Manipulating Diet Selection to Control Weeds

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Abstract

Weeds continue to spread across western North America despite millions of dollars of public and private funds spent on herbicides and biocontrol. Herbicides and biocontrol address the symptom, not the cause, of the weed "problem". Grazing livestock on weeds has the potential to reduce the spread of weeds and control current infestations, assuming we can stimulate or increase the consumption of weeds by large and small herbivores. Stimulating or increasing consumption may be affected by inherent anatomical or morphological constraints, lack of experience with the weed, lack of an appropriate mentor, adjustment of rumen microbial populations, or potentially the use of anti-toxicants which adsorb or bind with plant allelochemicals present in many weeds. Increasing the use of weeds by domestic livestock, large and small, will begin to address one of the causes of weed infestations, an imbalance in the use of plant communities by single species grazing.

Introduction

Invasion by exotic species is one of the most significant ecological threats of our modern era. Exotic plant species reduce forage for livestock and wildlife, accelerate soil erosion, and lower biodiversity. Weeds continue to invade and spread in western North America despite the best efforts of researchers and land managers. Carefully managed grazing has the potential to control weeds where traditional methods (e.g., mechanical, cultural, biological, and chemical) are restricted or limited by environmental or economic concerns (Olson and Lacey 1994). Further, livestock grazing has a distinct advantage over other control methods. While controlling a noxious weed with livestock, income from their meat and fiber creates positive net returns (Walker 1994, Williams et al. 1996), compared with most herbicides which are out of pocket expenses that usually must be reapplied for adequate weed control.

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Like any tool, livestock grazing can be misapplied and cause harm. Overgrazing has been implicated in encouraging the spread of weeds. However, carefully managed grazing could be used as a tool to control weeds if we understood more about why animals select certain plants and avoid others. This would broaden our perspective from considering grazing solely for its ability to sustain wild and domestic animals to considering it a powerful tool to control weeds. Appropriate use of this tool will require information on plant and animal characteristics that influence which plants are preferred and which are avoided by different animal species.

Herbivores prefer certain plants that are inherently palatable or because the herbivore experienced positive postingestive consequences in the past (Provenza 1995, Provenza and Launchbaugh this volume). Herbivores avoid certain plants because they are unpalatable or because of negative postingestive consequences (Pfister this volume). Our dominant large herbivores in western North America, cattle and horses, usually avoid grazing weeds. If weeds were preferred by these large herbivores they would not be considered "weeds", and would only be a minor part of plant communities as they are in their countries of origin. These plants are usually not "invasive" in their countries of origin because they are kept in check by natural invertebrate enemies, pathogens, and herbivores. In their "home" countries, the dominant herbivores are often sheep and goats, not cattle and horses. In this review, I will describe why and how we might be able to stimulate or encourage the use of these plants by large and small herbivores alike.

Selecting Weeds Is a Function of Plant Characteristics

Palatability is a collective term for the plant characteristics that influence whether an herbivore will prefer or avoid a plant. Plant palatability is affected by taste, smell, texture, tearing resistance, and moisture content. Many weeds have an acrid or bitter taste or have a "noxious" smell, at least to humans. Yet, mule deer savor "bitter" brush (*Purshia tridentata*), and sheep and goats readily consume the bitter-tasting spotted knapweed (*Centaurea maculosa*). Bitter tastes and noxious smells are often associated with significant quantities of secondary compounds. Although some weeds are high in structural components, imparting great tearing resistance and presumably reducing palatability, many are similar in structural components and digestibility to native grasses and forbs. Further, weeds as a group do not have any lower or higher moisture content than native species. In fact, many weeds, such as leafy spurge (*Euphorbia esula*), remain greener, more succulent, and more nutritious longer into summer than associated cool season plants (Fox et al. 1991, Olson et al. unpublished data).

In addition to reducing palatability, plant allelochemicals may cause negative digestive consequences when eaten. For example, plant allelochemicals (terpenoids) in essential oils from big sagebrush (*Artemisia tridentata*) inhibit *in vitro* growth of gram-positive and gram-negative rumen microorganisms collected from mule deer (Nagy et al. 1964). Monoterpene alcohols in Douglas fir (*Pseudotsuga menziesii*) inhibit rumen microbial activity of sheep and deer, reflected by sharp decreases in microbial activity (Oh et al. 1967). Leaves and inflorescences of spotted knapweed contain high concentrations of cnicin, a secondary compound (Locken and Kelsey 1987, Olson and Kelsey 1997). Although levels of crude protein and digestibility of leaves and inflorescences of spotted knapweed are higher than stems, rumen microbial activity is lower with leaves and inflorescences than stems, presumably because of the presence of cnicin (Olson and Kelsey 1997). Negative effects on microbial activity, resulting in negative postingestive feedback, may explain why some ruminants limit their consumption of certain weeds. In contrast to spotted knapweed, the high nutritive value of leafy spurge in early summer appears to counteract any negative effects associated with its plant allelochemicals (Roberts and Olson 1999).

Plant availability also influences which species are "preferred" by herbivores. Preferred species comprise a greater proportion of the diet than they represent in the plant community. Preferences for these species will change as the plant community is grazed. As preferred species become less available, the herbivore must switch to less preferred species, in some instances, weeds. This concept is implied when using the proper use factor. For example, in southwestern Montana the proper use factor for cattle grazing their preferred bluebunch wheatgrass (*Pseudoroegneria spicata*) may be 50%, but only 10% for spotted knapweed. This does not imply that spotted knapweed can only tolerate 10% use while bluebunch wheatgrass can tolerate 50% use. It simply indicates that if cattle are using spotted knapweed, a species they normally avoid, use on the preferred bluebunch wheatgrass would be excessive.

Availability of the weed may influence whether or not it is grazed. For example, when a particular weed is uncommon in the community, consumption may be relatively high. This is partly because animals are curious and seek diverse diets. If every animal in a pasture takes just a few bites of an uncommon plant, it may sustain rather high utilization. Plus, potential negative postingestive consequences from the weed are buffered because consuming large quantities of preferred forages may dilute the negative effects associated with the weed (Pfister this volume). On the other hand, with dense weed infestations the weed is no longer novel, the animal seeks other foods to provide diversity, and the full "negative" effects associated with consuming large quantities of the weed may surface. In these situations, the same herbivore may avoid the plant. In addition, animals avoid dense infestations of certain weeds because these infestations are a physical deterrent to animal movement (Lym and Kirby 1987).

Selecting Weeds Is a Function of Animal Characteristics

Besides plant palatability and availability, whether an animal consumes a plant depends on the animal's capabilities and previous experience with the plant. Designing effective livestock grazing systems to control weeds will require selecting appropriate animals and preparing these animals with desired dietary experiences.

Species of herbivore

Certain types of animals prefer certain types of plants. Cattle prefer grasses, sheep prefer forbs, and goats prefer shrubs. These inherent preferences partly reflect different morphologies and anatomies of these animal types, which influences their ability to prehend different plants and, or plant parts, and to detoxify plant allelochemicals. For example, goats have relatively large mouth openings and longer lips whereas cattle have relatively small mouth openings and shorter lips (Hofmann 1989). Tongues of goats are more dextrous than the heavily cornified tongues of cattle. These characteristics allow goats to strip leaves from stems or remove inflorescences from weeds, whereas the limited dexterity of a cow's mouth is ideal for tearing clumps of grass, not for stripping leaves or handling forbs.

Small ruminants evolved eating forbs and woody plants and have relatively large parotid salivary glands. Salivary excretions in small ruminants may counter the effects of plant allelochemicals (Hofmann 1989), which may explain why specialist grazers and browsers typically consume forages with high concentrations of plant allelochemicals. Sheep, goats and mule deer also produce high amounts of tannin-binding proline in their saliva, allowing them to use forages containing condensed tannins (Robbins et al. 1987, Austin et al. 1989, Mehanso et al. 1992). Cattle do not produce these salivary proteins (Jones and Mangan 1977, Austin et al. 1989). Browsing herbivores, such as goats, also have relatively large livers which may improve their ability to detoxify plant allelochemicals absorbed from the digestive tract (Pfister this volume). Salivary excretions and liver capacity may explain why specialist grazers and browsers typically consume forages with higher concentrations of plant allelochemicals than generalist grazers like cattle. Therefore, sheep and goats are more likely than cattle to consume and thus control weeds that contain significant amounts of plant allelochemicals. However, many weeds also become quite fibrous at maturity. Compared with small ruminants, cattle and horses are more able to digest fibrous materials, and would be more likely to trample or breakdown stiff stems that limit movement of smaller grazers and wildlife.

How important is grazing experience?

In southwestern Montana, we assessed whether yearling sheep exposed to leafy spurge as lambs graze this weed more readily than yearlings that were not exposed to it as lambs (Olson et al. 1996). We also determined whether this difference, if present, persists through the grazing season. We found that experienced yearlings spent more than twice as much time grazing leafy spurge in early summer (late May-early June) compared with naive yearlings, but neither group actively selected the plant. This may reflect that the associated cool-season grasses were highly palatable and nutritious in early summer. In addition, these yearlings did not have mature role models to influence their diet selection, positively or negatively. By mid-summer, both groups were grazing leafy spurge, up to 45% of their diet. Our findings indicated that: 1) there would be a slight advantage to using experienced sheep on leafy spurge, but only in early summer, and 2) inherent dietary preferences for forbs such as leafy spurge is strong in sheep.

In a more recent study, we compared how sheep and goats, in adjacent small pastures, used five invasive weeds including leafy spurge, spotted knapweed, sulfur cinquefoil (*Potentilla recta*), dalmation toadflax (*Linaria dalmatica*), and oxeye daisy (*Chrysanthemum leucanthemum*). Neither the sheep or goats had any previous experience with these weed. They only had a two day “exposure” to these infested pastures before we observed their grazing behavior for three days in early summer and again in late summer. Even with only two days exposure, the sheep and goats grazed each of these weeds. Apparently, their innate preference for broad-leaved forbs, despite the presence of allelochemicals in most of these weeds, predominated over their lack of experience with these species. However, these were short term trials and other forage was available to buffer allelochemical effects. Potentially, the animals could have developed an aversion to one or more of these weeds if we had forced them to graze the weeds over a longer period.

With ruminants, whether the previous experience is positive or negative it reflects the response of two interdependent systems, the whole animal system and the rumen microbial ecosystem. If the plant tastes bad, causes nausea, or is directly toxic to the animal (e.g. toxins absorbed directly into the system) the animal will avoid the plant in the future. Alternatively, if a plant does not taste bad, does not cause nausea, or is not toxic to the whole animal, the animal ingests the plant, at least initially.

Once ingested, the plant material has passed the first line of defense, the decision making system. The plant may contain allelochemicals that affect the line of defense, the rumen microbial population. With rumen microbial populations, plant allelochemicals can affect species composition of the rumen bacteria, fungi, and protozoa, and/or the level of rumen microbial activity. If the compounds negatively affect rumen microbial species composition and thereby reduce microbial activity, forages will be digested at a slower rate. This will result in negative postingestive consequences, reducing subsequent intake, and presumably reducing subsequent preference for the plant. A change in diet is probably the most important factor influencing numbers and relative proportions of different microbial species in the rumen (Yokoyama and Johnson 1988), partly because ruminal bacteria vary widely in the nutrients they require (Russel 1984), and partly because they have different tolerances or abilities to metabolize plant allelochemicals.

If the appropriate microbial species composition is needed for a ruminant to ingest a weed, altering microbial composition could increase intake of the plant. Rumen fluid from sheep consuming leafy spurge was added to the rumen of cattle to see if this would increase their consumption of a novel food paired with leafy spurge (Kronberg et al. 1993b). Cattle, with and without sheep rumen inoculum, consumed similar amounts of the novel food, suggesting that either sheep rumen microorganisms cannot exist in cattle rumina, or that ruminal microbes in cattle may produce an aversive substance from leafy spurge; whereas, sheep do not produce an aversive substance. Simply inoculating an animal with the appropriate “weed adapted” rumen microbial composition from another animal is not usually the answer.

What Can We Manipulate? Plant Characteristics

In limited areas, we may be able to improve the palatability of weeds to increase their use by small and large herbivores. Fertilizing with nitrogen (N) often increases crude protein levels of forage, but it can also stimulate excessive growth which may dilute nutrient concentrations in plant tissues (Kronberg and Walker 1999a). When fertilizing increases plant N concentrations, more N is available to the rumen microbial population which increases their activity and thereby increases forage digestibility. More importantly, fertilizing with N may lower concentrations of plant allelochemicals in weeds. By increasing the uptake of N, the increased synthesis of amino acids and proteins will reduce the amount of carbon available to synthesize carbon-based plant allelochemicals. On nutrient poor soils, nutrient uptake is limited so plants accumulate carbon-based plant allelochemicals (Bryant et al. 1983). For example, spotted knapweed plants from a fertile range site had lower cnicin concentrations than plants from an infertile, loamy sand site (1.8% versus 3.9%; Locken and Kelsey 1987, Olson and Kelsey 1997). In a 4-day trial, sheep consumed greater quantities of leafy spurge harvested from a fertilized site than from an adjacent unfertilized site (Kronberg and Walker 1999a). Although not quantified, I attributed this difference to the effect that fertilizing had on reducing concentrations of one or more carbon-based plant allelochemicals, because crude protein and fiber only differed slightly between leafy spurge from fertilized and unfertilized sites.

Palatability may be increased by spraying sweeteners, such as molasses, on weeds. Most herbivores have a "sweet tooth". Sweeteners may offset the bad taste or smell associated with plant allelochemicals. In addition, some sweeteners, such as molasses, are rich in sulfur (S). Sulfur is an important nutrient for rumen microbial activity in the synthesis of the S-bearing amino (e.g., acids, methionine and cysteine) and can improve detoxification in the liver (Launchbaugh 1996). On the Deseret Ranch in northern Utah, a dilute solution of molasses was sprayed on a patch of musk thistle (*Carduus nutans*; Greg Simonds, personal communication) to encourage cattle to use the spiny weed. The cattle readily consumed the musk thistle, and grazed the patch the following year even though it was not sprayed that year.

At times, spraying weeds with phenoxy herbicides can increase animal preference for them. This has been observed with 2,4-d and glyphosate. The actual mechanism is unknown, but these herbicides are essentially plant growth regulators, often accelerating growth rates. Accelerated growth rates may increase the amount of sucrose or salts, and possibly curtail the production of allelochemicals in the plant. In southwestern Montana, a patch of stinging nettle (*Urtica dioica*) was sprayed with glyphosate to eradicate the plant. Before spraying, the landowner's cashmere goats had avoided the stinging nettle but the goats grazed the stinging nettle avidly after it had been sprayed.

Why spray and graze a weed if spraying alone will control the plant? First, when weeds are sprayed late in their growth cycle, the stimulated growth rate may actually allow the plant to produce viable seed. Grazing this regrowth can reduce seed production; and degradation of consumed seed in the rumen can further degrade viability seed (Wallander et al. 1995, Olson et al. 1997a). Second, it would reduce the amount of standing dead material, decreasing a fire hazard, and opening the canopy for growth of desirable species. Third, many dense weed infestations, dead or alive, deter animal movement. Finally, the animals benefit by consuming a nutrient-rich resource when the weeds are sprayed early in the growing season. Arresting growth in early summer prevents the seasonal translocation of nutrients from aboveground leaves and stems to the root system. However, using herbicides to encourage consumption of weeds should be avoided where the grazing animals are producing milk or will soon be slaughtered for meat. It is important to follow label instructions of the herbicide.

What Can We Manipulate? Animal Characteristics

Can we encourage livestock, especially large herbivores, to graze forages readily that they normally avoid? Avoidance related to morphological or anatomical constraints can only be addressed by selecting the appropriate species. Avoidance related to lack of experience can be addressed by exposing the herbivore to the weed at a young age or with appropriate mentors. Avoidance related to rumen microbial attributes, resulting in negative postingestive feedback, may be addressed by appropriate adjustment periods to the weed, or by using anti-toxicants. For most herbivores, avoidance is probably a function of not one, but a combination of these factors. Therefore, designing systems to use livestock to control weeds must begin by identifying the factors that cause avoidance.

Manipulating stocking rate

The most common approach to getting livestock to eat weeds is to increase stocking rate to "force" the animals onto them. Altering plant availability by adjusting stocking rate will certainly affect the use of weeds by herbivores. At low stocking rates, herbivores may graze the weeds because they are seeking a varied diet (Provenza 1996), or because they will not ingest enough of a phytotoxin to cause a negative postingestive consequence. At high stocking rates, an animal's ability to avoid certain plants is compromised. All plants will be grazed. But even at high stocking rates, animals will graze preferred species to a greater degree than less preferred, weedy species, resulting in a competitive advantage for the weed.

Concentrating animals (e.g., high animal densities for short periods of time) to control palatable weeds can reduce weed populations. Intensive cattle grazing reduced the number of seedlings and rosettes of the invasive oxeye daisy *Chrysanthemum leucanthemum*, but the impact was attributed more to trampling than cattle actually consuming significant amounts of the forb (Olson et al. 1997b). Sheep or goats would have grazed this weed more readily than cattle (Howarth and Williams 1968). Concentrating animals limits their ability to select, which is intuitively appealing, but it does not always work. In southwestern Montana, sheep were concentrated on dense infestations of leafy spurge with a portable, power fence. Although sheep normally graze the highly nutritious leafy spurge, they went "off feed" after 10 days (personal observation). Either the sheep were bored with spurge and desired a more varied diet (Provenza 1996), or the whole animal or rumen microbial populations were affected by high levels of plant allelochemicals in their diet. Activity of sheep rumen microorganisms is reduced when leafy spurge exceeds 75% of their diet (Roberts and Olson 1999).

Animal preference can be neutralized by extremely high stocking rates. One producer in western Montana maintains 350 goats on 13 acres. His land is surrounded by spotted knapweed but he does not have any spotted knapweed on his land. However, he has to feed hay much of the year. Admittedly, in this example, a goat's ability to select preferred species is negated, but at the expense of the land resource.

Choosing the best species for weed control

Another approach to getting animals to eat weeds is to manipulate animal selectivity or use the most appropriate animal species, one with a predilection for grazing the target weed. Given that cattle and horses actively avoid most weedy forbs, the common practice of single species grazing of these large herbivores in western North America exacerbates the tendency for weed populations to increase and spread. In contrast, multi-species grazing may help restore a balance to the plant community. In southcentral Montana, foothill rangelands infested with leafy spurge are grazed by sheep during the "yellow bract" stage (W. Pearson, personal communication). The sheep are herded quickly through the area, removing the tops of the leafy spurge plants. They consume the developing flowerheads which eliminates seed production, and allows sunlight to reach the grasses below. Then, cattle are "turned out" for the normal grazing season. When possible, the sheep are rotated through the area in August to graze the highly nutritious leafy spurge regrowth.

Social influences on weed consumption

Exposing an herbivore to a weed at a young age can begin in the fetal stage. Many compounds pass from the mother through the placenta to the fetus (Keeler 1988). Mother's ingestion of a certain weed during pregnancy can reinforce food preferences in offspring, provided that it is not toxic to the fetus. If the mother avoids the weed, this may reinforce avoidance. Foods ingested by the mother also influence the flavor of her milk (Bassette et al. 1986) and can reinforce preferences. Finally, young herbivores learn which foods to eat and which foods to avoid from their mothers when they begin foraging (Mirza and Provenza 1990, Nolte et al. 1990). For mothers that avoid weeds because their mothers avoided weeds, etc., the challenge is to break these generational patterns by identifying ways to increase their consumption of weeds; which, could start a new pattern of preferred forages.

Providing appropriate mentors, such as peers or adult females, might be another way to increase consumption of weeds. This is most effective with young animals when they are relying less on their mother's milk and influence, and are highly influenced by their peers or other mentors (Mirza and Provenza 1990). An example of the possible influence of social models occurred in Montana where sheep are being used to control leafy spurge along streams and rivers. Along one river in southeastern Montana, a band of sheep was herded through areas infested with leafy spurge to control the plant, yet this particular band avoided leafy spurge for several years, even though this is a highly nutritious forb. One year, this band of sheep was inadvertently mixed with a band of leafy spurge-eating sheep. The "avoider" band then learned that leafy spurge was "OK" and subsequently grazed leafy spurge readily.

Grazing behaviors are readily socially transmitted among animals within the same species which normally ingest similar types of foods. Whether this learning occurs between species has received less attention. For example, goats, which readily consume leafy spurge, occasionally graze leafy spurge-infested pastures in the presence of cattle. Whether this increases cow or calf consumption of the weed has not been documented.

Managing dietary experiences

Herbivores have been "taught" through aversive conditioning to avoid plant species that are poisonous or preferred (Provenza and Burritt 1991, Ralphs 1992). Whether herbivores can be "taught", via positive post-ingestive feedback, to increase their intake of a "less preferred" species, such as a noxious weed, has received little attention (Provenza 1992).

Previous dietary experience can influence which flavors animals prefer later in life (Nolte and Provenza 1991). They can also influence the ability of animals to digest (Distel et al. 1994), detoxify (Distel and Provenza 1991, Robbins et al. 1991) and harvest (Ortega-Reyes and Provenza 1993) certain plants. Further, experiences when animals are young, often have a longer lasting effect than experiences later in life (Distel et al. 1994). Thus, exposing young animals to weeds after weaning, with appropriate mentors, should encourage consumption of these weeds later in life.

Manipulating rumen microbial populations

Avoidance could be related to effects of the weed on rumen microbial activity or composition, resulting in negative postingestive feedback. The composition of rumen microbial populations varies with diet, and these populations take time to adjust to dietary changes (Yokoyama and Johnson 1988). If, at one time, the animal rapidly consumed large quantities of the weed, the rumen microbial population may not have been able to adjust to the change or metabolize the plant allelochemicals, resulting in negative postingestive feedback and subsequent avoidance.

In a recent study with five invasive weed species, we increased the percentage of each weed in the diet of a sheep by 5% increments daily until the weed comprised 35% of its diet (adjusted sheep). Another sheep received only chopped grass hay (unadjusted sheep). We then collected rumen fluid from these two sheep, and fermented the fluid in flasks containing different proportions of the weed (weed:grass hay; 100:0, 50:50, 0:100) under conditions that simulated a rumen. With the 100:0 and 50:50 "diets", adjusted rumen microbial populations had greater microbial activity than unadjusted populations (Olson and Grindeland, unpublished data). This suggests that exposing animals to small populations of weeds, assuming the animals consume small quantities of the weed, will allow microbial populations to adjust to the weed. This may ensure greater consumption of the weed in the future.

Offering nutrient resources to increase weed consumption

If increasing the consumption of weeds containing allelochemicals is desired, starving animals onto certain weeds may not be the answer. Nutrient deprivation often decreases the ability of the animal or rumen microbial populations to detoxify the compounds and thus increases an animal's toxic response (Boyd and Campbell 1983). Conversely, with some weeds, vitamins, minerals, amino acids and carbohydrates could be added to enhance the ability of herbivores to detoxify or tolerate plant toxins (Freeland and Janzen 1974, Conn 1979, Brattsten 1979, Boyd and Campbell 1983). Research and management opportunities exist to identify compounds that complex and inactivate allelochemicals in the diet (McNabb et al. 1993). A complete understanding of pathways that detoxify specific compounds can lead to supplementation programs that encourage, rather than coerce livestock into eating weeds containing allelochemicals.

Offering anti-toxicants to increase weed consumption

Alternatively, if the avoidance is related to phytotoxic effects, anti-toxicants may be used to detoxify compounds in the weed. In concept, this is similar to "Bloat Guard" blocks for animals grazing alfalfa, but commercial "anti-toxicant" products have not yet been developed to increase the consumption of weeds. Polyethylene glycol increases the intake of foods with high concentrations of tannins, a secondary compound, but only if more nutritious alternatives are not available (Provenza, personal communication). Many weeds contain tannins. Activated charcoal, which adsorbs various plant allelochemicals such as terpenes, increases intake of sagebrush by sheep (Provenza, personal communication). Many weeds also contain various types of terpenes. Certain clays have the potential to bind with some toxicants (Smith 1992). Some organic compounds, or co-substrates including glucuronic acid, acetate, and sulfates, will conjugate with certain toxic compounds (Smith 1992). This increases the rate of excretion of the compound or renders it less toxic. Potentially, these co-substrates of detoxification could be added in feed, water, or a mineral block.

Conclusions

The preceding examples illustrate how small ruminants with a predilection for consuming forbs have the potential to control weeds. Grazing weedy forbs and shrubs, particularly by small ruminants, help maintain a balance in the plant community. But, numbers of small ruminants continue to decline throughout western North America for various reasons. If we continue with single species grazing of large herbivores such as cattle or horses, a greater challenge is to find ways to encourage these large herbivores to consume weeds in greater quantities.

As resource managers, can we truly manipulate diet selection to stimulate the use of weeds by larger herbivores or to increase the use of weeds by small herbivores? Is there a magic answer with some yet-to-be-developed compound or genetically altered animal or rumen microbial population that will solve the "problem"? Yes, when fully developed these techniques may help us manage the problem, but we must remember the problem did not arrive overnight and it will not leave overnight. Further, most of our weed control techniques, including herbicides, biocontrol with insects or pathogens, revegetating with competitive desirable plant species, and altering diet selection, are aimed at addressing the "symptom" not the cause of the problem. Weed infestations are not "caused" by a lack of herbicides or by a lack of biocontrol agents. They are caused by a form of management that encourages their spread. Thus, we should identify ways to "manipulate" diet selection to control weeds, and simultaneously assess ways to "manipulate" our traditional management schemes to minimize the spread of weeds.

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