Chapter 5

Planned Herbivory in the Management of Wildfire Fuels

Roger S. Ingram, Morgan P. Doran and Glenn Nader

Additional information is available at the end of the chapter

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1. Introduction

Wildfires are increasing in number, intensity, and size. Five of the most significant wildfire seasons in the United States since 1960, as measured by total area burned, have occurred since 2000 [1]. The vegetation or fuel profile, a major factor determining fire behavior, is studied in two aspects: vertical and horizontal arrangement and amount. The vertical arrangement of fuel determines the degree of its mixture with air and, thus flame height and duration of elevated heat. The continuity of horizontal fuel arrangement determines potential fire spread across the landscape. Fuel attributes, along with topography and weather conditions (wind and fuel moisture), determine the kind of wildfire that will occur. Many management and ecological conditions have allowed fuels to accumulate. The increasing number of residences occurring in forest and rangeland ecosystems provides more ignition sources and restricts the ability to manage fire. Introduction of exotic plants like cheatgrass in the Inter-Mountain region of the United States has also changed fire behavior in many sagebrush plant communities [2]. Reducing biomass and the architecture of vegetation with chemical and mechanical methods can be effective, but are costly and complicated by rough terrain. Herbivory can result in short-term seasonal impacts on vegetation amounts and structure and long-term shifts in plant community composition and structure [3]. Grazing by domesticated ruminants is perhaps the most widely applied type of herbivory and can alter vegetation to reduce wildfire risks, which is often an inadvertent result in livestock grazing systems. Native herbivores can also have similar impacts on vegetation and wildfire [3,4], but specific behaviors can also increase wildfire risks [4]. An important distinction between grazing by wild and domestic herbivores on private and public lands is the ability to manage grazing in order to achieve specific vegetation management objectives. This review is focused on planned and managed herbivory, which is often not possible with wild herbivores and is therefore not discussed. Utilizing and manipulating livestock grazing for wildfire fuel management can be a sustainable alternative to other vegetation management methods when applied with an understanding of fire behavior, the forage environment and ecological objectives.

2. Concepts of fuel management

The intensity of wildfires is determined by thermal dynamics or the transfer of heat. Fuels must be preheated until absent of moisture and then it produces flammable gases that are easily ignited. The smaller the diameter of the material, the less heat input required for it to dry, produce gas and ignite. Larger diameter fuels, due to size or mass, require more heat before gas is produced for ignition. This is why the rate of spread of a grass fire is much faster than a brush fire. The horizontal density and or space between plants (fuel sources) will impact the transfer of heat that is required for pre heating across the landscape. The vertical space between plants will also impact the heat transfer. Continuous fuel in that plain is called ladder fuel. A continuum of fuel is one of the factors that controls flame height. Other factors that contribute to the fire behavior are the slope of the land surface and weather. A steeper slope will transfer heat between fuels more efficiently and create an explosive environment. In steep canyons, as the heat rises above to plants the angle combines horizontal and part of the vertical heat transfer. This is why most fuel reduction is conducted on flat topography areas like the tops of ridges.

Fuel treatments are generally arranged in two different approaches. Fuel breaks are linear fuel modifications often situated along a road or ridge. They can range in width from 10 to 120 meters and are designed as a tool for fire fighters to stop fires. Landscape area treatments are designed to reduce flame height and change fire behavior over a large area. Long term landscape treatment efforts are focused on changing the plant community to decrease the flame height when fire occurs. Both approaches require maintenance to remain valuable fire management tools. The objective for fuel reduction is to change fire behavior by impacting the following: fuel bed depth, fuel loading, percent cover, and ladder fuels that results in a fire flame of less than four feet. At that level all fire fighting management tools can be used while maintaining fire fighter safety.

3. Disturbance to reduce fuels

Interruption or the disturbance of the plant growth can be achieved through grazing, burning or other treatments. Mechanized disturbance treatments are used by land managers to alter or remove vegetation included mowing, mastication, and biomass harvesting. Mastication involves the use of a large mechanized device that chops shrubs and trees to break up the fuel pattern and decrease combustibility by placing fuels on the ground. It changes fire behavior by rearranging the fuel profile and by distributing some of the fuel on the ground. This action also causes a reduction of ladder fuels, which decreases potential for vertical extension of fire into tree canopies; crown fires are extremely difficult for fire fighters to control.

Mastication can be used as a pretreatment followed by prescribed fire or grazing treatments. Some of the disadvantages of mastication are the costs, ground disturbance, short life of the treatment in some areas, terrain and surface roughness limitations, and soil compaction. Mastication will result in death in some brush species, but many will re-sprout from the roots and require retreatment. Mechanized disturbance treatments also include the thinning of over-story vegetation through biomass harvesting. The harvested biomass is brought to a chipping unit and the resulting material is transported off the site for use in energy power plants. The sale of the biomass chips reduces the cost of this treatment. Thinning can provide desired conditions for both ladder fuels and crown spacing in one treatment. Soil moisture condition is the only limitation on the time of year that the treatment can be conducted. Disadvantages include transportation costs of hauling biomass and removal of nutrients from the ecosystem. In some cases, trees that are removed can be sold as commercial saw logs to offset fuel treatment costs.

Mowing is generally used in grass communities to drop the fuel on the ground, where it has less contact with air and decreases the combustibility. Mowing needs to be applied during end of the green season since it can cause fires from the blades striking rocks when dry grass is present.

Herbicides can be sprayed to kill specific plants, but this does not alter the fuel pattern immediately. Herbicide treatment of targeted species can be the cheapest methods. The disadvantages include concerns about its impact on the environment and short term increases in fuel flammability.

Prescribed fire can be used to change the fuel load and pattern. Air quality concerns and the need for the correct fire weather conditions (wind, air and plant humidity) may limit the use of prescribed fire to a narrow time period in the season that implementation can occur. A mechanical or hand removal treatment may also be required prior to the reintroduction of fire into the ecosystem to achieve desired fire behavior. The disadvantages of this treatment are reduced aesthetics, tree mortality, impaired air quality, liability concerns, pretreatment costs where applicable, required qualified people that understand prescribed fire, treatment variation (it may burn hotter or cooler than planned), and it may not be appropriate for some plant communities such as low-elevation sagebrush that can be converted to cheatgrass post fire.

Hand cutting and stacking of fuels for burning is very selective and is often the preferred method to treat larger diameter fuels on steep slopes where mechanized equipment cannot operate. The cost for this labor intensive method is comparatively high and depends on the type and amount of vegetation and terrain.

3.1. Grazing for fuel management

Grazing is best used when addressing the smaller diameter vegetation that make up the 1 and 10-hour fuels. One-hour fuels are those fuels with a moisture content that reaches equilibrium with the surrounding atmosphere within one hour and are less than 6 mm in diameter. Ten-hour fuels range from 6 to 25 mm in diameter. Grazing can impact the amount and arrangement of these fuels by ingestion or trampling as seen in Figure 1.

Figure 1. Goats altering the fine fuels.

Grazing is a complex dynamic tool with many plant and animal variables, which requires sufficient knowledge of the critical control points to reach treatment objectives. Those control points involve the species of livestock grazed (cattle, sheep, goats or a combination), the animals' previous grazing experience that will effect their preference for certain plants, time of year as it relates to plant physiology (as the animals consumption is directed by the seasonal nutrient content), the animal concentration or stocking density during grazing, grazing duration, plant secondary compounds, and animal physiological state. Grazing treatments can be a short term application to reduce flammable vegetation or a long term practice designed to change vegetation structure and composition through the depletion of root carbohydrates in perennials and the seed bank of annual plants. The fire prevention objectives are to change the fire behavior through modification of the fuel bed, fuel loading, percent cover, and ladder fuels.

The plant community and fire prevention objectives will determine the targeted vegetation of concern and the plants' life cycle (annual or perennial) will determine the type of grazing that will be applied for fuel management. Control of annual plants will require annual treatments that will remove plant material prior to the fire season. Grazing before seed set can change seed bank dynamics and long-term implementation of grazing can change plant species composition. Control of perennial plants will require repeated grazing treatments that deplete root carbohydrates and cause mortality of targeted species, which also changes plant species composition. Root carbohydrate reserves are at their lowest level just after the period when plants initiate active shoot elongation. If plants are severely grazed early in the growing season, carbohydrate reserves will be depleted and plant vigor reduced [5]. Removal of bark or repeated defoliation are two other ways to destroy perennial plants. In shrub species, the concept of changing the fuel profile the first year and managing it thereafter with grazing over large areas appears to be most sustainable.

Integration of different treatments could provide the best strategy. Livestock cannot effectively control mature shrubs that either grows higher than the animals can effectively graze or have large diameter limbs. Mastication, under burning, hand cutting can be used to manipulate the large diameter 100-hour shrub fuels and grazing can be used as a follow up treatment for controlling re-sprouting species or shifting the species composition to herbaceous plant fuel material. Tsiouvaras [6] suggests that grazing followed with prescribed fire can be used safely to kill the above ground part of shrubs and further open the stand. Magadlela [7] reported that cutting and herbicide increased sheep effectiveness by reducing the shrubs below 20% in one year, but increased the costs.

4. Grazing impacts on fuels

Prescribed grazing has the potential to be an ecologically and economically sustainable management tool for reduction of fuel loads. However, much of the information on grazing for fuel reduction is anecdotal and scientific research is limited. Existing data indicate there are two ways in which grazing impacts the fuel load, removal of vegetation and hoof incorporation of fine fuels. Smith *et al.* [8] found that in Nevada 350 ewes grazed intensively on *Artemisia tridentata (*sagebrush) and *Bromus tectorum* (cheatgrass) in a 2.5-mile fuel break divided into 20 pastures reduced fine fuels from 2,937 to 857 kg/hectare. Vegetative ground cover decreased 28 to 30 %, ground litter increased 20 to 23 % and bare ground increased 4%. Planned herbivory treatments in Idaho reduced cheatgrass biomass resulting in reductions in flame length and rate of spread. When the grazing treatments were repeated on the same plots in May 2006, cheatgrass biomass and cover were reduced to the point that fires did not carry in the grazed plots [9]. Tsiouvaras [6] studied grazing on a fuel break in a California *Pinus radiata* (Monterey pine) and eucalyptus forest in the fall at a stocking rate of 279 Spanish goats/hectare for three days and reduced the brush understory by 46% and 82% at a 58 centimeter and 150 centimeter height respectively. Forage biomass utilization by the goats in the brush understory was 84%. *Rubus ursinus* (California blackberry) showed the largest decrease in cover (73.5%) followed by *Heteromeles arbutifolia* (Toyon), *Baccharis pitularis* (coyote brush), *Lonicera spp.* (honeysuckle), herbaceous plants, and *Arbutus menziesii* (madrone). *Toxicodendron diversilobum* (poison oak and eucalyptus exhibited very little change. Grazing of goats not only broke up the sequence of live fuels, horizontally and vertically up to 150 centimeters, but also reduced the amount of 1 and 10-hour dead fuels 33.2% and 58.3% respectively, while the 100-hour fuels remained constant. The litter depth was also reduced as much as 27.4% (from 7.4 centimeters before to 5.1 centimeters after grazing). Animal trampling resulted in crushing of the fine fuels and mixing them into the mineral soil, thus reducing the chance of ignition. In Southern California Green *et al*. [10] grazed 400 goats to create fuel breaks through chaparral in July. The goats utilized 95% of the leaves and small twigs to 1.6 mm diameter from all the *Cercocarpus spp.* (mountain mahogany) plants. Use of *Quercus berberidifolia* (scrub oak) was 80%, while use of *Adenostoma fasciculatum* (chamise), *Arctostaphylos glandulosa campbelliae* (eastwood manzanita), and *Eriogonum fasciculatum foliolosum* (California buckwheat) was low and *Ceanothus spp.* was only taken under duress. Under "holding pen" conditions, use of less palatable species approached the use of palatable plants [10]. Lindler [11] reported that goats stocked at seven per acres for three weeks in the summer in a ponderosa pine forest had an estimated vegetation removal of 15 to 25% depending on the plant species present and the length of stay in the pasture. The cost of the grazing treatment was $148 to $173 per hectare. Herbicide comparison costs on adjacent sites were $148 to 309 per hectare and removed 75 to 90% of the vegetation understory in the pine forest. Intensive grazing of cattle to control shrub growth has been demonstrated as being useful that could be used for maintenance of fuel breaks [12-16].

Perevolotsky [17] found that mechanical shrub removal and cattle grazing at the peak of green season in Israel during four consecutive years proved the most effective firebreak treatment. Heavy grazing for a short duration removed more than 80% of the herbaceous biomass, but affected the regeneration rate of shrubs for only 2 years. They stated that using goats or other browsing animals may increase the amount of shrub material removed by direct grazing, but may decrease the physical damage to shrubs. Henkin [15] found that under heavy grazing (175–205 cow grazing days per hectare), the basal regrowth of the oaks was closely cropped and the vegetation was maintained as predominantly open woodland. In the paddock that was grazed more moderately (121–148 cow grazing days per hectare), the vegetation tended to return to dense thicket [15].

Each species of animal has a unique grazing utilization pattern that is a function of mouth size and design, past grazing experience, and optimization of nutritional needs [18]. The mouth size will control how closely animals are able to select and graze to a given surface. Animals also differ in their forage preferences and diet composition, thus when developing a fuel reduction grazing program it is important to select the type of livestock that will consume the desired species and alter the fire behavior. Provenza & Malechek [19] showed a 50% reduction of tannin in goat masticated samples compared to un-masticated samples. This illustrates the goats can tolerate one of the secondary compounds that are present in some shrub species allowing higher amounts intakes. When preferred forage is absent or unpalatable, grazing animals are capable of changing their food habitat.

Forage type	Animal species		
	Cattle	Sheep	Goats
Grass	78	53	50
Forbs	21	24	29
Browse	1	23	21

Table 1. Percent of time (%) spent by animals feeding on diverse plant types in Texas [20].

Magadlela [7] found that goats grazing in Appalachian shrubs defoliated shrubs early and then grazed herbaceous material later in the season. Sheep preferred to graze herbaceous material first, but increased grazing pressure forced sheep to defoliate shrubs earlier in the season. They found that goats reduced shrub cover from 45% to 15% in one year. Sheep took three years to create the same results. Goats had improved shrub clearing when they followed sheep, reducing total shrubs from 41 to 8% in one year. By the end of five years of goat grazing, the shrubs were reduced to 2% cover. Luginbuhl *et al*. [21] found that *Rosa* *multiflora* (multiflora rose) was practically eliminated from the Appalachian Mountains after four years of grazing by goats alone (100%) or goat + cattle (92%). Simultaneously, vegetative cover was increased with only goats (65 to 86%) and with goats + cattle (65 to 80%), compared with the control plot where vegetation cover decreased from 70 to 22%. Lombardi *et al*. [22] studied the use of horses, cattle and sheep in Northwest Italy for five years and found that grazing reduced woody species cover and stopped the expansion of shrub population. The impact varied with animal. Cattle and horses had a higher impact on the plants caused by trampling. They found that the effectiveness of control depended on palatability and tolerance of woody species to repeated disturbance. Juniper and Rhododendron species were reported not to have been grazed. Hadar *et al*. [16] reported that the inconsistent response of some plants to grazing could be the interaction between grazing pressure and moisture conditions. They found that heavy cattle grazing (840 - 973 cow grazing days per hectare) during 7 to 14 days at the end of the growing season decreased species richness by consuming the seeds of herbaceous plants.

Sheep and goats grazing California chaparral presented dissimilar foraging strategies over the three grazing seasons [23]. They selected fairly similar species, but in different proportions at different seasons. Narvaez [23] found the proportion of browse in sheep and goat diets was greater when shrubs in chaparral areas were more abundant than herbaceous species. Browse accounted for 86.7% of the total forage ingested by goats and 71% by sheep. Seasonal grazing differences were also observed with sheep shifting from a browse dominated diet in fall and winter months to an herbaceous dominated diet in the spring when grasses were abundant and at their most nutritious state for the year. Goats maintained a browsing preference across all seasons and had a higher dry matter and nutrient intake than sheep over the three grazing seasons. Dry matter intake for goats was sufficient to meet maintenance requirements as was not the case with sheep. Goats were more effective than sheep in reducing fuel load in California chaparral as they consumed more vegetation and did not appear to be nutritionally limited by the low quality of the landscape. Sheep may be more effective in an herbaceous dominated landscape for fuel load reduction.

The impact of grazing on specific plant species will depend on the time of year grazing is applied. Herbivores will respond to the nutritional status of plants and their parts by selecting and concentrating their consumption on the most palatable and nutritious parts. As the physiological status of a plant changes throughout the year, the nutritional value of its parts change which can increase or decrease the desirability of those parts to herbivores. Taylor [20] reported studies in Idaho using heavy grazing by sheep showed that season of use impacted the utilization. Late-fall grazing reduced *Artemisia tripartita* (three tip sagebrush), while grazing during the spring increased sagebrush and decreased grasses.

Grazing impact can change with the density of animals and duration of grazing. The shorter the duration the more even the plain of nutrition will be. Over long periods of time in a pasture animals will first select the most nutritious forage and then move down in their preference of plants consumed. Stock density will have a great impact on the consumption and trampling of fuels. Fences, herding, topography, slope, aspect, distance from water, placement of salt, and forage density will all impact the distribution of animals and their

Figure 2. Electric fence netting for targeted goat grazing.

utilization of the forage. By concentrating animals into a smaller area for short periods of time, plant preference and selectivity will decrease as animals compete for the available forage. Increasing stock density will also increase hoof action and incorporation of the fine fuels into the ground. Spurlock *et al.* [24] stated that high stocking rates with little supplementation forces goats to graze even less palatable species and plant parts and resulting in the eradication of many shrubs in 2-3 years. Lindler [11] suggests that a stocking rate of 37 goats per hectare in a California pine forest is required to effectively treat understory brush.

Stoking rate	Forage type		
	Browse	Grass	Forbs
Light	16	55	28
Heavy	55	39	5

Table 2. Sheep diet consumption in Texas varied with stocking rate [25].

Grazing intensity	Bare soil	Vegetation cover (%)	Litter
Light	+6	-22	+25
Moderate	+4	-28	+20
Heavy	+4	-30	+23

Table 3. Results with sagebrush/grass pastures grazed at different intensities by sheep in northern Nevada [8].

Hadar [16] reported that light grazing provided greater plant diversity on treated sites. Thus, when proposing a stocking rate for treatment consumption, the environmental impact needs to be considered.

5. Nutritional and anti-nutritional factors

Low nutritional value and the presence of secondary compounds, such as tannins, in many California chaparral species are limiting factors for their use as forage by animals grazing this type of vegetation, especially during summer and fall [23]. The most abundant California chaparral species had low crude protein content (< 8%) and low digestibility especially in the summer and fall. This would include: *Adenostoma fasciculatum* (chamise), *Arctostaphylos canescens* (hoary manzanita), *Arctostaphylos glandulosa* (Eastwood manzanita), *Arctostaphylos stanfordiana* (Stanford manzanita), *Baccharis pitularis* (coyote brush), *Ceanothus cuneatus* (buck brush), *Eriodictyon californicum* (yerba santa), *Quercus durata* (leather oak), *Heteromeles arbutifola* (toyon), *Quercus douglasii* (blue oak), and *Quercus wislizenii* (interior live oak). Chaparral plants with the highest crude protein from leaf and stem samples included: *Baccharis pitularis* (coyote brush), *Ceanothus cuneatus* (buck brush), and *Eriodictyon californicum* (yerba santa) [23].

Ruminant diets with crude protein below 7-8% reduce feed intake because it does not provide the minimum rumen ammonia concentration for microbial growth. Nutritional supplementation would be needed for optimum performance in small ruminants used to reduce fuel loads in California chaparral. California chaparral had high fiber (neutral detergent fiber, NDF and acid detergent fiber, ADF) in most shrubs. *Baccharis pitularis* (coyote brush) and *Eriodictyon californicum* (yerba santa) had the lowest fiber concentrations. Organic matter digestibility and metabolizable energy were higher during spring plant growth for all species tested [23]. Taylor found that cottonseed meal and alfalfa supplements increased redberry juniper consumption by 40% [26].

Over time plants have developed mechanisms to limit or prohibit herbivory. Launchbaugh *et al*. [27] summarized this plant-animal interaction as follows: plants possess a wide variety of compounds and growth forms that are termed "anti-quality" factors because they reduce forage's digestible nutrients and energy or yield a toxic effect that deter grazing. Secondary compounds (e.g. tannins, alkaloids, oxalates, terpenes) can control the plant-animal interactions that drive intake and selection.

California chaparral plants with the highest total condensed tannins include: *Arctostaphylos canescens* (hoary manzanita), *Arctostaphylos glandulosa* (Eastwood manzanita), *Arctostaphylos stanfordiana* (Stanford manzanita), *Ceanothus cuneatus* (buck brush), and *Quercus douglasii* (blue oak). Narvaez [23] showed that condensed tannins concentrations in California chaparral shrubs might negatively impact ruminant feed utilization in addition to the impact of protein binding.

Forage intake and digestibility of two common chaparral shrubs, *Adenostoma fasciculatum* (chamise) and *Quercus douglasii* (blue oak), as a sole diet were low and did not meet the nutritional requirements for sheep and goats grazing in this type of vegetation [23]. Greater understanding of nutrition of chaparral shrubs being grazed in prescribed herbivory and monitoring of animal condition are needed to know when and what to use for strategic supplementation or replace thin animals with those in better condition.

Animals may expel toxic plant material quickly after ingestion, secrete substances in the mouth or gut to render the compounds inert, or rely on the rumen microbes or the body to detoxify them. The grazing practitioner can address plant toxins in different ways. A species of livestock can be selected that can detoxify compounds or have a smaller mouth that allows them to eat around thorns. Nutritional or pharmaceutical products can be offered to aid in digestion and detoxification. Breeding stock can be selected based on an individual animal's tolerance to toxic compounds. Tannins are the most important defense compounds present in browse, shrubs, and legumes forages. Concentrations in woody species vary with environment, season, plant developmental phase, plant physiological age, and plant part. Levels in excess of 50 g/kg DM can reduce palatability, digestibility, voluntary feed intake and digestive enzymatic activity and can be toxic to rumen micro-organisms [28-32]. In some cases, when the plant compound is known, methods of interceding can be used. Polyethylene glycol (PEG) is a polymer that binds tannins irreversibly, reducing the negative effects of tannins on food intake, digestibility, and preferences [33]. Polyethelyne glycol was used in California to overcome the protein binding of tannins and make protein and energy more available to sheep and goats. Supplementation with PEG significantly increased consumption of *Arctostaphylos. canescens* (hoary manzanita) by small ruminants [23]. Appropriate nutritional and non-nutritional supplementation may help develop prescribed herbivory into a viable fire fuel management strategy for California and other areas with chaparral plant communities. More nutritional analysis of shrubs and increased understanding of the impact of associated plant secondary compounds on consumption and utilization by ruminants are needed.

For oxalates, calcium supplementation has shown to ameliorate the diet suppression. Launchbaugh [27] suggested that supplementation of protein, phosphorous, sulfur, and energy can also make a difference in intake of plant material containing secondary compounds. They even postulate that clay could be used to detoxify compounds.

6. Integrating grazing into the ecosystem

It is important to recognize the different viewpoints people will have on using grazing for vegetation management purposes. These viewpoints can affect the way grazing is applied, the long-term success of grazing for controlling wildfire fuels and the cost of using grazing. If grazing is viewed and used as another tool or method to be applied as other vegetation control methods (i.e. mechanical and chemical methods), the success may be limited and the cost of grazing may be greater than necessary. An alternative is a systems approach in which grazing is integrated as part of the ecosystem so that the system is both benefited by and benefits grazing.

Under a systems approach grazing becomes a more regular disturbance pattern that encourages growth of herbaceous vegetation and the smaller diameter fuels that are more nutritious and readily consumed by herbivores. These fuel classes are important as they can greatly impact the rate of spread of a fire along with the flame height. When grazing is used infrequently, as it often is when viewed in the same context as other single event fuel treatments, the vegetation will likely consist of older vegetation of poor nutrition that is more costly to graze due to the higher physiological cost to the animal and higher labor inputs for managing portable fencing. A regular grazing regime will create improved nutrition by providing smaller re-growth of higher nutrition vegetation allowing animal performance to improve while maintaining a desirable fuel profile. Weber *et al*. [34] found compelling evidence that regular livestock grazing on public land grazing allotments between the years 1993 and 2000 effectively maintained a lower fuel profile and reduced the risk of wildfires.

Figure 3. Goats grazing a treated ridge following other land treatments.

Another aspect of a systems approach to managing wildfire fuels with grazing is to strategically use grazing in combination with other methods of vegetation management. Weber *et al*. [34] found that wildfire and grazing alone reduced mean fuel loads 38% and 47% respectively compared to control treatments. When the effects of wildfire and grazing were combined fuel loads were reduced 53%. Integrating fire and grazing in a strategic manner can provide conservation benefits and increase livestock performance. In an 11-year study pyric-herbivory, or patch burning, was applied to tallgrass and mixed-grass prairie in the United States to re-introduce more natural fire regimes and improve wildlife habitat [35]. Livestock performance was not affected by the use of pyric-herbivory on the tallgrass prairie (8 years) while on the mixed-grass prairie stocker cattle had greater weight gains and more consistent performance over the 11-year period [35]. Another successful combination of vegetation management methods that is often employed in areas with larger diameter woody fuels is to initially use mechanical treatments to reduce the woody biomass and then apply grazing to maintain a shorter and more herbaceous vegetation structure. The combination of vegetation control methods in managing wildfire fuels is consistent with the Integrated Pest Management (IPM) strategies commonly and successfully used in agricultural pest management systems.

Grazing is best used when addressing the smaller diameter vegetation that make up the 1 and 10-hour fuels. These two fuel classes are important as they can greatly impact the rate of spread of a fire along with the flame height. Many fire managers have looked at grazing in the same context as other single event mechanical fuel treatments. These grazing treatments have been expensive to implement as they have a physiological cost to the animal and higher costs of portable fencing to reach fuel objectives in one year. Perhaps a sustainable use of grazing would be annual grazing of large areas following mechanical treatment. This will provide improved nutrition by providing smaller regrowth that is higher in nutrition allowing animal performance to improve while maintaining a specific fuel profile.

7. Practical considerations

Grazing animals can effectively distinguish between plants that differ in digestible energy or nutrients. The animal's consumption is driven by their physiological state. Non-lactating animals have much lower nutrient requirements than lactating females or growing weaned animals and can consume a wider array of plants to meet their nutritional needs. Animals can be forced to eat below their nutritional needs and they will balance their needs by catabolizing body fat and protein. The animal can tolerate short-term energy or protein deficits, but sustained periods at this status can be reason for concern. For this reason lactating and young growing animals may not be recommended for fuel control. Growing animals can be used to consume new shrub growth in a shrub grazing system designed to maintain the fuel profile.

Because of the complexity of plant and animal interactions, a project evaluation should be developed considering measurable and attainable objectives before grazing is used. It should include a review of treatment objectives, desired outcomes, and environmental impacts. This will dictate the kind of animal needed, grazing intensity, timing of the grazing event, and duration of the grazing period. Variation in animal-plant interaction is driven by forage type, grazing season, yearly season variation, animal interaction with the grazing system (animal density and competition), previous grazing experience, mixture of grazing animals, and pre-grazing treatment (integrated approach). The treatment and resulting outcomes are not conveniently predicted and may require adaptive onsite management. Treatment standards include stubble height for grass, percent vegetation cover by shrubs, plant mortality, or removal of 1 and 10-hour fuel and fuel bed depth.

Any grazing plan designed for fuel reduction will need to review the grazing impacts on parameters other than just fuel reduction. The effects of the grazing management should be studied for its impact on water quality, soil compaction, riparian vegetation, disease exposure from wildlife (bluetongue, pasturella) and weed transmission. The positive aspects of grazing over other treatments should also be weighed, including the recycling of nutrients into the products of food and fiber.

The grazing contractor will use, in most cases, portable electric polywire or netting to contain small ruminants in an area. A low-impedance solar-powered energizer with adequate grounding will power the electric fence material. Predators will be a concern for small ruminant safety and will require use of a guardian animal for protection. Guardian dogs are the preferred choice in most remote areas. Herders may be needed on large contracts. Mineral supplementation will be necessary to keep animals productive and healthy. Protein supplements may be needed in fall and summer. Lack of available stock water will require a way to haul water to meet daily requirements. In hot weather, water intake of small ruminants can approach two gallons per head per day. A truck and trailer will be needed to haul animals and a herding dog will most likely be needed for moving stock. Adequate general liability and automobile insurance will be required in bids and must be maintained by the contractor. Livestock and full mortality insurance should be considered. Third party firefighting and fire suppression expense liability should be considered if doing many fuel load reduction or firebreak contract.

The social aspect is often an important and overlooked part of prescribed herbivory in contract grazing situations. Grazing contractors will benefit by taking the time to engage the general public in explaining and answering questions regarding grazing and animal husbandry. Suburban and urban residents commonly question concerns about perceived loss of wildlife habitat or landscape view, guardian animals and animal welfare when new grazing projects are implemented adjacent to populated areas. These topics need to be addressed in a calm, rational manner. Timely corrective response to any issues such as livestock escaping fences will be important.

Current and historical perceptions by the public of grazing will influence acceptance and understanding of grazing treatments for fuel control. It is important for grazing contractors to have well defined contracts and consider public education as one of their roles, especially with contracts near residential areas. Consumptive use, such as grazing, may not be compatible with recreation land use in some areas. A survey by Smith *et al*. [8] indicated that 90% of residents near a fuel break stated that sheep were a preferred alternative for fuel reduction. Only 10% felt that they were inconvenienced by the treatment. Some responses indicated the ignorance of many residents to grazing and grazing management, such as concerns of electrocution of animals and humans by the electric fence. This condition will need to be addressed when making grazing proposals with an understood that public education will be a necessary part of the process.

8. Conclusion

The modification of wildfire fuels is an important issue in many regions of the world. The use of grazing animals for fuel management has a limited research knowledge base to direct the timing and intensity to reach the fuel management objectives in comparison to other methods. Also seasonal variation of nutrition content and secondary compounds of shrubs need to be further defined. Most of the grazing fuel modification study work has been conducted with goats, due to their preference for targeted plant species. Grazing animals can modify wildfire fuels through consumption and trampling. Animals are most effective at treating smaller diameter live fuels and 1and 10-hour dead fuels. These fuels are important components of fire behavior by providing the flammable material that creates a ladder of fuel for a fire to extend up from the ground into the shrub and tree canopy. Science-based research on the use of grazing to achieve fuel management objectives exists, but is very limited and many studies only had a single-year grazing treatment. In a grass ecosystem this may be effective if timed correctly, but shrub vegetation often require grazing treatments over multiple years to create and maintain a fuel profile that is more desirable.

There are many issues that need to be considered as part of grazing for fuel reduction. Grazing has a more varied outcome than the mechanical fuel reduction treatments. Until grazing is viewed in a systems approach in which the numerous factors that affect grazing effectiveness are considered, the dominant management will be to force utilization by limiting nutrition and or preference. The understanding of animal preference and the proper timing and livestock management required to meet the objective are all critical elements in implementing an effective and sustainable grazing program for wildfire fuel management.

Author details

Roger S. Ingram*
University of California Cooperative Extension, Auburn, California, United States

Morgan P. Doran
University of California Cooperative Extension, Fairfield, California, United States

Glenn Nader
University of California Cooperative Extension, Yuba City, California, United States

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* Corresponding Author

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