forage or they may lack suitable bacteria in the gut to digest the plant species (Moss et al., 2008). It may take several weeks for the livestock to build up adequate amounts of the right bacteria to digest the plant species. During that period animals should be provided with high quality nutritional supplements to ease the transition (Moss et al., 2008). Experience may be the most important factor in implementing a successful targeted grazing program. For livestock without experience grazing a target species, training is a potential and proven option (Walker et al., 1992).

Diet training has been used with varying success for many years (Bailey et al., 2019). The training method developed by Kathy Voth (Voth, 2010) appears to be the most successful method of training livestock to eat plants they are unfamiliar with or have previously avoided. It is possible that livestock training lasts only for short periods and retraining may be required (Tierney, 2013).

Animal Welfare

Regardless of the overall objectives of targeted grazing treatments, animal health and welfare should always be the primary consideration. The transient confinement (animals held in relatively small, fenced grazing systems) and induced consumption of potentially toxic plants raise concerns around animal welfare (Goodman et al., 2014; Stephenson et al., 2016).

Targeted grazing activities usually involve the modification of natural herbivore behaviour (Kilgour, 2012; Špinka, 2006), which may pose a point of concern as the expression of natural behaviours is often

considered essential to animal welfare (Bracke & Hopster, 2006) and codified in the various codes of practice developed by Canada's National Farm Animal Care Council[2].

These concerns around animal health and welfare can be addressed through proper animal husbandry (including provision of adequate additional forages, water, and supplements) in combination with intermittent targeted grazing of specific animals and herds, removing the pressure of treatments and allowing them to express their natural behaviours. It is important to ensure contingency plans for animal health considerations based on site assessments and discussions with veterinary professionals.

Knowledge Gaps

There are knowledge gaps that currently limit the guidance available to support targeted grazing applications in western Canada. These gaps are largely related to the response of specific invasive plants and plant communities to targeted grazing, stocking rates necessary to meet vegetation objectives, and the palatability and toxicity of certain plants of interest.

There are several plant species that lack information on the effectiveness of targeted grazing, and on the toxicity and palatability of plants to livestock. Some of these species include Absinth wormwood (*Artemisia absinthium*), Field scabious (*Knautia arvensis*), Blueweed (*Echium vulgare*), Orange hawkweed (*Hieracium aurantiacum*), yellow hawkweeds (*Hieracium spp.*), Scentless chamomile (*Tripleurospermum inodorum*), Wild caraway (*Carum carvi*), Common mallow (*Malva neglecta*), and Green foxtail (*Setaria viridis*). Additionally, the toxicity effects of other plants have not been fully defined for all livestock species, resulting in gaps in important information to support targeted grazing prescriptions.

Stocking rates or estimated utilization rates are not defined for targeted grazing applications, and are highly variable across objectives, plant communities, species of interest, and even year-to-year climatic variation. Although they may not be easily defined, there is value in pursuing a better understanding of thresholds.

During this review, targeted grazing practitioners and experts identified a number of topics for which detailed reviews similar to this would be useful to enhance the practice of targeted grazing. These areas include the effects of targeted multi-species grazing, information on seed transfer of targeted plants both through the stomach (rumen) and via pathways of invasion, target plant species nutritional content, and methods to minimize the effects on livestock of different plant toxins.

As research progresses gaps can be addressed over time, and guidelines can be enhanced to better support targeted grazing prescriptions.

Summary

The complex relationships between the multitude of factors that affect the relationship between animal behaviour and grazing are well summarized by Provenza (1995) who noted that:

[2] National Farm Animal Care Council Codes of Practice https://www.nfacc.ca/codes-of-practice

> '…the dynamics of foraging involves appreciating the uniqueness of individuals and subgroups of animals, each with their own genetic and behavioral history, and recognizing that foraging behaviors may not be stable, optimal, or even predictable in the conventional sense.'

This can be a difficult concept to come to terms with when seeking predictability of targeted grazing applications, but the nature of working with living organisms, in this case animals and plant communities, is that management and outcomes are influenced by many complex factors. This complexity makes prediction of outcomes difficult, and it is important to accept that results are not immediate, and there is a learning curve associated with every targeted grazing application (Bailey et al., 2019; Frost et al., 2012).

Learned behaviours and the complex postingestive feedback mechanisms all play a role as part of the social and biophysical environments that interact with an animal's current state to shape their forage preferences to suite the local forage conditions and landscape at any given time or place (Galyean & Gunter, 2016).

Likewise, it is important to consider that target plants have a variety of traits such as palatability, toxicity, and reproductive strategies that are related and interact with grazing livestock. Choosing the timing, intensity, and duration of grazing that most affects the target plant, facilitates grazing of the target plant, maintains the health of the livestock, and enhances the desirable vegetation on the site is a complex task as optimizing for one factor often results in negative outcomes for another.

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Appendix 1: Anatomy and Digestive System Comparisons

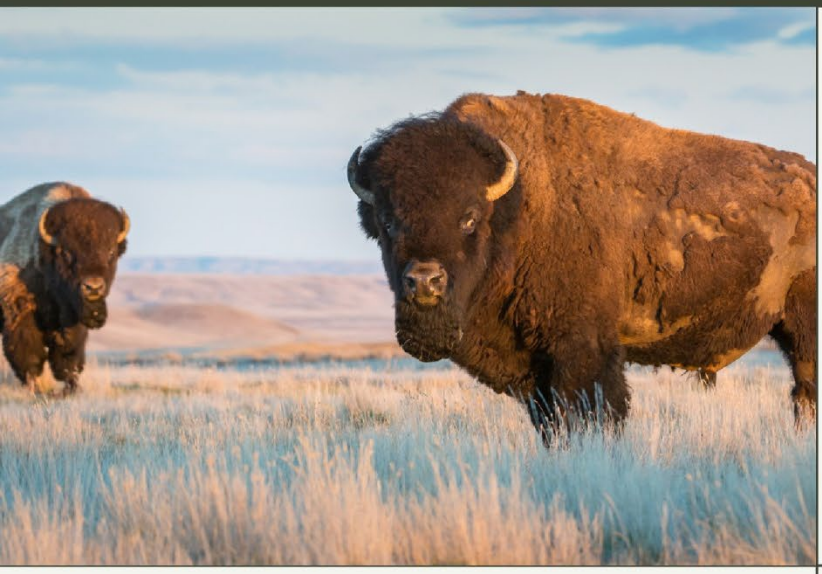
Table 7. Comparison of anatomy and digestive systems of browsers and grazers, adapted from Hofmann (1986, 1988).

Comparison	Browsers	Grazers	Significance
Mouth opening	large, narrow	small, wide	Larger mouth opening allows stripping of twigs and gnawing of flowers and fruit.
Lips	flexible	rigid	Flexible lips allow more selectivity of plant parts eaten.
Tongue	slender	thick	Browser uses slender tongue with lips to select individual plant parts. Grazers wrap tongue around clumps of forage, not efficient for individual leaf selection.
Taste buds	few	many	Smell is probably more important in browser food selection and taste avoidance is probably more important in grazers.
Teeth	sharp	flat	Browsers can puncture plant material quickly releasing easily fermented cell contents. Grazers grind food, cell walls freed for microbial digestion.
Jaw muscles	light	heavy	Heavy grazer muscles needed in grinding fibrous plant material.
Salivary glands	large	small	Browsers need more saliva to keep rumen pH from becoming too acidic from fermentation of large quantities of rapidly fermented cell contents.
Rumen	simple	subdivided	Allows food in the browser rumen to leave rapidly, a disadvantage on high fiber forages like grass which require more fermentation time. Grazers are able to hold food in rumen longer allowing high fiber forages more time to ferment.
	small	large	Browsers cannot hold large quantities of food. Grazers can store larger quantities of forage in the rumen which is an advantage with slower fermenting high fiber forages.
Rumen muscles	light	heavy	Heavy muscles allow grazers to handle larger amounts of forage held in rumen.
Rumen papillae	cover rumen wall	lower rumen	With an increase in these structures, absorption occurs over a greater portion of the rumen in browsers allowing acids produced during fermentation to exit the rumen quickly and help control rumen pH.
Reticulum			
size	large	small	Small size, many and deep subdivisions hold forage in the grazer rumen longer allowing more time for fermentation.
subdivisions	few shallow	many deep	
Omasum	small	large	Larger size provides more absorption surface.
Liver	large	small	Larger liver is needed to absorb more rapidly fermented cell contents from browser rumens and to detoxify chemicals in browse.
Hindgut volume	large	small	Larger volume indicates that hindgut fermentation is more important in browsers. Less-digestible plant material which quickly exits the browser rumen and undergoes additional fermentation in the hindgut providing additional energy.

Appendix 2: Livestock Profiles

Prescriptive Grazing Profile

Bison/*Iinnii*



Functional Feeding Group

Bison/Iinnii are **bulk feeders** or **grazers**. They prefer a grass-dominated diet although they will eat small amounts of forbs and shrubs.

They have a higher daily forage intake than other feeding groups, are less selective while foraging, and consume large amounts of relatively low quality forage.

Target Plants

Bison/Iinnii are well-suited for landscape level restoration through grazing for specific plant community and vegetation outcomes, such as improved biodiversity and wildlife habitat.

Bison may also be suited for targeted grazing of invasive non-native forages, including invasive annual grasses.

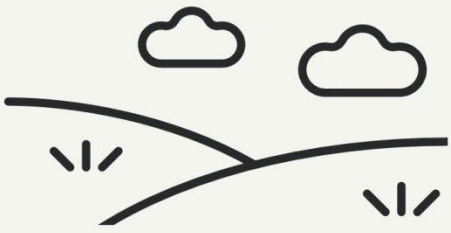
Toxicity Considerations

Bison/Iinnii are more susceptible to toxicity effects than selective and intermediate feeders.

Bison lack digestive mechanisms that allow them to mitigate toxic compounds often associated with shrubs and invasive species.

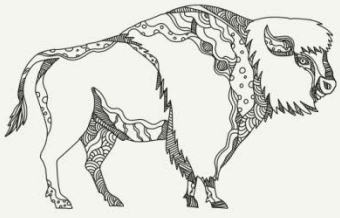
Habitat Selection

Bison prefer gentle terrain relatively close to water, this includes grasslands, cutblocks, coniferous boreal forests, and herbaceous wetlands.



Bison Summary

Habitat: Flatter areas close to water
Forage Preference: Grasses
Toxicity: Susceptible to toxicity effects



Prescriptive Grazing Profile

Cattle

Functional Feeding Group

Cattle are **bulk feeders** or **grazers**. They have a grass-dominated diet although they will eat small amounts of forbs and shrubs.

They have a higher daily forage intake than other feeding groups, are less selective while foraging„ and consume large amounts of relatively low quality forage

Target Plants

Cattle are well-suited for targeted grazing of forages as well as non-invasive and select invasive species:

- Smooth brome
- Timothy
- Crested Wheatgrass
- Invasive annual grasses
- Burdock
- Canada Thistle
- Hoary Cress
- Greasewood
- Leafy Spurge
- Diffuse, Russian and Spotted Knapweed
- Saskatoon
- Scotch Broom
- Sweetclover

Toxicity Considerations

Cattle are more susceptible to toxicity effects than selective and intermediate feeders.

Cattle lack digestive mechanisms that allow them to mitigate toxic compounds often associated with shrubs and invasive species.

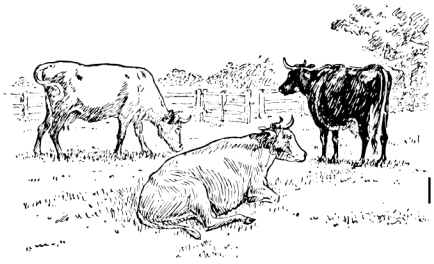
Habitat Selection

Cattle prefer flatter areas close to water, preferentially using primary range areas within 1.5km of water and salt resources and avoiding slopes of over 30%.

Cattle will overuse these primary range areas if management tools and strategies are not used to improve distribution.

Cattle Summary

Habitat: Flatter areas close to water
Forage Preference: Grasses
Toxicity: Susceptible to toxicity effects



Prescriptive Grazing Profile

Goats

Functional Feeding Group

Goats are **selective feeders** or **browsers.** They select primarily for forbs and shrubs.

They are smaller in size, have narrow muzzles for selective foraging, and large salivary glands to mitigate plant toxicity. They consume smaller amounts of relatively high quality forage.

Target Plants

Goats are well-suited for targeted grazing of invasive and non-invasive species such as:

- Burdock
- Canadian Thistle
- Common Tansy
- Diffuse, Russian, and Spotted Knapweed
- Hoary Cress
- Hound's Tongue
- Leafy Spurge
- Kochia
- Leafy Spurge
- Scotch Broom
- Sweetclover
- Saskatoon
- Tall Buttercup

Toxicity Considerations

Goats are less susceptible to toxicity effects than bulk and intermediate feeders.

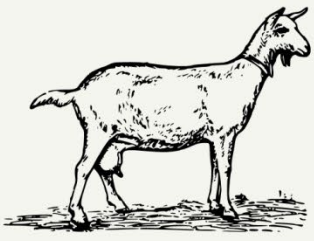
Goats have the ability to degrade toxic compounds through salivary proteins, gut flora, and enzymes that mitigate toxic metabolites. They also have large livers that can more quickly and efficiently process compounds, supporting their ability to mitigate toxicity effects.

Habitat Selection

Goats prefer steep slopes, will disperse further from water sources, sometimes travelling through areas of abundant forages along the way, and tend to bed down in open upland areas.

Goat Summary

Habitat: Steeper slopes further from water
Forage Preference: Forbs and shrubs
Toxicity: Less susceptible to toxicity effects



Prescriptive Grazing Profile

Horses

Functional Feeding Group

Horses are **bulk feeders** or **grazers**. They prefer a grass-dominated diet although they will eat small amounts of forbs and shrubs.

They have a higher daily forage intake than other feeding groups, are less selective while foraging, and consume large amounts of relatively low quality forage.

Target Plants

Horses are well-suited for targeted grazing of non-native forage species such as:

- Smooth brome
- Timothy
- Crested Wheatgrass
- Invasive annual grasses

Toxicity Considerations

Horses are more susceptible to toxicity effects than selective and intermediate feeders.

Horses lack the digestive mechanisms that allow them to mitigate toxic compounds often associated with shrubs and invasive species.

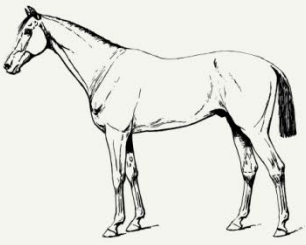
Habitat Selection

Horses prefer flatter areas close to water, and avoid closed canopy forests, preferentially using open grasslands and/or cutblocks close to water and salt as primary range.

Horses will overuse these primary range areas if management tools and strategies are not used to improve distribution

Horse Summary

Habitat: Flatter areas close to water
Forage Preference: Grasses
Toxicity: Susceptible to toxicity effects



Prescriptive Grazing Profile

Sheep

Functional Feeding Group

Sheep are **intermediate feeders**. They are adapted to both browsing and grazing and will make use of grasses, forbs, and shrubs.

They are opportunistic and adapt their feeding habits to whichever forage resources are available.

Target Plants

Sheep are well-suited for targeted grazing of forages as well as invasive and non-invasive species such as:

- Burdock
- Canadian Thistle
- Common Tansy
- Diffuse, Russian, and Spotted Knapweed
- Greasewood
- Hoary Cress
- Hound's-Tongue
- Kochia
- Leafy Spurge
- Scotch Broom
- Sweetclover
- Saskatoon
- Tall Buttercup

Toxicity Considerations

Sheep and other intermediate feeders are less susceptible to toxicity effects than bulk feeders, but more susceptible than selective feeders.

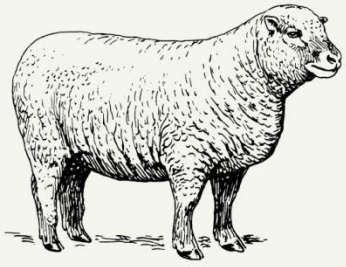
Sheep have short-term and seasonal dietary shifts, where their forage selection is associated with shifts in forage quality.

Habitat Selection

Sheep prefer steeper slopes, dispersing further from water sources, sometimes travelling through areas of abundant forages along the way, and tend to bed down in open upland areas.

Sheep Summary

Habitat: Steeper slopes further from water
Forage Preference: Grasses, forbs and shrubs
Toxicity: Moderately susceptible to toxicity effects



Prescriptive Grazing Profile

Swine

Functional Feeding Group

Swine are **monogastric omnivores.** They are highly adaptable and will feed on almost any forages or foodstuffs available.

In addition to consuming above-ground forages, they will root through the earth, and can pull out plant roots and crowns.

Target Plants

Swine are well-suited for targeted grazing of most plant species, general reduction of biomass, and any applications where total eradication of vegetation (both above and below-ground) is the the goal.

Toxicity Considerations

As monogastric animals swine are moderately susceptible to toxicity effects, and are differ in their sensitivity to toxic compounds relative to ruminants.

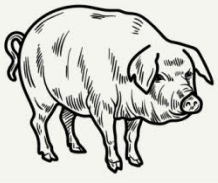
Swine have different nutritional requirements than ruminants, specifically a high requirement for the amino acid lysine, and cannot survive on plant-based forages alone.

Habitat Selection

Swine prefer shaded areas close to water.

Swine Summary

Habitat: Shady areas close to water
Forage Preference: All forages
Toxicity: Moderately susceptible to toxicity effects



Appendix 3: Plant Profiles

DOWNY and JAPANESE BROME

Prescriptive Grazing Profile: Annual Grasses

TOXICITY & PALATABILITY

Downy brome (cheatgrass) and Japanese brome are species that have similar characteristics and respond similarly to grazing. Neither species contains any toxins affecting livestock. However, florets are susceptible to Ergot, a fungus that is toxic to livestock. These bromes are palatable to livestock in early spring during the vegetative and bud stages when nutrient content is highest. They become unpalatable once seed heads are produced due to long, stiff awns that can puncture the mouth and throat tissues of livestock causing injuries and infections such as lumpjaw.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Downy and Japanese brome. Effective control has been demonstrated using cattle and sheep. Cattle and bison may be most suitable for controlling these species due to their preference for utilizing grasses. Targeted grazing of these species is most effective when combined with other control measures such as burning and herbicides.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Downy and Japanese bromes are most susceptible to impacts from grazing during the vegetative and bud stages. It is moderately susceptible to grazing during the seedling stage.

GRAZING PRESCRIPTION CONSIDERATIONS

An intense skim or flash graze in early spring once Downy or Japanese brome reaches the vegetative stage is most effective. Graze to prevent seed production. Remove livestock when the target species begins to produce seeds or when livestock begin to graze non-target plant species. A second skim graze later in the season is recommended if new seedlings emerge or grazed plants regrow. Two or more years of intense grazing is recommended.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Annual Forbs

KOCHIA

TOXICITY & PALATABILITY

Kochia contains a number of toxic substances including saponins, alkaloids, oxalates and nitrates. All parts of the plant are toxic throughout the growing season. In quantities comprising more than 50% of an animal's diet, toxicity impacts can range from weight loss to mortality. Kochia is considered moderately toxic to goats, and highly toxic to sheep, cattle and horses. During early stages of growth, Kochia is highly palatable to all species of livestock.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Kochia. Goats may be most resistant to impacts of toxicity. The duration of grazing should not exceed 60 days in order to minimize the potential for toxic impacts to livestock.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Kochia is most susceptible to impacts from grazing during the seedling and vegetative stages. It is moderately susceptible to grazing during the bud/bolt stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to prevent flowering and seed production. Multiple grazes (a minimum of two) of regrowth in a single growing season are required. It may take several years of targeted grazing of Kochia before an impact is evident due to the amount of seed in the soil.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

YELLOW and WHITE SWEETCLOVER

Prescriptive Grazing Profile: Biennial Forbs

TOXICITY & PALATABILITY

Sweet clovers contain no substances toxic to livestock in pasture. However, livestock may be susceptible to bloat as with alfalfa if large quantities are consumed when animals are introduced to the pasture. Toxicity issues can arise when sweet clover is used as hay. Sweet clovers are most palatable early in the growing season and become woody later in the season making them less attractive to livestock. The hardened plant structure can cause eye infections due to scratches and pollen dust. Sweet clovers are also less palatable than other legumes due to a bitter coumarin taste.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze sweet clovers.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Sweet clovers are most susceptible to impacts from grazing during the seedling and vegetative stages. It is moderately susceptible to grazing during the bud/bolt stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze early in the growing season with a goal of preventing flowering and seed production. This may require multiple grazes of regrowth in a single growing season.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

KENTUCKY BLUEGRASS

Prescriptive Grazing Profile: Perennial Grasses

TOXICITY & PALATABILITY

Kentucky bluegrass contains no substances toxic to livestock. It is palatable to all species of livestock throughout the growing season.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Kentucky bluegrass. Cattle and bison may be most suitable for controlling these species due to their preference for utilizing grasses.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Kentucky bluegrass is most susceptible to impacts from grazing during the seedling and vegetative stages. It is moderately susceptible to grazing during the bud and flowering stages.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze as early as possible in the growing season before other plants have begun active growth. Use a short intense mob graze. Target a minimum of 80% removal of biomass. Remove livestock when non-target vegetation begins active growth. A second graze of regrowth later in the growing season may be necessary. It may take several years of targeted grazing of Kentucky bluegrass before an impact is evident.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

CANADA THISTLE

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Nitrate poisoning has been noted in horses eating substantial quantities of Canada thistle. However, nitrate poisoning is generally considered a low risk for other livestock species. Canada thistle is most palatable early in the growing season and becomes less palatable as the plant matures due to the spines on the leaves.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Canada thistle. However goats are the most effective as they will consume the plant through all stages of growth, whereas sheep, cattle and horses are less likely to consume Canada thistle once it flowers due to the spines on the foliage.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Canada thistle is most susceptible to impacts from grazing during the seedling and vegetative stages. It is moderately susceptible to grazing during the bud/bolt stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Target removal of top growth. Graze to prevent flowering and seed production. This may require multiple grazes of regrowth in a single growing season. It may take three or more years of targeted grazing of Canada thistle before an impact is evident, particularly in dense infestations.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Perennial Forbs

COMMON BURDOCK

TOXICITY & PALATABILITY

Common burdock contains no substances toxic to livestock, but its spiny burs can become attached to animals fur and cause trauma. Common burdock is generally considered palatable to livestock and most palatable to sheep.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Targeted grazing trials for Common burdock are rare, so it is difficult to determine effectiveness of grazing by different livestock species.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Common burdock is most susceptible to impacts from grazing during the bud/bolt stage, just before flowering. It is moderately susceptible to grazing during the seedling, vegetative and flowering stages.

GRAZING PRESCRIPTION CONSIDERATIONS

Leave a minimum of 6” to 8” of residual vegetation to provide shade which reduces Common burdock seed germination. Graze to prevent flowering and seed production. This may require multiple grazes of regrowth in a single growing season. It will take multiple years of targeted grazing of Common burdock before an impact is evident.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

COMMON TANSY

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Common tansy contains no substances toxic to livestock, but is often reported as toxic. This confusion is thought to have arisen because Tansy ragwort is sometimes marketed as Common tansy. Common tansy is considered palatable to sheep and goats and unpalatable to cattle and horses.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep are known to effectively target graze Common tansy and it is likely that goats are effective as well.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Leafy spurge is most susceptible to impacts from grazing during the seedling, vegetative and bud/bolt stages. It is moderately susceptible to grazing during the flowering stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Target 90% removal of top growth. Graze to prevent flowering and seed production. This may require multiple grazes of regrowth in a single growing season. It may take two or more years of targeted grazing of Common tansy before an impact is evident in dense infestations.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

DIFFUSE KNAPWEED

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Diffuse knapweed contains no substances toxic to livestock. Diffuse knapweed is palatable to all species early in the growing season. Palatability declines as the plants mature, especially for cattle and sheep.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep, goats and cattle are known to effectively target graze Diffuse knapweed. Sheep and cattle will consume it in the early growth stages, while goats will graze all stages. Targeted grazing can reduce plant vigour, size, and flower production.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Diffuse knapweed is most susceptible to impacts from grazing during the vegetative and bud/bolt stages. It is moderately susceptible to grazing during the seedling and flowering stages.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze heavily to prevent flowering and seed production. Remove livestock for approximately two weeks and then regraze. It will take a minimum of three years of targeted grazing of Diffuse knapweed before populations begin to decline. Control of Diffuse knapweed can be more effective if targeted grazing is combined with another method of control such as herbicide application.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Perennial Forbs

HOARY CRESS

TOXICITY & PALATABILITY

Hoary cress contains the glycoside glucosinolate, making it toxic to livestock year round. Hoary cress is considered mildly toxic to cattle. It is generally unpalatable for all classes of livestock, however it is somewhat palatable to sheep and goats early in the growing season.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep and goats will consume hoary cress more readily than cattle. Cattle will consume Hoary cress, but may need to be trained, and toxic impacts are a risk.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Hoary Cress is most susceptible to impacts from grazing during the seedling, vegetative and bud/bolt stages.

GRAZING PRESCRIPTION CONSIDERATIONS

Target 85% removal of top growth. Graze to prevent flowering and seed production. This will require at least two grazes of regrowth in a single growing season. It may take a minimum of three years of targeted grazing of Hoary cress before an impact is evident.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

LEAFY SPURGE

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Leafy spurge contains the alkaloid euphorbon, making it toxic to livestock. All parts of the plant contain the toxin. Leafy spurge is considered moderately toxic to sheep and goats, and highly toxic to cattle and horses. It is generally unpalatable, although the flowers may be readily consumed.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep and goats are known to effectively target graze leafy spurge, and will readily consume it after it has been introduced into their diet. Cattle and horses are not recommended for use in targeted grazing of leafy spurge.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Leafy spurge is most susceptible to impacts from grazing during the vegetative, bud/bolt and flowering stages. It is moderately susceptible to grazing during the seedling stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Target 95% removal of top growth. Graze to prevent flowering and seed production. This may require multiple grazes of regrowth in a single growing season. It may take four or more years of targeted grazing of leafy spurge before an impact is evident in dense infestations.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Perennial Forbs

OXEYE DAISY

TOXICITY & PALATABILITY

Oxeye daisy contains no substances toxic to livestock, but does have a bitter taste. It is most palatable to sheep and goats, and is generally avoided by cattle and horses.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Grazing trials of Oxeye daisy are limited. However, sheep and goats may effectively target graze it. Cattle grazing has not been found to be effective in reducing Oxeye daisy.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Oxeye daisy is most susceptible to impacts from grazing during the seedling, vegetative, and bud/bolt stages. It is moderately susceptible to grazing during the flowering stage.

GRAZING PRESCRIPTION CONSIDERATIONS

Close rotational grazing or continuous grazing by sheep has been shown to have the most impact on Oxeye daisy although grazing trials are limited. Targeted grazing of Oxeye daisy is more effective when combined with herbicide treatment.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

PURPLE LOOSESTRIFE

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Purple loosestrife is generally considered non-toxic in North America. However, it does contain alkaloids and is considered toxic to livestock elsewhere. It is generally considered moderately palatable to goats and sheep and low to moderately palatable to livestock overall.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Intensive, rotational, targeted grazing by sheep has been shown to successfully reduce flowering in purple loosestrife populations, resulting in a reduction of Purple loosestrife cover of up to 40 percent. However, in urban areas where Purple loosestrife invades wetlands and other sensitive habitats, targeted grazing using goats has been less successful.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Purple loosestrife is most susceptible to impacts from grazing during the seedling, vegetative and bud/bolt stages. It is moderately susceptible to grazing during the flowering and seed stages. The reduction of the invasive-dominated canopy by early season grazing stimulates colonization by native and naturalized species and can result in an increase in species richness.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to prevent flowering and seed production. This may require up to four grazes of regrowth in a single growing season. At least 3 years of treatment is recommended. Control of Purple loosestrife can be more effective if targeted grazing is combined with another method of control.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

RUSSIAN KNAPWEED

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Russian knapweed contains no substances toxic to livestock, but does have a bitter taste. It is palatable to sheep and goats early in the growing season, and is generally avoided by cattle and horses.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep, especially dry ewes, and goats are known to effectively target graze Russian knapweed, but may need to be trained. Cattle and horses are not recommended for use in targeted grazing of Russian knapweed.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Russian knapweed is most susceptible to impacts from grazing during the seedling, vegetative, bud/bolt and flowering stages. It is moderately susceptible to grazing during seed set.

GRAZING PRESCRIPTION CONSIDERATIONS

Target 80% removal of biomass. Graze to prevent flowering and seed production. This may require at least three grazes per season, allowing 8 to 10 inches of regrowth between treatments. Three or more years of successive grazing treatments may be necessary to suppress populations. Cessation of grazing may result in populations returning to pre-treatment densities. Control of Russian knapweed can be more effective if targeted grazing is combined with other control methods such as herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

SPOTTED KNAPWEED

Prescriptive Grazing Profile: Perennial Forbs

TOXICITY & PALATABILITY

Spotted knapweed contains no substances toxic to livestock. Younger, smaller plants are preferred and palatability declines as the plants mature due to a bitter taste. It is not recommended for livestock diets to consist of more than 70% Spotted knapweed.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep and goats are known to effectively target graze Spotted knapweed. Targeted grazing can reduce plant vigour, density, size, flower stems, and seed production. Cattle and horses are not recommended for use in targeted grazing of Spotted knapweed.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Spotted knapweed is most susceptible to impacts from grazing during the bud/bolt and flowering stages. It is moderately susceptible to grazing during the seedling, vegetative and seed set stages.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass and seed production. Two short, intense grazing periods per year are recommended. The first should occur during either the vegetative or bud/bolt stage and the second during the bud/bolt stage. It may take three to six consecutive years of grazing to impact biomass and seed production.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Pakii'p / CHOKECHERY

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Chokecherry contains cyanogenic glycosides. All parts of the plant are toxic except the berries. Concentrations of the toxin are higher when the plant is stressed by drought or frost. The cyanide potential is highest in the new growth of the plants. It is palatable to sheep and goats.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Sheep and goats are more likely to utilize Chokecherry than cattle or sheep based on their dietary preferences.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Chokecherry occurs in early spring during the first flush of leaf growth and when plants are seedlings or young sprouts. Chokecherry is moderately susceptible to grazing when flowers are budding. However, early in the growing season is also when the plants are most toxic.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. This may require multiple grazes of regrowth in a single growing season including a light (to minimize effects of toxicity) early season graze and a heavier mid summer graze. Ensure livestock always have access to ample alternate forage to minimize the risk of toxic impacts. It may take several years of targeted grazing of Chokecherry before an impact is evident. Control of Chokecherry can be more effective if targeted grazing is combined with another method of control such as prescribed fire, mechanical removal or herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Woody Perennials

GREASEWOOD

TOXICITY & PALATABILITY

The buds and young leaves of Greasewood contain soluble sodium salts of oxalic acid which are toxic to all livestock. This plant can be detoxified in the rumen but an adaptation period is required. Lambs are the most susceptible to Greasewood poisoning, but adult sheep and cattle are also commonly affected. Toxicity increases with maturity of leaves. Greasewood is palatable to sheep and cattle, and likely goats, once adapted to oxalate.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Greasewood. However, sheep and goats are most likely to utilize it given their dietary preferences. Greasewood can be consumed safely in light to very moderate amounts in the spring while the leaves are growing, as long as there is an adequate amount of alternate forage available.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Greasewood occurs in early spring during the first flush of leaf growth and when plants are seedlings or young sprouts. It is moderately susceptible to grazing when flowers are budding.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. Due to toxicity issues, a single early season graze is recommended. It may take several years of targeted grazing of Greasewood before an impact is evident, particularly in dense stands.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Okonok / SASKATOON

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Saskatoon contains cyanogenic glycosides. All parts of the plant are toxic except the berries. Concentrations of the toxin are higher when the plant is stressed by drought or frost. The cyanide potential is highest in the new growth of the plants and declines rapidly after the plant flowers. It is palatable to sheep, goats and cattle.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Saskatoon. However, sheep and goats are most likely to utilize it given their dietary preferences.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Saskatoon occurs in early spring during the first flush of leaf growth and when plants are seedlings or young sprouts. Saskatoon is moderately susceptible to grazing when flowers are budding. However, early in the growing season is also when the plants are most toxic.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. This may require multiple grazes of regrowth in a single growing season including a light (to minimize effects of toxicity) early season graze and a heavy mid summer graze. Ensure livestock have access to ample alternate forage, especially in spring, to minimize the risk of toxic impacts. It may take several years of targeted grazing of Saskatoon before an impact is evident. Control of Saskatoon can be more effective if targeted grazing is combined with another method of control such as prescribed fire, mechanical removal or herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

SCOTCH BROOM

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Scotch broom contains a variety of quinolizidine alkaloids that can cause mildly toxic responses in livestock. Cattle, sheep and horses are all susceptible to toxicity from Scotch broom, while goats are more resistant. It is generally considered unpalatable to livestock, although it may be moderately palatable to goats.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Season-long grazing by goats is moderately successful in sites where Scotch broom comprises less than 10% cover. Targeted grazing of Scotch broom using llamas has been effective in California. Targeted grazing trials using sheep and cattle have proven ineffective.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Scotch broom is most susceptible to impacts from grazing during the active growth period. Research has not been conducted on the exact stage of growth in which Scotch broom is most harmed by grazing.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce foliar cover and prevent flowering and seed production. High intensity grazing can cause high levels of mortality, particularly on younger plants. Adult female goats should be removed from grazing Scotch broom three weeks prior to blooming and not returned until after kidding. Achieving impacts may require multiple grazes or season-long grazing. Control of Scotch broom requires between 4 and 30 years of treatment. Control of Scotch broom can be more effective if targeted grazing is combined with another method of control.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Misisaimi;soyiis / WOLFWILLOW

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Wolfwillow or Silverberry contains no substances toxic to livestock. It is palatable to goats and sheep, and less palatable to cattle.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Goats and sheet can effectively graze Wolfwillow.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Wolfwillow occurs when Wolfwillows are in the seedling or young sprout stage and once leaves have emerged. They are moderately susceptible to grazing when flowers are budding and when in full flower.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. This may require multiple grazes of regrowth in a single growing season. It may take several years of targeted grazing of Wolfwillow before an impact is evident, particularly in dense stands. Control of Wolfwillow can be more effective if targeted grazing is combined with another method of control such as prescribed fire, mechanical removal or herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Prescriptive Grazing Profile: Woody Perennials

WESTERN SNOWBERRY

TOXICITY & PALATABILITY

Western snowberry contains no substances toxic to livestock with the exception of the berries which are considered toxic. It is palatable to sheep and goats, particularly early in the growing season. Western snowberry is less palatable to cattle.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Although both goats and sheep can be effective grazing Western snowberry, goats have been shown to browse snowberry to a greater extent than sheep. Cattle can also be effective at reducing Western snowberry populations but only using mob grazing.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Western snowberry occurs when shrubs are in the seedling or young sprout stage or when leaves are young. They are moderately susceptible to grazing when flowers are budding. Western snowberry may also be susceptible to late season grazing (August) the year after a burning, logging, mowing, or dozing event.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. Mob grazing is likely most effective. This may require multiple grazes of regrowth in a single growing season. It may take several years of targeted grazing of Western snowberry before an impact is evident, particularly in dense stands. Control of Western snowberry may be more effective if targeted grazing is combined with another method of control such as prescribed fire, mechanical removal or herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

Ostipiis / WILLOWS

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Most willows contain no substances toxic to livestock. Willows are considered the most palatable of the native woody species on western Canadian rangelands. Willows are palatable to all species of livestock, but especially to goats and sheep. Willows are most palatable during early stages of growth in the spring.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze willows. However, sheep and goats are most likely to utilize willows given their dietary preferences.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of willows occurs when shrubs are in the seedling or young sprout stage or when leaves are young. They are moderately susceptible to grazing when flowers are budding. Willows may also be susceptible to late season grazing (August) the year after a burning, logging, mowing, or dozing event.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to reduce biomass. Mob grazes may be most effective and a single graze per year may be sufficient. However, it may take several years of targeted grazing of willow shrubs before an impact is evident. Control of willow may be more effective if targeted grazing is combined with another method of control such as prescribed fire.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca

A'kíítoyi / TREMBLING ASPEN

Prescriptive Grazing Profile: Woody Perennials

TOXICITY & PALATABILITY

Trembling aspen contains no substances toxic to livestock. It is palatable to all species of livestock, but especially to sheep. Trembling aspen is most palatable during early stages of growth in the spring. Leaves of aspen have the highest protein and nutrient levels in June and these levels decline as the growing season progresses.

EFFECTIVENESS OF GRAZING LIVESTOCK SPECIES

Any livestock species can effectively graze Trembling aspen. However, sheep and goats are most likely to utilize aspen given their dietary preferences.

PLANT GROWTH STAGE MOST SUSCEPTIBLE TO GRAZING

Best control of Trembling aspen occurs when trees are in full leaf and the terminal leaf has just emerged (late May or June). When the terminal leaf has broken bud or is in full leaf, the tree is at its lowest level of root reserves. Trembling aspen may also be susceptible to late season grazing (August) the year after a burning, logging, mowing, or dozing event.

GRAZING PRESCRIPTION CONSIDERATIONS

Graze to prevent flowering and seed production, or to prevent carbohydrate reserves from being translocated to the roots. This may require multiple grazes of regrowth in a single growing season. It may take several years of targeted grazing of Trembling aspen before an impact is evident, particularly in dense stands. Control of Trembling aspen can be more effective if targeted grazing is combined with another method of control such as prescribed fire, mechanical removal or herbicides.

Targeted Grazing: Plant and Animal Interactions (2022)
grasslandrestorationforum.ca