

The Changing Role of Shrubs in Rangeland-Based Livestock Production Systems: Can Shrubs Increase Our Forage Supply?

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On the Ground

- Loss of grasslands to shrublands continues.
- Demand for livestock products is expected to continue to grow.
- Increased demand for red meat may stimulate rangeland livestock production.
- Methods for increasing shrub use are needed to meet increasing forage demands.

Keywords: cattle, goats, grasslands, secondary plant metabolites, sheep, woody plants.

Rangelands 36(2):25–31

doi: 10.2111/RANGELANDS-D-13-00066.1

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In the past 50 years, cattle, sheep, and goat numbers have increased from about 2.3 billion animals in 1961 to 3.4 billion in 2010,¹ and are projected to reach nearly 4.2 billion animals by 2030.² Three continents (Africa, Asia, and South America) experienced a cumulative increase of nearly a billion ruminants during the past three decades.¹ Projections suggest that by 2030, ruminant livestock numbers in developing countries will exceed those on the entire planet in 2000.³ The world's goat population has nearly doubled in the past three decades, from ~474 million in 1981 to ~910 million in 2010, with much of this growth in Asia and Africa.¹ Increased demand for red meat is driven by population growth, urbanization, and improved economies (especially Asia), a trend projected to continue through 2030.^{2,4} Rural/peripheral small-farm growth in places such as sub-Saharan Africa has also contributed to rising numbers of small ruminants.^{5,6}

Approximately one-third of the world's ruminants are in grazing-based systems.⁷ Grasslands are in decline in many parts of the world.³ Many factors (invasive species, drought tolerance, urban sprawl, climate change, differential herbivory, changing fire cycles, reduced prescribed burning, etc.) contribute to loss of native grasslands.^{8–10} Two major contributing factors are 1) conversion to cropland to support increased demand for cereal and oilseed production and 2) shrub encroachment.² Arable land in developing countries is projected to increase by almost 300 million acres² (an area about the combined size of Texas, Oklahoma, and New Mexico) by 2030, and much of this will likely be native grasslands marginally suited for crop production.

Approximately 93.5 million acres of the world's rangelands are classified as “woody” compared to 31.6 million acres categorized as grassland.³ Woody plant expansion/dominance is especially prevalent on arid/semiarid rangelands.¹¹ Though rangeland ecosystems are diverse and complex, most contain some proportion of woody plant species, many of which are used sparingly or avoided by livestock. Restoration of degraded rangelands is costly and slow, if not impossible in some cases¹⁰; yet, demand for forage to support projected increases in livestock will escalate. An estimated 3.2 billion tons of forage will be required annually to feed these extra livestock.³ Other systems will undoubtedly absorb some of this growth (i.e., intensive systems, mixed farming).² Even though intensive production systems have increased in recent years, they may not be sustainable, given that intensive systems rely heavily on an inexpensive oil supply and are likely to be hardest hit by rising oil costs associated with impending peak oil.^{12,13} There will likely be unprecedented pressures on rangelands, especially in developing countries, and it would behoove us to learn how to more efficiently use the forage base on these landscapes. A paradigm shift is needed to produce livestock with less grass, and development of methods

to safely and sustainably use woody species as forage is one element of that shift.³

Current US Situation

As in most of the world, many US rangelands are degraded to some extent and contain some proportion of woody species. Approximately 426.4 million acres of the continental United States are considered “shrub/scrub” while 288.8 million acres are classified as “grassland/herbaceous”¹⁴ (Fig. 1). “Shrub/scrub” comprises nearly 35% of the 17 western states (Fig. 1).

In contrast to global trends, livestock inventories have actually decreased to varying degrees during the past few decades in developed countries.¹ In the United States, total cattle numbers have declined by about 29% (> 38 million head) since peaking in 1975, and are currently at their lowest point since 1952.^{1,15} Sheep decreased from 14.5 million to 5.6 million in the United States during the same timeframe.¹ Though grazing has been the primary historical use of western rangelands, competing uses (e.g., oil/gas, recreation, wildlife, timber, grazing) and decreased profitability have caused

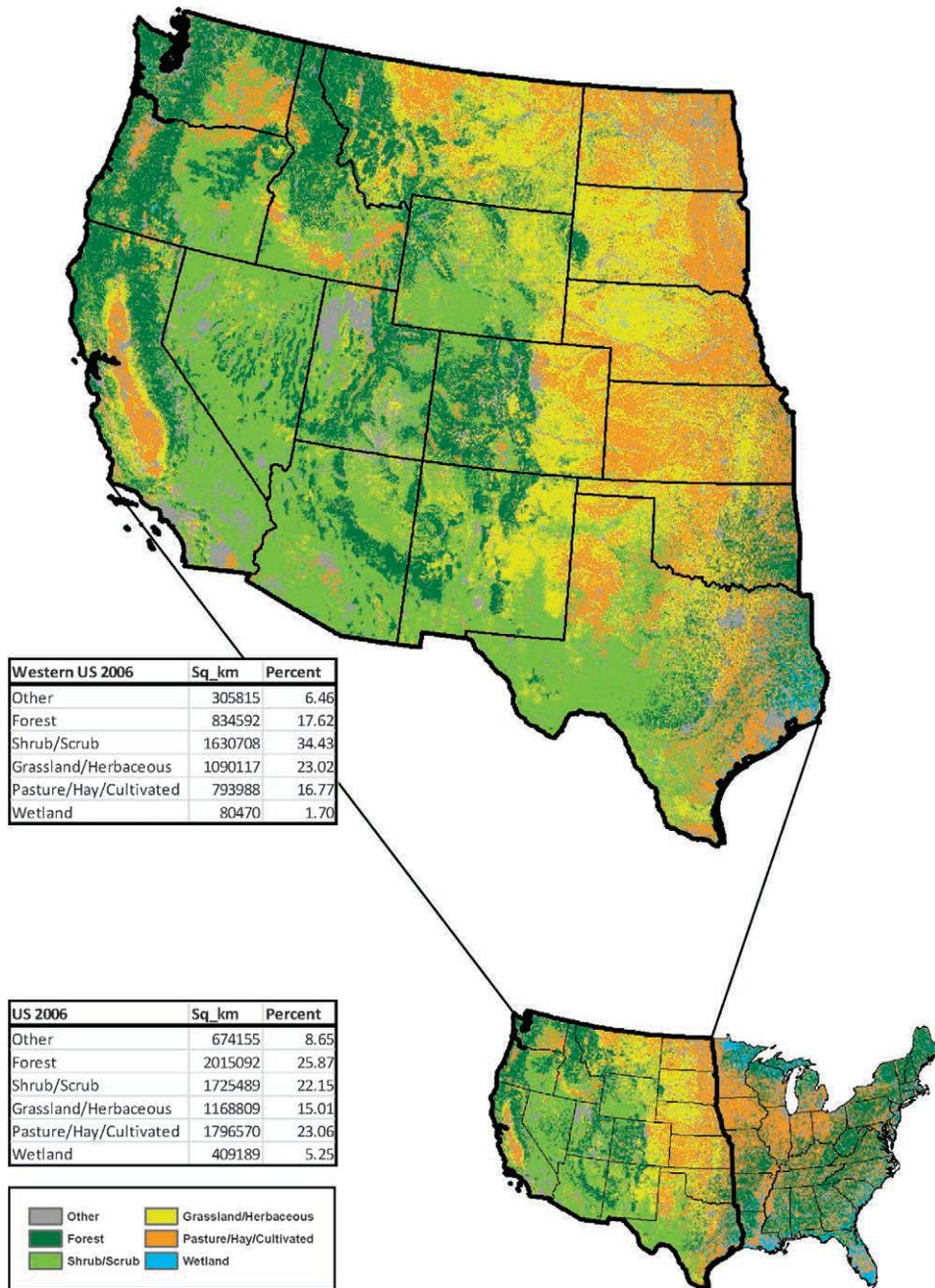


Figure 1. Land cover for the continental United States and 17 western states based on an assimilation of land cover classes into one of six cover classification types or “other.”¹⁴

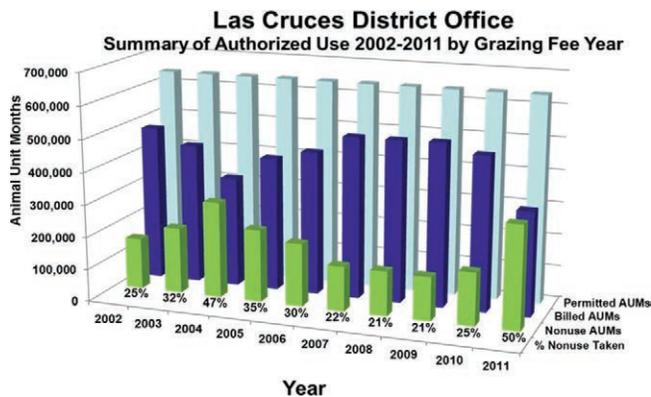


Figure 2. Permitted vs. used animal unit months (AUMs) in the Las Cruces BLM grazing district between 2002 and 2011.¹⁹ 2011 data include only first half of year.

a decline in livestock numbers in recent years.¹⁶ Part of the decrease on western rangelands between the 1970s and now is due to a paradigm shift in management strategies from investing in land improvements geared to increase production per acre (brush control, seeding, fencing, etc.) to increasing efficiency of individual animals (e.g., adapted biotypes, conservative stocking, decreased supplementation, stringent culling, reduced predation, technology for improved distribution, etc.) in an attempt to minimize financial risk triggered by rising costs relative to return on investment.¹⁶ This transition from high to low input strategies represents a shift from primarily agronomic (forage production) to animal-based (nutrition, genetics, behavior) approaches.¹⁷

On public lands, stocking rates have decreased by more than 50% between 1954 and 2012, from 18.2 to 8.9 million animal unit months (AUMs).¹⁸ Grazing allotments on public lands have not been fully stocked at permitted levels in many areas. For example, only 50–75% of the allotted AUMs in the Las Cruces Grazing District (603 allotments in six counties in southern New Mexico) were used in any year during a 10-year span¹⁹ (Fig. 2). Reduced stocking requests are due to several factors, but less available forage and lower profitability are likely contributors.

The current pattern of decreasing livestock numbers in developed countries and specifically in the western United States could reverse given increasing demands coupled with global economic changes and rising energy costs (and consequently feed costs).¹³ Combined with shrinking resources and potential weather extremes (e.g., drought), these factors will likely place further demands on existing rangelands. While pressures are expected to be especially pronounced in developing countries, these economic scenarios could stimulate rangeland beef production in the United States.¹⁷ Recent trends in US cattle confinement operations indicate heavier entry weights¹⁵ (Fig. 3). Placement of animals > 800 pounds into feedlots has steadily increased while placement of cattle between 600 and 800 pounds has steadily declined during the past decade. While many factors (drought, prices, etc.) af-

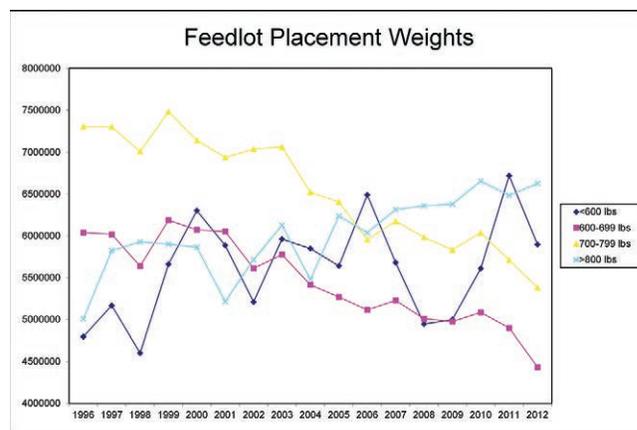


Figure 3. Cattle numbers entering US feedlots in different weight placement categories between 1996 and 2012 (operations > 1000 head).¹⁵

fect placement weights, a major factor is an attempt to reduce feed costs. Stocker/backgrounding programs on improved pastures, wheatgrass, etc. currently supply much of the forage needed to achieve these heavier weights. However, given the competition for a finite land base and water resources coupled with the projected increased demand for red meat, a trickle down effect may be a greater reliance on efficiently utilizing alternative rangeland forages in the United States.

Specific Considerations on Shrub Use

Amount of woody plant use by livestock is determined by many factors (e.g., plant species, animal species, phenology, availability of other forage), but is typically low and/or sporadic. Impediments to increased woody plant use include both physical and chemical elements. This section will focus on chemical deterrents.

Plant secondary metabolites (PSM) are often abundant in shrubs, and can affect not only palatability and intake, but also behavior, physiology, digestion, and rumen function. Negative effects depend on the specific chemical, the amount eaten, and other diet constituents. Because of these constraints, livestock often avoid a potentially valuable nutrient source. How can we 1) overcome effects of PSM/toxins on metabolism and 2) change relative preference vs. other more desired forage? The answers are manifold, but most involve some aspect of 1) using the appropriate animals for the landscape and 2) increasing individual performance. Some of these solutions are intuitive, while others are less obvious.

One approach is to capitalize on inherent animal genetics by matching animals (species, breeds, or individuals) to landscapes. Goats are more adept browsers than cattle and sheep, which may partly explain the global goat population explosion, averaging more than 4.5 million head per year added to the planet during the past 30 years.¹ Exotic heritage livestock breeds that evolved in shrubby conditions and contain isolated gene pools may provide genetic material for developing shrub consumers.²⁰ Specific animals (outliers) in a population with genetic predisposition for shrub consumption may

be identified and used to develop shrub eaters. Heritability of sagebrush (*Artemisia tridentata*) intake by sheep and ashe and redberry juniper (*Juniperus ashei* and *J. pinchotii*) by goats was 25–28 and 13%, respectively.^{21,22} Although heritability of shrub consumption is in the moderate to low range, potential exists for improvement. Progress would likely be slow, but it would be a low-cost approach for increasing shrub intake.

A second potential avenue for stimulating shrub intake concerns the physiology of detoxification. Animals with a predisposition for eating shrubs may provide clues (e.g., blood metabolites) about indicators for detecting shrub eaters. Sheep dosed with a dominant sagebrush terpene (1,8-cineole) stopped eating in response to elevated blood concentrations and resumed eating after levels dropped.²³ Similarly, goats selected for high or low juniper intake differed pharmacokinetically; a terpene dose representing 30% dietary juniper resulted in more camphor in the blood of low juniper eaters (i.e., less efficient clearance), suggesting camphor may be a good marker of consumption of some woody species.²⁴ Campbell and colleagues²⁴ suggested challenging animals with camphor might be a way to identify animals for genetic selection. This method could possibly be generalized to different landscapes by choosing site-appropriate chemical challenges to determine suitable markers. Alternatively, markers of detoxification may be discovered through systematic searches of blood metabolite profiles of animals fed shrubs or isolated chemicals. Liver enzyme assays and gene expression techniques that identify genetic markers may help us recognize animals with increased detoxification capabilities.²⁵ Transfer of genetic material from species able to cope effectively with PSM to the animal itself or to rumen bacteria is another potential mechanism for encouraging shrub use. A common theme is that these methods capitalize on unique attributes of outliers and unusual (or adapted) populations. Making these technologically intensive approaches a reality would be expensive initially but would permit more rapid progress.

A third practical way to improve shrub intake involves use of supplements and additives. Replenishing nutrients used to metabolize toxins can increase intake of woody plants.^{26,27} For example, protein supplementation can bind/deactivate certain types of PSM, help maintain acid/base balance, and provide precursors for detoxification pathways.^{28,29} Additives such as charcoal and polyethylene glycol (PEG) have been shown to interfere with absorption of PSM and increase intake of certain shrub species.^{30,31} PEG has been particularly effective in improving intake of shrubs containing tannins.^{32,33} Decreases in several plasma amino acids were observed after consumption of one-seed juniper plus quebracho tannin, and many of those amino acids were restored when PEG was added to the diet.³⁴ Because animals can increase tolerance to PSM over time through mechanisms such as microbial adaptation and enzyme induction,^{35,36} techniques may be developed (i.e., inoculants, antibodies, etc.) for increasing tolerance to woody plants and/or desensitizing naive animals to new landscapes.

Strategic use of supplements and additives is an approach that is readily available but more expensive and labor-intensive.

A fourth aspect of increasing intake of woody plants relies on principles of animal behavior. Animals sometimes regulate intake of PSM by adjusting rate and/or pattern of eating (e.g., frequency, amount, time between eating bouts, changing locations, etc.) based on feedback from blood PSM/metabolites.^{37,38} Some of these behaviors (e.g., diet switching/mixing) increase diet breadth and can dilute intake of a specific PSM and increase diet complementarity (diets containing multiple PSM that are detoxified by different mechanisms and pathways) and ultimately increase total intake.^{39,40} Training animals to increase diet breadth⁴¹ is a potential mechanism to increase shrub consumption when complementary PSM profiles exist on a landscape. Animals may be conditioned to learn to eat foods they would normally avoid by limiting familiar foods and by optimizing factors such as diet quality and sequence and timing of feeding.^{42–44} However, behavior modification has met with only limited success under field conditions, likely because of the complexity and constantly changing nature of plant communities and chemical signals that animals must process.^{45,46} When production systems are compatible, small improved pastures or strategically seeding arid-adapted plants might allow for increased shrub intake by improving complementarity, capitalizing on sequence of PSM intake, etc. In systems where animals are penned at night or herded, changing sequence and meal patterns (from within-day to over season) may improve the balance of PSM consumption. While these options have limited application, specialized programs in which high inputs are more tolerated and small farms in developing countries that rely heavily on crops and residues may benefit from such strategies. In general, behavioral manipulation approaches are site-specific, with cost of implementation depending primarily on existing facilities.

High-density stocking and rapid rotation may allow ruminants to learn to incorporate less-preferred forages in their diet because selectivity is reduced and animals can more easily discern the benefits of complementary diets consumed close together in time.^{47,48} For example, goats spent more time browsing juniper vs. herbaceous species in high- vs. low-density treatments⁴⁹ and sheep increased sagebrush browsing with increased animal density and time of exposure.⁵⁰ Whether high-density stocking and mixed-species grazing can encourage shrub use without harm to the herbaceous understory is another question that depends on many factors (e.g., pasture condition, animal and plant species, etc.). Added to the complexity is the fact that a variety of PSM exist, and their concentrations vary temporally and spatially within and among plant species. Clearly, systems that maximize shrub use and minimize PSM consequences while maintaining the herbaceous component are needed. Again, these are approaches that can be inexpensive to implement, depending on management objectives and existing facilities.

New paradigms that involve more finely regulated feeding may be useful for optimizing woody plant use by integrating

concepts of diet mixing and dilution of PSM. Local knowledge from small farmer/herder practices in developing countries that has accumulated through history may be useful. For example, shrub harvesting (hand-harvesting, mowing, etc.) and preservation (stacking, ensiling, fodder) methods used in small scale operations could be incorporated into shrub feeding programs. Many of these methods allow PSM to volatilize or degrade (a strategy similar to rodent caching) and improve quality. Air-dried redberry juniper had lower monoterpene levels than fresh material and could be substituted for cottonseed hulls as the roughage source in feedlot diets without reducing long-term intake or gain by lambs.⁵¹ Replacing wheat straw with pine bark (containing > 10% condensed tannins) at up to 30% of the diet increased intake and average daily gain and decreased fecal egg counts of goats.⁵² Mixing woody plants/plant parts with other feeds and residues in finely tuned feeding systems to dilute PSM and capitalize on complementarities may have utility in a variety of situations, particularly since much of the onus for meeting increased demand for red meat will be placed on developing countries, many of which utilize mixed farming systems that incorporate crop residues and nontraditional harvested forages.^{2,6} The economics of such practices would be site-specific and a trade-off would exist between cheap feed and increased labor. Changes in the prevailing economics of livestock production in developed countries could make these approaches more attractive in the United States. Strategies for increasing shrub use could be important for rural communities to adapt to changing climate and shrub cover and for the livestock industry to adapt to predicted growth.

It is noteworthy that consumption of PSM prevalent in woody plants can benefit animal health (e.g., antiparasitic) in small doses in certain situations.^{48,53} Condensed tannins have been shown to improve protein status⁵⁴ and terpenes can positively influence fermentation and decrease methane production.^{55,56} The potential beneficial environmental impacts of consuming PSM-containing shrubs (i.e., reduced methane and ammonia release) are intriguing and could stimulate research (and funding) on enhancing shrub intake as a means of mitigating effects of increased livestock numbers on climate change.

Summary

Clearly the goal of increasing use of woody species is daunting, given the fact that they typically contain PSM and are often unpalatable, especially when alternatives exist or if animals have previously experienced negative feedback. At best, traditional rangeland livestock eat minimal amounts for short times when they have other options. Progress has been slow in developing mechanisms for encouraging shrub use for a variety of reasons. Until recently, there was plenty of grass, less shrub encroachment, a lower human population, and less consumer demand. That animals typically avoided woody plants (and why) was unimportant. Range nutrition research was geared toward the study of dietary habits and production systems rather than changing feeding behavior. As grass has

become in shorter supply globally, interest in shrub use has increased. Progress has also been hindered by site-specificity; many factors cause animals to avoid plants to varying degrees. Landscapes and the plants within vary in infinite and constantly changing permutations of chemical profiles and concentrations. Nevertheless, methods for increasing shrub intake are being developed that take advantage of genetics, behavior, and physiology to identify or create ruminants that eat and cope with PSM.

Genetic selection is hampered by low heritability and long generation intervals, but is a viable long-term solution. Much work is needed for marker development to be a practical reality. Though expensive, supplements and additives can be used to stimulate intake and counteract toxins.

Much of the world's rangelands are woody-dominated, and it is unrealistic to believe we can sustain livestock production on many of these ecosystems given present knowledge; regardless, they will be grazed. We have over three billion cattle, sheep, and goats now. This number will likely reach four billion in the next 20 years. Over half of these will be sheep and goats, which are capable of wider dietary breadth (especially goats). Given that goats are more suited to shrub consumption than other ruminants, some of the increase in goat numbers is likely due to efforts to increase use of shrubs and woody species byproducts. The extent to which goats will be part of the solution to increasing meat production on US rangelands is unclear, given their management issues in extensive environments and social bias against goats in certain segments of society. The two billion cattle that are predicted to be present globally have a narrower dietary niche, and mechanisms are needed to increase their use of woody plants. Though much has been learned in recent decades, we are far from ready to efficiently extract nutrients from this vast resource.

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