Interactions among Grazing, Fire, and Invasive Plants in the Sagebrush Steppe Ecosystem

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ABSTRACT

The number of large wild fires has increased in recent decades across the western US, including the sagebrush steppe ecosystem in the Great Basin. This increase in annual area burned has generated much interest in causal factors and management options. There is an urgent need to better understand the effects of historic and current grazing practices on fuels, ignition risk, fire spread, fire behavior, and post-fire effects on soil and plant communities.

Some research suggests that livestock grazing is a powerful tool in fuels management, while others suggest that grazing promotes wildland fire because it promotes invasive annual grasses. The truth lies somewhere between these extremes and requires an analysis that accounts for vegetation community, kind and amount of livestock grazing, and fire weather conditions. Opportunities to reduce burned area with managed livestock grazing exist in areas dominated by herbaceous vegetation

relative to shrubs under low to moderate fire weather conditions. In areas with high shrub cover, livestock grazing is less effective for fuels management, however fall grazing by sheep or goats can reduce shrub biomass. The combined effects of grazing under conditions of moderate fire weather could lead to fires that burn at lower intensity, with increased patchiness, decreased rate of spread, and improved survival of plants after fire. Under severe fire weather, the potential for livestock grazing to affect fire behavior is limited.

Fire and grazing are important factors affecting the establishment and expansion of cheatgrass (Bromus tectorum L.), a flammable, exotic annual grass present throughout the Great Basin. The response of cheatgrass to grazing varies immensely with the timing and intensity of grazing in relation to plant phenology and the level of cheatgrass present. Research results clearly show that grazing can promote or suppress cheatgrass in sagebrush steppe ecosystems depending on how and when it is applied.

INTRODUCTION

The Bureau of Land Management and the U.S. Forest Service report that the annual area burned in wildfires is on a long-term upward trend (Davison 1996; Westerling et al. 2006). Over 3.6 million ha burned in wildfires in both 2006 and 2007, and over 1400 fires burned more than 0.7 million ha across Idaho in 2007 (http://www.nifc.gov). In 2007, the Murphy Wildland Fire Complex alone burned over 243,000 ha of mainly sagebrush steppe in southern Idaho and northern Nevada. Westerling et al. (2006) predict that under the current warming climate trend, a larger proportion of precipitation will come as rain rather than snow, which in turn will lead to an earlier snow melt and a prolonged fire season with larger and more severe fires. The 2007 fire season, and the need for reducing the risk for such extensive fires in sagebrush steppe ecosystems, has focused considerable attention on the effects of historic and current grazing regimes on fire effects, behavior, and fuels.

The grasslands, shrublands, and woodlands that characterize more than half of the landscapes in western North America are maintained and influenced by forces of climate, grazing, and fire. These powerful natural forces are inherently important components of the health and productivity of these ecosystems. The historic fire return interval in big sagebrush steppe habitats ranges from 5-25 years for mountain big sagebrush (*Artemisia tridentata* Nutt. *ssp. vaseyana* (Rydb.) Beetle*;* Miller and Rose 1999) to 50-100 years for Wyoming big sagebrush (*Artemisia tridentata* Nutt. *ssp. wyominensis* Beetle & Young*;* Whisenant 1990). However, human influences during the settlement and development of these lands over the last 150 years brought invasive plants, altered fire regimes, and contributed habitat fragmentation, recreational uses, and inappropriate livestock grazing (Beck and Mitchell 2000; Miller and Eddleman 2001; Bunting et al. 2002; Baker 2006). Increasingly large and severe fires are occurring primarily because of changes in fuel loads and arrangements (Peters and Bunting 1994; Davison 1996). Invasive annual grasses (e.g., cheatgrass) are filling in the interspaces between shrubs, creating a continuous fuel bed, which allows fire to spread across the landscape (Davison 1996).

Of particular interest across the Great Basin is the interaction among livestock grazing, wildfire and invasive annual grasses that influence the function and structure of sagebrush steppe ecosystems. These ecosystems once covered 61 million ha of land in western North America, primarily in the Great Basin and on the Columbia Plateau (Miller and Edelman 2001). Sagebrush steppe has been described as "biologically outstanding" with 296 endemic species (Ricketts 1999; Nachlinger et al. 2001). Information on how to manage pre- and post-fire grazing is needed in light of the fires that occurred in Idaho and throughout the Great Basin and Columbia Plateau in recent years.

Much is known about interactions between grazing, fire, and invasive annual grasses. However, this information is widely scattered in sources of published research stretching from the 1930s to present. Reviews of plant invaders and their effects on fire are available (e.g., Brooks and Pyke 2002), but such reviews lack a comprehensive treatment of rangelands in the Great Basin. Relevant information on the interactions between grazing, fire, and invasive plants are published in journals related to livestock grazing, invasive plants, ecological restoration, and general ecology. This paper provides a comprehensive literature review and scientific synthesis of published research, focusing on two related topics: 1) the potential influence of livestock grazing on fire ignition and spread in different plant communities and under varying fire weather conditions, and 2) how grazing affects the cheatgrass abundance in sagebrush steppe ecosystems.

HISTORIC LIVESTOCK GRAZING PATTERNS INFLUENCED FUEL LOADS IN THE SAGEBRUSH STEPPE

The introduction of domestic livestock to the sagebrush steppe resulted in many changes to these ecosystems. Cattle, sheep, and horses were first introduced to the sagebrush steppe in the 1860s which led to large-scale ranching, and severe overgrazing during the settlement and homesteading eras (Miller and Narayanan 2008). After several decades of heavy stocking and season-long use in the late 1800s and early 1900s, the grass and forb understory was considerably depleted throughout much of the sagebrush steppe (Vale 1974; Burkhardt 1996). By the 1930s, it was estimated that the herbaceous forage and resulting grazing capacity in western North America had decreased 60-90% (Miller and Eddleman 2001). One of the greatest effects of this excessive grazing pressure was the removal of the fine fuels that had previously carried natural wildfires (Burkhardt 1996; Miller and Rose 1999). Heavy grazing pressure resulted in a low number of fires and acres burned. In the 32-year period from 1880 to 1912, a period of particularly high stocking rates and forage utilization, only 44 fires were reported in Great Basin rangelands, which burned only 4,500 ha (Miller and Narayanan 2008).

In the absence of fire, shrublands and woodlands subsequently expanded and the cover of woody plants in these habitat types increased (Miller et al. 1994; Burkhardt 1996; Miller and Eddleman 2001). Livestock grazing also promoted woody plant growth by suppressing competition from herbaceous plants through preferential grazing of grasses and forbs (Miller et al. 1994; Loeser et al. 2007). The increased sagebrush cover and reduced herbaceous understory resulting from grazing also provided safe sites for juniper (*Juniperus* spp.) establishment and sapling growth in sagebrush communities adjacent to juniper woodlands (Miller et al. 1994; Miller and Rose 1999). A decrease in fine herbaceous and fine woody fuels (shrubs) has been reported as juniper species begin to dominate a site (Yanish 2002). A fire history study in western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*) woodland in South-Central Oregon showed that the expansion of western juniper after settlement was chronologically correlated with the introduction of livestock (Miller and Rose 1999).

Another example of long-term grazing effects on woody plant growth was recorded in Washington grasslands on the ponderosa pine (*Pinus ponderosa* C. Lawson) ecotone (Rummell 1951). Two plateaus of similar geologic origin, elevation, climate, and forest habitat types were studied. While one plateau table had never been grazed by livestock, the other had been heavily stocked by livestock during the 40 years preceding the study. Pinegrass (*Calamagrostis rubescens* Buckley) biomass was 3.5 times greater on the ungrazed mesa compared to the grazed mesa, confirming the potential of biomass removal and reduction through grazing. Grassland openings on the grazed mesa were invaded by ponderosa pine, while openings on the ungrazed mesa remained largely free of ponderosa pine. Whereas there were only 85 sapling trees per acre on the ungrazed mesa, there were 3,291 saplings on the grazed mesa. Herbaceous and shrubby understory averaged 35% cover on the ungrazed mesa compared to only 14% on the grazed mesa. The higher vegetative ground cover and litter observed on the ungrazed mesa were thought to have prevented the establishment of tree seedlings (Rummell 1951).

Similar findings were reported when grazed and ungrazed mesas were compared in southern Utah. Both mesas examined in a study by Madany and West (1983) had experienced long fire-free intervals. While changes in vegetation structure resulted in decreased fire frequency on the grazed mesa, the ungrazed mesa retained savanna like conditions despite the absence of fire. In addition to finding increased ponderosa pine densities and reduced herbaceous coverage on the grazed mesa, heavy grazing also led to an increase in gambel oak (*Quercus gambelii* Nutt.) stem density (Madany and West 1983). Individual clones of gambel oak may have been able to more readily establish when the grassy interspaces between oak mottes were disturbed.

Grazing management programs designed to improve native perennial grass communities were first implemented in the 1940s (Stoddart et al. 1975). Managed grazing that included year-long periods of rest, seasonally deferred grazing rotations and reduced stocking rates were widely implemented in the last 50 years (Krueger et al. 2002). With the reduction of stocking rates and increased control over grazing patterns, herbaceous fuel loads generally increased to the point that wildfires became more commonplace and sagebrush and other non-sprouting shrubs were effectively eliminated from many areas (Young and Blank 1995).

GRAZING CAN ALTER PROPORTIONS OF HERBACEOUS AND WOODY PLANTS IN SAGEBRUSH STEPPE COMMUNITIES

It is clear the heavy and poorly timed grazing can reduce the abundance of herbaceous perennial grasses and forbs in sagebrush steppe ecosystems (Vale 1974). However, the effect of light to moderate intensity livestock grazing on sagebrush steppe vegetation is more obscure as it is difficult to discern grazing effects from other biotic effects and abiotic environmental conditions (Miller et al. 1994; Holechek et al. 2006). When grazing is removed from a site, substantial increases in perennial grass cover often result (Robertson 1971) though this is not always the case (West et al. 1984). Clearly, individual and community responses may be greatly influenced by yearly climatic fluctuations, and/or other landscape scale disturbances (West et al. 1984; Miller et al. 1994; Loeser et al. 2007). Further research is needed to discern the effects of light or moderate grazing and grazing exclusion on native perennial herbaceous vegetation in sagebrush steppe ecosystems.

Conflicting evidence exists regarding intensive grazing and its role in the increase of sagebrush density (Beck and Mitchell 2000). Increased densities of sagebrush and rabbitbrush (*Chryosthamnus* spp.) have been attributed to repeated heavy grazing (Peters and Bunting 1994). It has been found that young sagebrush far outnumbered their older counterparts where spring grazing had been consistently heavy (Frischknect and Bleak 1957). Likewise, sagebrush increased in response to spring grazing in a three-tip sagebrush (*Artemisia tripartita* Rydb.) community (Laycock 1967; Bork et al. 1998). In the absence of grazing, increases in sagebrush cover have also been observed. Shrub cover on a site in south-central Idaho increased from 18% in 1950 to 25% in 1975 almost entirely due to increases in cover of big sagebrush between 1957 and 1965 (Anderson and Holte 1981). In this study, increased sagebrush cover can be attributed to succession and adequate rainfall, and it would be difficult to separate the effect of natural succession from the potentially accelerating effect that light/moderate livestock grazing may have on shrub establishment in sagebrush steppe.

Grazing can also reduce sagebrush cover when applied in the fall at sufficient stocking rates (Mosely 1996; Banner and Guttrey 2007). Heavy late fall grazing by sheep decreased sagebrush cover and increased perennial grasses and forbs in a three-tip sagebrush community (Laycock 1967; Bork et al. 1998). Fall grazing with sheep during the time when perennial grasses and forbs are dormant can suppress sagebrush growth and increase herbaceous diversity and productivity (Bork et al. 1998).

MANAGING LIVESTOCK GRAZING PATTERNS TO MODIFY FUEL LOADS

Weather, fuel characteristics, and landscape features, affect fire spread, severity, and intensity (Fig. 1). These factors influence fire behavior across a landscape and they collectively determine the impacts of fire. Livestock grazing only influences factors related to the type and amount of herbaceous fuel including the: (1) amount of herbaceous biomass, (2) relative abundance of herbaceous and woody fuel, (3) live/dead fuel mix and (4) continuity of fuel at a patch and landscape scale (Fig. 1). Fire behavior

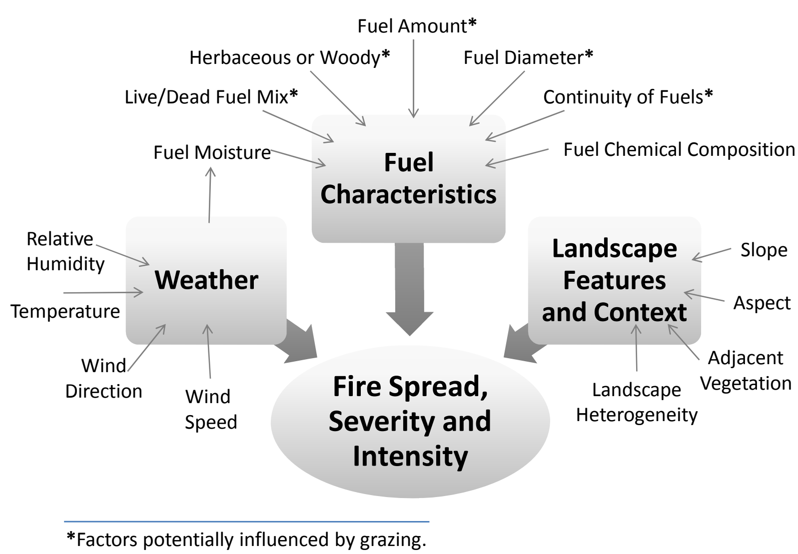


Figure 1. The factors that affect rate of spread, severity, and intensity of wildland fires can be separated into factors related to weather, fuel characteristics, and landscape features and context. The factors that grazing can influence are related to fuel characteristics

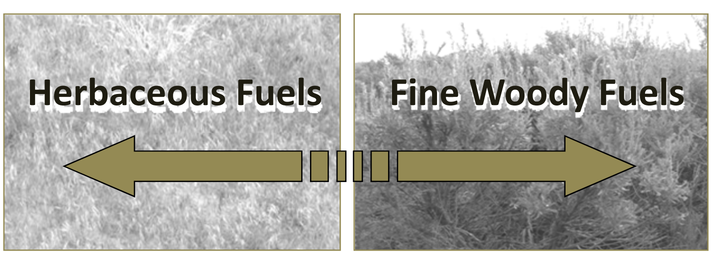
is also determined by weather factors (e.g., daily and seasonal fire weather conditions including temperature, relative humidity and wind), which determine fuel moisture. Landscape features (e.g., degree of slope and aspect) influence how fire moves across landscapes.

Sagebrush steppe vegetation is composed primarily of fine herbaceous grasses and forbs. Shrubs create fine woody fuels (i.e., less than 3 inch stem diameter) which are more difficult to ignite but burn longer and hotter. Fine herbaceous and fine woody fuels contribute different characteristics to fire ignition, behavior, and effects (Fig. 2). Fine herbaceous fuels cure over the summer, and rapidly equilibrate with the ambient relative humidity, and are thus prone to easy ignition in summer and early fall. Fire spreads fast through these fuels usually at low intensity due to the lower amount of biomass per unit area. Fine woody vegetation (e.g., sagebrush) increases flame length and hence fireline intensity. Because the amount of biomass per unit area is higher, such fires burn at higher intensities resulting in more severe fire effects. Woody fuels, such as sagebrush, also contain volatile oils and terpenes that can create highly flammable fuel loads contributing to the flame lengths and fire spread (Buttkus and Bose 1977), and fire effects.

Fuel management objectives in grassland and shrubland systems aimed at reducing flame lengths and fire spread could be accomplished by altering the fuel bed depth, fine fuel loading, cover and continuity such that the flame length never reaches four feet (Nader et al. 2007). Livestock grazing primarily impacts small diameter fuels (< 0.2 inch diameter) including grass and small woody stems that equilibrate with the ambient humidity and temperature within 1 hour (i.e., the 1 h time lag or 1-htl fuels). Livestock can also impact larger fuels (0.25 inch) diameter or 10-htl fuels) through browsing and trampling (Davison 1996; Nader et al. 2007). Hence grazing could be a useful management tool for reduction of grass and shrub biomass (1-htl and 10-htl fuels).

Grazing Affects Herbaceous Biomass and Fuel Loads

It is well documented that livestock grazing can reduce biomass within a growing season (Rummell 1951; Vale 1974; Zimmerman and Neuenschwander 1984; Eckert and Spencer 1986; Eckert and Spencer 1987; Tausch et al. 1994b; Davison 1996; Belsky and Blumenthal 1997; Beck and Mitchell 2000; Blackmore and Vitousek 2000). Although there are few quantitative studies of grazing effects on herbaceous biomass in sagebrush steppe ecosystems, we may be able to draw parallels with effects in other vegetation types. Grazing reduced fine fuel loads and fire frequency in ponderosa pine forests (Rummell 1951; Madany and West 1983; Belsky and Blumenthal 1997). On the island of Hawaii, grazing successfully



- Required for ignition
- Equilibrates quickly to ambient relative humidity & temperature
- Rapid fire spread
- Low fire intensity & severity

- Act as ladder fuel
- Higher flame lengths
- High intensity
- High burn severity
- Smoldering

Figure 2. The fuels of sagebrush steppe ecosystems can be categorized and described as herbaceous (i.e., grasses and forbs) and fine woody fuels (i.e., < 7.6 cm (3 inch) diameter woody stems). The fuels vary in how they contribute to fire behavior and severity.

reduced biomass with the goal of fuels management (Blackmore and Vitousek 2000). The herbaceous biomass primarily comprised introduced grasses kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) and fountain grass (*Pennisetum setaceum* (Forssk.) Chiov.). In grazed areas, the biomass of kikuyugrass was reduced from 7,701 to 2,290 kg/ha. Grazing is now considered an essential link in the control of fire risk (Blackmore and Vitousek 2000). Reduction in fine fuels by grazing was also recorded in the Douglas-fir/ninebark (*Pseudotsuga menziesii* (Forssk.) Chiov. */Physocarpus malvaceus* (Greene) Kuntze) forest association where the total live herbaceous fine fuels was estimated to 720 kg/ha in ungrazed areas compared to 467 kg/ha in grazed areas (Zimmerman and Neuenschwander 1984). Zimmerman and Neuenschwander (1984) concluded that livestock grazing reduced the fire ignition potential and spread by removing understory vegetation and accelerating litter decay through trampling. A consequence was however, that bunchgrasses were replaced by non-palatable, more flammable herbaceous species following repeated heavy grazing. Livestock grazing increased duff accumulations and did not accelerate decomposition, which contributed to smoldering fires once ignited. This could lead to less frequent fires that burned with increased intensity resulting in more severe fire effects, when they occur in Douglas fir/ninebark communities.

The specific season and timing of grazing is important in determining herbaceous biomass levels. Grazing with the goal of reducing herbaceous fuel loads is generally more effective if it takes place right before the season of greatest fire risk, which generally coincides with peak biomass and the initiation of dormancy (Taylor 2006). If grazing occurs early in the growing season, grasses can regrow and biomass can be reestablished to levels similar to ungrazed areas (Anderson and Frank 2003). Grazing or mowing which occurs later in the season, after plants have initiated seed formation and reached peak biomass, can reduce biomass below levels of ungrazed plants and paddocks (Miller et al. 1990; Anderson and Frank 2003). Grazing late in the growing season can remove live and dormant forage thereby reducing the residual biomass left on the site and reducing the fire hazard the following spring and summer (Launchbaugh et al. 2008). And furthermore, grazing this late in the season has lower impact on plant vigor and survival than when it occurs before floral initiation (Hendrickson and Olson 2006).

Grazing Affects Continuity of Fuels

Besides reducing the amount of fine fuel biomass, grazing can also create fuel load heterogeneity across a landscape and thereby decrease the risk of large wildfires (Fuhlendorf and Engle 2001; Kerby et al. 2006). Sheep or cattle might preferentially graze certain habitats while avoiding others. At landscape scales this depends on stocking rate, animal husbandry practices, and the resulting livestock use patterns. Fire modeling in the tallgrass prairie of Kansas revealed that fires are smaller and have more complex shapes in heterogeneous landscapes with a variety of vegetation types and biomass attributes (Kerby et al. 2006). Alternatively, grazing management practices aimed at creating spatially uniform patterns of biomass and utilization may reduce vegetation heterogeneity and increase the risk or extent of fires (Fuhlendorf and Engle 2001). Although heavy grazing has been attributed to reducing biomass and fine fuel loads, light grazing can produce patchy burn patterns in continuous fuels (Bunting et al. 1987). Light grazing can remove sufficient fuel as well as break up fuel continuity to significantly reduce fire spread (Bunting et al. 1987). Patchy burn patterns are particularly important in sagebrush steppe regions where maintenance of sagebrush cover (e.g., for wildlife habitat) is a management objective. Patchy burns leave islands of unburned sagebrush, thereby creating a seed source for reestablishment of sagebrush plants across the steppe (Colket 2003).

OPPORTUNITIES FOR GRAZING IN FUEL MANAGEMENT DEPENDS ON WEATHER AND VEGETATION COMPOSITION

Grazing can be a powerful tool to reduce fine fuel loads and thereby the rate of spread and final extent of fires, and ultimately fire frequency, in sagebrush steppe. However the level to which grazing affects fire spread is dependent on a number of physical and environmental conditions such as ambient temperature, wind speed, humidity, fuel composition, fine-scale continuity (tuft-scale), spatial distribution and topography (Fig. 1). One way to explore the role grazing might play in modifying fuel characteristics and affect fire behavior is to identify thresholds in fuel load, fuel moisture, and weather conditions for when fire will no longer ignite or spread.

Fuel loading and fuel moisture directly affect the fire behavior and consumption rates in sagebrush ecosystems under most environmental conditions. In the absence of sagebrush cover, if the fine fuel loading is less than 560 - 650 kg/ha, fires will sustain only at extreme environmental conditions (less than 15% relative humidity, temperatures exceeding 29°C, dead fuel moisture less than 12%, and wind speeds greater than 16 km/h; Bunting et al. 1987; Clark et al. 1984; Launchbaugh et al. 2008). However, when the fine fuel loading is above 1682 kg/ha, fire will spread under a wide array of environmental conditions (Bunting et al. 1987). With these estimates, livestock grazing could remove sufficient fine fuel to reduce the risk for fire ignition and spread throughout most of the year. Consequently, areas that are selected for a prescription fire, should not be grazed the season before the planned fire to allow for fine fuel accumulation (Bunting et al 1987).

In sagebrush steppe the shrub component adds vertical structure to an understory of herbaceous forbs and grasses. Brown (1982) suggested that at 20% sagebrush cover, a cured fine fuel load of at least 336 kg/ha would be required to sustain a fire with a 16 km/h wind. Areas with greater sagebrush cover may burn at lower fine fuel loads. Lower fuel moistures, typical in the fall, increase the rate of spread, flame lengths and fire intensity when compared with spring burns (Sapsis and Kauffmann 1991). Consumption rate of 10-htl and 100-htl woody fuel also increases with lower fuel moisture content (Sapsis and Kauffmann 1991). In addition to fuel moisture and weather, topography also affects fire behavior such that at 30% slope the fire rate of spread is 2-3 times greater than a flat area while at 50% slope the rate of spread increases 4-7 times (Brown 1982). Therefore, from the above studies one can conclude that herbaceous loading, sagebrush loading, and environmental conditions are important in predicting fire behavior as well as post-fire effects.

Reducing levels of fine fuels, as could be accomplished with livestock grazing, reduced the modeled surface rate of spread and fire line intensity in a simulated shrub and grassland communities (Launchbaugh et al. 2008). However, the effects of reduced fuel load on fire behavior were more pronounced at low wind speeds and high fuel moisture. When burning conditions became extreme, changes in live herbaceous fuel load and amount of dead herbaceous fuels (1-htl fuel classes) had little effect on fire behavior variables. Under less-extreme fire weather conditions, reductions in herbaceous fuels resulting from livestock grazing will influence fire behavior, making a fire in these shrub and grassland plant communities easier to contain.

The main factors driving fire behavior and effects in sagebrush steppe are fuel characteristics and fire weather (Fig. 3). Grazing has the highest potential to affect fire spread and intensity in areas dominated by herbaceous fuels with low sagebrush cover under low to moderate weather severity, (i.e., conditions represented in the upper left region of Fig. 3). In sagebrush dominated communities, livestock grazing has a reduced opportunity to affect fuels and fire behavior unless grazing is targeted at reducing the height and cover of sagebrush and other shrubs. Grazing by cattle is generally focused on grasses and other herbaceous forage, therefore cattle grazing would have limited potential to alter fire behavior that is driven primarily by sagebrush cover (i.e., conditions represented in the lower left region of Fig. 3). However, under moist and cool conditions (i.e., low and moderate fire weather severity), grazing can influence fires that move through sagebrush communities by influencing the movement of fire along the herbaceous understory between shrubs. Targeted grazing, using animals that browse sagebrush during a season when the grass is dormant (e.g., fall grazing with sheep or goats), could contribute to reduction in sagebrush fuels. The opportunity for grazing to influence fire behavior in a range of grassland and shrubland communities depends on factors including fuel continuity and topography. Under extreme weather conditions, characterized by low fuel moisture and relative humidity, and high temperature and wind speed, wildland fires are driven more by weather conditions than by fuel characteristics. Therefore, as fire weather conditions become extreme, the potential role of grazing on fire behavior is limited (e.g., conditions represented on the right side of Fig. 3).

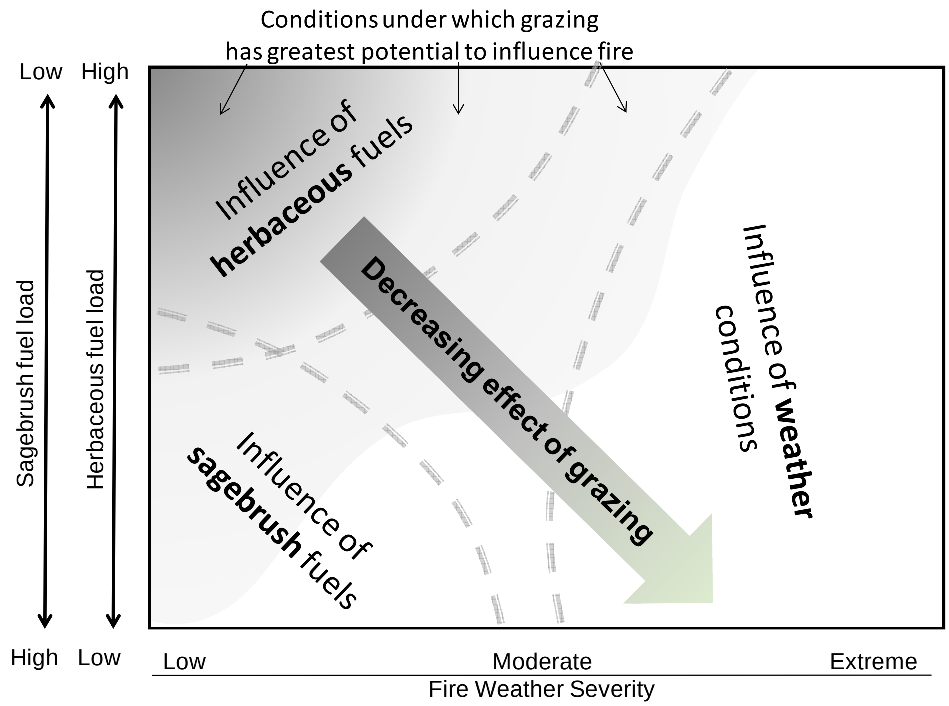


Figure 3. The potential for grazing to influence fire behavior occurs along continuums of fuel and weather conditions. In this conceptual model, fuel composition is displayed on the y-axis and severity in fire weather is displayed on the x-axis. Low fire weather severity values are characterized by high fuel moistures, high relative humidity, low temperature, and low wind speeds, while high fire severity weather is characterized by the opposite. The potential for grazing to be effective in reducing the risk of fire initiation and spread is largest when the sagebrush cover is low and the fire weather severity is low to moderate.

The impact of climate and extreme climatic events on fire can vary depending on the spatial and temporal scales over which information is collected and analyzed. Climate, topography, and vegetation vary in importance at different spatial scales (Simard 1991). At relatively fine spatial scales, fire ignition and spread are dominated by fuel type, moisture, and continuity of fuels, microclimate, and microtopography (Rothermel 1983). Analysis at the broad scale may provide a regional understanding of fire regimes, fuel patterns, climate variability or change, and anthropogenic disturbance that can be used for broad-scale prioritization.

INTERACTIONS AMONG LIVESTOCK GRAZING AND CHEATGRASS IN THE SAGEBRUSH STEPPE

Cheatgrass is an invasive annual grass introduced to North America in the 18th century, likely as a contaminant in grain seed (Mack 1981). The fine textured, flammable, and early curing cheatgrass has altered the timing and frequency of wildfires in large expanses of sagebrush steppe. Thus, it is inadequate to discuss the effects grazing has on fire patterns in sagebrush steppe ecosystems without including a discussion of how grazing affects cheatgrass abundance. Cheatgrass is a finely divided fuel that is highly flammable when dry and can support rapidly spreading fires (Klemmendson and Smith 1964; Brown 1969; Young and Blank 1995; Link et al. 2006). Cheatgrass provides a dense, continuous fine fuel layer, not created by native bunchgrasses (Davison 1996; Menakis et al. 2003), which allows fires to burn more uniformly leaving less unburned vegetation than in sagebrush communities dominated by bunchgrasses (Young et al. 1987; Whisenanat 1990). Cheatgrass also becomes senescent by early June, which shifts and expands the fire season by nearly two months in sagebrush communities (Hull and Pechanec 1947; Klemmendson and Smith 1964; Young and Blank 1995).

Fire is a natural part of sagebrush ecosystems, but when cheatgrass becomes established in these systems it changes the fuel characteristics and the fire return interval (Stewart and Hull 1949). When a fire occurs in sagebrush steppe after cheatgrass becomes part of the community it only takes a few years (i.e., 3 to 6) to develop a sufficient fuel continuity that would readily support another fire (Peters and Bunting 1994). The abundance of cheatgrass also increases the likelihood of fire ignition and spread (Bunting et al. 1987; Link et al. 2006). For example, in a study examining fire risk associated with cheatgrass and bunchgrass communities in southwest Washington, the fire ignition risk was 100% when the cover of cheatgrass was 45% or more; when cheatgrass cover was 12% or less, fire risk dropped to 46% (Link et al. 2006). Dominance of perennial grasses and native shrubs are generally lost when the fire free interval drops below five years (Peters and Bunting 1994). Frequent burning in the steppe does not allow enough time between fires for the perennial grasses and shrubs to establish and eventually the seedbank becomes depleted of perennial seeds, permanently altering the steppe vegetation (Knapp 1996).

Reducing the biomass of cheatgrass on a site can alter fire behavior. Call et al. (2007) found that 80-90% utilization in early-May and again in mid-May significantly reduced cheatgrass biomass and cover, resulting in reduced flame lengths in mid-October prescribed burns from 2.3 to 0.2 m. Similarly, fire behavior models run to examine the effect of reducing levels of cheatgrass fuels, as might be accomplished by grazing, on fire behavior in simulated shrub and grassland communities revealed a reduced surface rate of spread and fire line intensity (Launchbaugh et al. 2008).

Cheatgrass production is highly variable and related to yearly rainfall patterns (Young et al. 1987). One study in southern Idaho showed that cheatgrass biomass varied 10-fold depending on annual precipitation; from 404 to 3879 kg/ha in a dry compared to a wet year (Hull and Pechanec 1947). Furthermore, cheatgrass responds more rapidly to precipitation during a drought than do perennial grasses (Menakis et al. 2003). Cheatgrass can gain a competitive advantage over native perennial grasses in the Great Basin because it grows early in the spring at lower temperatures and can capitalize on moisture that comes in the winter and early spring (Stewart and Hull 1949; Knapp 1996; Pellant 1996). Cheatgrass maintains a competitive advantage over native plants only when moisture is consistently available during fall, winter and early spring (Bradford and Lauenroth 2006).

Grazing Affects Cheatgrass Abundance

Many studies show that grazing can hasten cheatgrass invasion, and lead to increased abundance of cheatgrass in sagebrush steppe ecosystems. Heavy grazing can suppress competition from native plants and cause soil disturbance that can favor cheatgrass (Pickford 1932; Daubenmire 1940; Mack 1981; D'Antonio and Vitousek 1992; Knapp 1996; Loeser et al. 2007). Cheatgrass density increased in heavily grazed experimental plots in Utah rangelands (Pickford 1932). The magnitude that cheatgrass cover increased varied from 15% to nearly 100% depending on the initial density of cheatgrass, specific site conditions, and grazing attributes (Pickford 1932). On areas where cheatgrass already dominated, burning and heavy grazing that depleted perennial grass competition by 85% allowed cheatgrass cover to nearly double (Pickford 1932).

Other studies show that cheatgrass can be suppressed by livestock grazing (Daubenmire 1940; Vallentine and Stevens 1994; Mosley 1996; Mosley and Roselle 2006; Loeser et al. 2007). In southeastern Washington, heavy sheep grazing pressure eliminated cheatgrass from a site within a few years though bunchgrass densities were also reduced (Daubenmire 1940). Daubenmire (1940) further documented that cheatgrass will rapidly reenter an area if spring grazing is reduced or eliminated. This may occur because cheatgrass seed can be viable in the soil for up to 5 years (Young et al. 1969).

Cheatgrass invasion has been correlated with heavy season-long grazing (Knapp 1996), however, the opposite – exclusion from grazing – apparently does not protect lands from cheatgrass invasion (Daubenmire 1940; Tisdale et al. 1965). While initial invasion of cheatgrass is often connected with some disturbance that exposes the soil, such as grazing or fire (Klemmendson and Smith 1964; D'Antonio and Vitousek 1992), cheatgrass persists after it becomes established (Knapp 1996). Courtois et al. (2004) reported few changes in species composition, cover, density or production inside and outside exclosures after 65 years and the absence of grazing did not prevent cheatgrass invasion. A vegetative comparison of a grazed and ungrazed canyon in Utah showed that cheatgrass was 1.5 times more frequent at the ungrazed than the grazed canyon (Cottam and Evans 1945). An assessment of a 73-ha kipuka (an area of older vegetated landscape surrounded by more recent lava flows) in Southern Idaho revealed that, though the area had never been grazed by domestic livestock, cheatgrass was able to invade and gain dominance. Anoha Island, an island in Pyramid Lake Nevada, represents a second example of an ungrazed and nearly undisturbed site that has experienced invasion by annual brome grasses including cheatgrass and red brome (*Bromus rubens* L.; Svejcar and Tausch 1991). The investigators that examined Anoha Island noted that the annual grasses were more abundant on the island than on the nearby mainland grazed by livestock and native ungulates (Svejcar and Tausch 1991).

Role of Precipitation Patterns and Season of Grazing

The impact of grazing on cheatgrass is highly variable and site specific, which gives rise to research and field observations that implicate grazing in the spread and abundance of cheatgrass while others suggest grazing suppresses cheatgrass. Two important factors contribute to these conflicting results: precipitation patterns and season of grazing.

Timing and amount of precipitation are immensely important factors in determining the reaction that cheatgrass exhibits in response to grazing (Young et al 1987). Because cheatgrass responds quickly to early season rains, grazed cheatgrass plants may even outperform ungrazed plants if moisture is available following spring grazing (Vallentine and Stevens 1994; Roselle 2007). In some cases, grazing appears to have less of an effect on cheatgrass abundance than do variations in climate and elevation (Stohlgren et al. 1999). At higher elevations cheatgrass can have low establishment, biomass, and seed production resulting from colder and shorter growing season (Chambers et al. 2007). Thus, invasibility of cheatgrass varies across elevation gradients and appears to be closely related to temperature at higher elevations and soil water availability at lower elevations (Chambers et al. 2007).

A study in a high-elevation, semiarid grassland in Arizona conducted by Loeser and colleagues (2007) demonstrated that grazing effects on cheatgrass are strongly tied to weather patterns. In this study, pastures subjected to high impact cattle grazing had similar levels of cheatgrass as ungrazed sites until a drought year occurred. In the two years after the drought year, the high-impact grazing treatment resulted in an 80% increase of cheatgrass cover and a frequency of occurrence of nearly 100% compared to about 40% on ungrazed sites (Loeser et al. 2007). The season of grazing was not specified in this study so we cannot infer interactions among season of grazing, precipitation patterns, and cheatgrass abundance. However, in this study high-impact grazing in combination with drought shifted the dominant vegetation type from native species to annual types, especially cheatgrass (Loeser et al. 2007).

Research results and practical experience confirm that response of cheatgrass to grazing varies tremendously depending on when grazing occurs (Fig. 4). Early spring grazing of cheatgrass can reduce cheatgrass density while sparing perennial vegetation because cheatgrass begins growing and matures before most native perennials in the Great Basin (Young and Allen 1997). Cheatgrass generally does not emerge any later than late May in the sagebrush steppe region (Mack and Pyke 1983). Early and late spring clipping that simulated grazing, reduced the biomass of cheatgrass compared to an unclipped control, though density of cheatgrass was unaffected (Tausch et al.1994b). Another similar clipping study found decreased cheatgrass seed density when cheatgrass plants were clipped in the boot stage and then clipped again two weeks later when plants were in the pre-boot to post-boot stages (Hempy-Mayer and Pyke 2008).

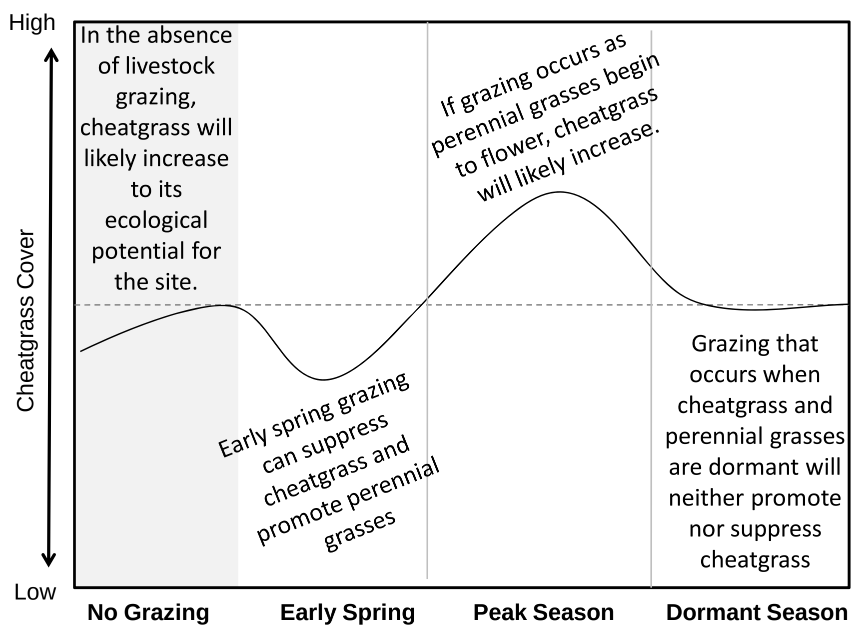


Figure 4. Conceptual depiction of how livestock grazing can influence cheatgrass abundance in a sagebrush steppe ecosystem with a significant component of perennial grasses. Grazing can suppress or promote cheatgrass depending primarily on the season of grazing.

There appears to be a window of opportunity for grazing when cheatgrass is still green, before the seeds reach the dough stage, and before native perennial grasses initiate bolting throughout much of the sagebrush steppe (Vallentine and Stevens 1994; Mosley and Roselle 2006; Fig. 4). Cheatgrass dominance may be augmented in such grazing scenarios where perennial plants are grazed preferentially to cheatgrass or at times when the perennial grasses are sensitive to damage by grazing (i.e., from bolting through seed-set; Pyke 1986; Melgoza et al. 1990). If bunchgrasses are grazed during their period of active growth, the competitive advantage will be shifted toward cheatgrass (Daubenmire 1940; Young et al. 1987; Fig. 4). Fall grazing has minimal impact on both perennial and annual grasses. Thus, the specific composition of cheatgrass and perennial bunchgrass in an area can influence grazing impacts and how that region is best managed in terms of grazing.

Targeted Grazing to Reduce Cheatgrass Abundance

Well-timed and closely controlled spring grazing can be an effective tool to suppress cheatgrass (Mosley and Roselle 2006). Because cheatgrass begins growing earlier than most native perennials, spring grazing of cheatgrass has potential to suppress cheatgrass versus deferring spring grazing to favor native perennial grasses (Daubenmire 1940; Klemmendson and Smith 1964; Tausch et al. 1994a; Tausch et al. 1994b; Young and Allen 1997). Grazing before the cheatgrass turns purple is essential to reduce seed viability (Mosley 1996). Grazing is most effective in the early boot stage, reducing cheatgrass biomass and density more than other times of defoliation (Finnerty and Klingman 1971; Tausch et al. 1994b). Cheatgrass seed density is also reduced most at this time (Hempy-Mayer and Pyke 2008).

The potential application of heavy spring grazing to control cheatgrass has been disputed, claiming that this is a time when perennial grasses are most susceptible to grazing, reducing perennial vigor and allowing cheatgrass a greater competitive advantage (Laycock 1967; Young et al. 1987; Miller and Eddleman 2001; Loeser et al. 2007). The effectiveness of spring grazing on cheatgrass control without adversely affecting perennial plant vigor appears to be highly dependent on the specific time of grazing, amount of cheatgrass in the stand (Davison 1996) and the occurrence of precipitation after grazing (Valentine and Stevens 1994).

Well-timed grazing pressure at intervals when cheatgrass is palatable and susceptible to grazing may prove effective at decreasing its competitive ability over time (Tausch et al. 1994b; Mosley 1996). On sites dominated by cheatgrass, high grazing intensity, (e.g., 80-90% utilization; Call et al. 2007), must be maintained or cheatgrass will quickly dominate an area (Daubenmire 1940; Klemmendson and Smith 1964; Pyke 1986; Call et al. 2007). Annual use levels between 60%- 70% did not result in long-term damage of cheatgrass dominated stands (Davison 1996). Some studies suggest that intermediate levels of grazing may inhibit cheatgrass dominance (Loeser et al. 2007); however this has not been tested and seems to depend more on the amount of cheatgrass already present on the site.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The legacy of livestock grazing has played an important role in shaping vegetation dynamics in the sagebrush steppe. Heavy grazing in the late 1800s resulted in a dramatic reduction in fine herbaceous fuels and fire frequency, and provided a competitive advantage for, and consequent increase in, woody plants. The implementation of grazing management programs began in the 1940s, and annual exotic grasses introduced as part of Euro-American settlement, began to establish and spread. The combination of reduced grazing pressure and increased cover of flammable exotic annuals, and more recently, a climate induced prolonged fire season, has lead to the current situation where fires are more frequent, and sometimes burn frequently enough to prevent establishment of sagebrush. In areas where woody plants (e.g., juniper) are beginning to dominate the steppe, fire frequency has decreased, allowing woodland development to progress.

There are several ways that contemporary livestock grazing practices can affect the consequences of fires in sagebrush steppe ecosystems. Carefully managed grazing can reduce the amount of fine fuels created by grasses, including cheatgrass, and forbs and small twigs of woody plants. Grazing can reduce the potential for fire ignition and spread by removing understory vegetation, reducing the amount of fuel, and accelerating the decay of litter through trampling. Grazing can further alter the continuity of fuels to slow rates of spread and intensity and create a naturally patchy burn that results in unburned islands of vegetation providing a seed source for re-establishment of plants after the burn. The effects of grazing could result in fires that burn at lower fire-line intensity, increased patchiness, decreased rate of spread, and increase subsequent survival of plants after fire, but the effects depend on the fire weather conditions and the structural composition of the plant community.

Livestock grazing in the early 1900s likely contributed to the ability of annual exotics to establish in the sagebrush steppe. Eliminating grazing will however not reduce cheatgrass in areas where it is present, but will rather allow undisturbed seed production and formation of a continuous, highly flammable fuel bed. Grazing has been shown to suppress cheatgrass if applied early in the season when cheatgrass is still green and perennial grasses are not yet flowering. Specific timing of grazing, the amount of cheatgrass present on the site, and the precipitation after grazing are important factors influencing the effectiveness of grazing for cheatgrass control, while avoiding adverse effects on perennial plants.

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