Chapter 11
Land Uses, Fire, and Invasion: Exotic Annual *Bromus* and Human Dimensions

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Abstract Human land uses are the primary cause of the introduction and spread of exotic annual *Bromus* species. Initial introductions were likely linked to contaminated seeds used by homesteading farmers in the late 1880s and early 1900s. Transportation routes aided their spread. Unrestricted livestock grazing from the 1800s through the mid-1900s reduced native plant competitors leaving large areas vulnerable to *Bromus* dominance. Ecosystems with cooler and moister soils tend to have greater potential to recover from disturbances (resilience) and to be more resistant to *Bromus* invasion and dominance. Warmer and drier ecosystems are less resistant to *Bromus* and are threatened by altered fire regimes which can lead to *Bromus* dominance, impacts to wildlife, and alternative stable states. Native Americans used fire for manipulating plant communities and may have contributed to the early dominance of *Bromus* in portions of California. Fire as a tool is now limited to site

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preparation for revegetation in most ecosystems where *Bromus* is a significant problem. Once *Bromus* dominates, breaking annual grass/fire cycles requires restoring fire-tolerant perennial grasses and forbs, which can compete with *Bromus* and resist its dominance. Current weed management policies often lack regulations to prevent further expansion of *Bromus*. Research is needed on how and where livestock grazing might help increase perennial grass and forb cover and density to create ecosystems that are more resistant to *Bromus*. Also, studies are needed to ascertain the role, if any, of oil and gas development in contributing to the spread of *Bromus*.

Keywords Energy development • Farming • Grazing • Management policies • Wildlife responses

11.1 Introduction

Although human occupation of the western USA began 12,000–30,000 years before present (Henige 1998), degradation of ecosystems by humans was likely minimal and localized (e.g., Anasazi culture; Janssen and Scheffer 2004). Not until Euro-American settlements did human land use begin to reshape ecosystems. Spanish exploration of New Mexico and California began in 1540, but settlements did not occur until 1598 and 1769, respectively. Additional Euro-American settlements associated with the fur industry began to appear in northern California, Oregon, and Washington in the early 1800s. Establishment of the Santa Fe and Oregon Trails in 1821 and 1842, followed by a series of travel routes into California, Utah, and the Northwest, resulted in migration to the West, and initiation of agrarian and mining communities throughout the region (Duffus 1972; Olson 2004). With these settlements came changes in land use from largely nomadic fur trading to ranching, farming, mining, and commerce. Rapid population growth in the twentieth century through present resulted in conversion of many native ecosystems to farmlands or urban and exurban population centers. To support these areas, development of water use, energy extraction, and vast transportation and utility networks became necessary (e.g., Chambers and Wisdom 2009; Smith et al. 2009). In less than a century, these lands have become fragmented and highly altered.

Land uses by humans modify ecosystem resilience to disturbance and resistance to invasion through modifications of abiotic attributes (e.g., nutrient deposition and hydrologic and geomorphic processes) along with biotic attributes (e.g., productivity, species composition, and species interactions) (see Fig. 1.1 in Germnio et al. 2015b; Brooks et al. 2015; Chambers et al. 2014a, 2015). Resilience of native ecosystems varies over environmental gradients and depends largely on soil temperature and moisture regimes and ecosystem productivity. Resistance to invasive species, specifically exotic annual *Bromus* species (*Bromus* hereafter), is a function of (1) suitable climate for establishment and persistence of *Bromus* and (2) interactions with the plant community such as competition for resources, herbivory, etc. (Chambers et al. 2015).

Over the last century and a half, *Bromus* has colonized, established, and become dominant over large expanses of the western USA (USDA NRCS 2014) largely as a function of human modification of lands (Bangert and Huntley 2010). Governmental regulations and policies may promote or constrain degradation. For example, the Mexican General Colonization Acts of 1824 in California and the various USA homestead acts of the late 1800s brought settlements, crops, and livestock into the region. Limited restrictions on use of public land coupled with policies to maximize livestock production during major wars contributed to widespread degradation. The recognition of the degradation, in turn, brought about conservation measures aimed at improving lands (Donahue 1999). Continued interpretations and changes in policy and land uses still shape these lands today.

In this chapter, we discuss the role of land uses and policies regarding land management and the sustainable use of natural resources that may play a role in *Bromus* invasion and potential dominance. We relate these uses and policies to ecosystems' resilience to disturbances and resistance to invasions by *Bromus* (Brooks et al. 2015; Chambers et al. 2015). Fire is a potential natural disturbance in nearly all ecosystems and can shift the resistance of communities to *Bromus* invasion leading to altered fire regimes in several western ecosystems (Germino et al. 2015a). We briefly discuss these changes and then discuss how fire remains a potential vegetation management tool that may assist in restoration and adjustments in fuels for wildfire management, but that carries inherent risks for management of other species in the ecosystem.

Since most of the available research on *Bromus* introductions and their shift in community dominance relative to land uses comes largely from studies on *Bromus tectorum* L. (cheatgrass or downy brome) in the Cold Deserts through the western Wyoming Basin, we focus the majority of our discussion on this species and these regions. The shift in dominance to *Bromus* in California was largely complete before ecologists understood the community associations and the impacts of land uses on vegetation. Therefore, we know less about resilience to disturbance and resistance to *Bromus* in those ecosystems (Bartolome et al. 2007). *Bromus hordeaceus* L. (soft brome or soft chess; syn. *B. mollis*) and *B. diandrus* Roth (ripgut brome; syn. *B. diandrus* ssp. *rigidis* or *B. rigidus*) occur in the moister northern portions of the Mediterranean California region, and *Bromus madritensis* L. (foxtail brome or compact brome; syn. *B. madritensis* ssp. *madritensis*) and *B. rubens* L. (red brome; syn. *B. madritensis* ssp. *rubens*) in arid southern portions of the Mediterranean California region and in the Mojave Basin and Range of the Warm Deserts. *Bromus* invasion and spread in the Wyoming Basin of the Cold Deserts and the Great Plains has been more recent than other regions with fewer studies. *Bromus arvensis* L. (field brome or Japanese brome; syn. *B. japonicus*) tends to replace or co-dominate with *B. tectorum* as the Wyoming Basin grades into the Northwestern Great Plains. We supplement the discussion of *B. tectorum* with information on other species and regions when available.

We conclude with management implications and research needs. In the management section we include some potential policy considerations that may enhance resilience of ecosystems and strengthen resistance to *Bromus* invasions. Research needs are focused on gaining a better understanding of early-warning indicators for effective adaptive management of land uses.

11.2 Fire Regimes and Uses Across Regions

Ecosystems with relatively high productivity and fuel continuity, and with climates conducive to seasons with dry fuel, had more frequent pre-settlement fires and typically evolved more fire-tolerant species (Pausas and Bradstock 2007). In contrast, ecosystems with limited fuel production and continuity tended to have smaller and less frequent fires. Species in these ecosystems evolved in the near absence of fire and were largely fire intolerant (Brooks and Minnich 2006). The relationship of fire frequency to fire-tolerant life forms can be observed along environmental/productivity gradients; resprouting species tend to increase while obligate seeders decrease with increasing productivity (Pausas and Bradstock 2007; Davies et al. 2012).

The annual life form tends to be fire tolerant due to the ability of seeds to escape high fire temperatures after they disperse on or below the soil surface. In both the Mediterranean California region and the Palouse Prairies of Washington and Oregon in the Cold Desert region, where productivity and plant cover was high, native annual plants may have coexisted with perennial grasses or shrubs contributing to a continuous fuel source (Bartolome et al. 2007; Keeley et al. 2012). Keeley et al. (2012) implied that Native American's use of fire in Mediterranean California may have tipped the balance from native perennials toward native annuals making some areas more prone to rapid expansion of exotic annual grasses (*B. hordeaceus*, *B. diandrus*, *B. madritensis*, and *B. rubens*) after their introduction (Keeley et al. 2012).

Before the introduction of exotic annual grasses into the Mojave Basin and Range of the Warm Deserts, the abundance of native annual plants varied yearly depending on winter and summer precipitation (Keeler-Wolf 2007), but did not likely contribute a continuous fuel source. Also, ignition sources were generally infrequent (Brooks 1999). Similarly, the Cold Deserts lacked fuel from annual plants, but perennials provided adequate amounts and continuity of fuel to carry fires in locations with higher annual precipitation (cool and moist communities). In contrast, warm and dry communities lacked adequate fuel amounts and continuity to carry fires (Germino et al. 2015a).

Plant invasions have the potential to alter fuelbed conditions, fire behavior, and fire regimes in a self-perpetuating process referred to as the invasive plant/fire regime cycle or annual grass/fire cycle for areas invaded by *Bromus* (D'Antonio and Vitousek 1992; Brooks et al. 2004). *Bromus tectorum* and *B. rubens* invaded arid and semiarid woody ecosystems of the Cold and Warm Deserts. They increased fine surface vegetation and horizontal fuel continuity and ignitability, and decreased coarse canopy fuels, leading to increased frequency, extent, and seasonal window of fires (Fig. 11.1, Brooks et al. 2006, 2015). The potential for these changes is driven by characteristics of the invaded ecoregion, specifically its resilience

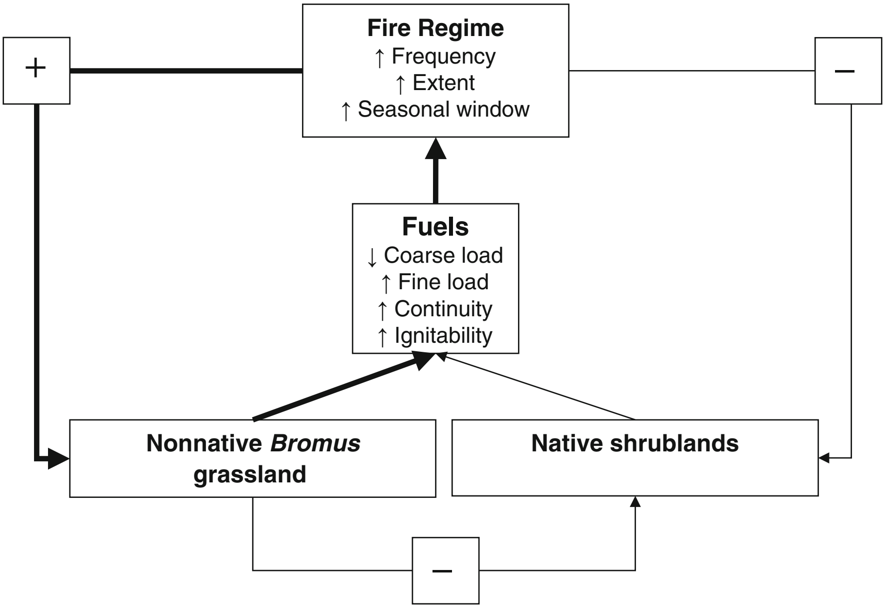


Fig. 11.1 Changes in fuelbed and fire regime properties caused by the invasion of exotic annual *Bromus* species into woody shrubland ecosystems. These new conditions are characterized by a positive feedback between *Bromus* grassland fuels and the altered fire regime, and a negative feedback between native shrubland fuels and the new regime. As successive, short-interval fires occur and fuels type-convert from native shrubland to *Bromus* grassland, the positive feedback becomes more prominent as highlighted by heavier weighting of that feedback loop in the figure (modified from Brooks 2006, Fig. 3.7)

to fire as influenced by the reference communities' fire regime without *Bromus* (Brooks et al. 2015).

Ecoregions with the greatest potential for an annual grass/fire cycle and vegetation type conversion to *Bromus* grasslands are those that experienced limited historical fire and possessed native species with low tolerance to fire, but are not so warm and dry (thermic to mesic and aridic) that resistance to *Bromus* invasion is high (Brooks et al. 2015). These include the more moist ecosystems of the Warm Desert and the more arid ecosystems of the Cold Desert and Mediterranean California ecoregions. Relatively hot and dry conditions in these ecosystems lead to low native plant productivity, growth rates, and fuel loads, and thus infrequent historical fire and low tolerance of native plants to fire.

Ecosystems with the least potential for an annual grass/fire cycle are those that have either high resistance to *Bromus* or high resilience to fire (Brooks et al. 2015). These include the hottest and driest ecosystems of the Warm Desert ecoregion where high temperatures and low precipitation levels exceed the tolerances of *Bromus* species (Fig. 2.2 in Brooks et al. 2015). They also include the cooler and moister ecosystem types of the Western Forest, Northwestern Great Plains, and Mediterranean California ecoregions where low temperature and high precipitation levels exceed *Bromus* tolerances on the cold and wet end of the climate spectrum (Fig. 2.2 in Brooks et al. 2015).

Land uses that reduce ecosystem resistance to *Bromus* and resilience to disturbance may increase the potential for an annual grass/fire cycle and altered fire regimes. A primary mechanism in this process is alteration of the historical reference disturbance regime. Fire regimes may be altered by increasing the amount of fire in space and time, as described above for the grass/fire cycle where land uses have reduced ecosystem resistance to *Bromus*. Alternatively, fire suppression, another form of human land use, reduces the amount of fire and can lead to fuel accumulation and high severity and intensity fires. This alternative is currently playing out in the Western Forest ecoregion (Hurteau et al. 2013). This situation has been greatly facilitated by forest clear-cutting and fire suppression that reduced forest resilience and ultimately led to conditions that favor *Bromus* species (e.g., Fig. 2.15 in Brooks et al. 2015). A consequence has been a twentieth-century loss of foothill pine and blue oak woodland and increased extent of exotic annual grasses (mostly *Bromus* and *Avena* species) in the western foothills of the central Sierra Nevada mountains during the 1900s (Thorne et al. 2008).

Fire, as a land use tool, may increase resistance to *Bromus* in relatively intact systems by enhancing the competitive ability of perennial herbaceous species (Chambers et al. 2014b) although temporary (3–5 years) increases in *Bromus* may occur (Miller et al. 2013). In systems where *Bromus* dominates, this reduction is only temporary, generally only lasting 3 years in the Mediterranean California (Bartolome et al. 2007) and in the Cold Deserts ecoregions (Miller et al. 2013). A fire-induced reduction of *Bromus* may be coupled with revegetation in an integrated weed management and perennial plant restoration project where fire is a site preparation tool for restoration (Monaco et al. 2015).

11.3 Land Uses

11.3.1 Native American Land Uses before Exotic Annual **Bromus** *Introduction*

It is difficult to say what native vegetation in the western USA was like before Euro-American colonization, especially before disease-induced population declines of Native Americans (pre-1500s; Lovell 1992). Paleo-botanical and archeological records provide insights into Native American land uses along with plant and animal dominance before Euro-American influences. The ratio of settled to nomadic lifestyle of each culture depended on climate within their homelands, sources of water, and the availability of seasonal foods and natural resources for subsistence. Wildlife were used by both nomadic and agrarian cultures as primary food sources, and wildlife were suspected to have fluctuated due to Native American hunting (Kay 1994; Hart 2001). Woody plants that were preferred by wildlife, and more sensitive to browsing, were likely reduced when wildlife populations were high and Native American populations were low resulting in plant community compositional changes (Laliberte and Ripple 2003).

The use of agriculture by the Ancient Pueblo (also termed Anasazi) cultures of the southwest began centuries before the current era and ranged from the Arizona/New Mexico Plateau and Colorado Plateau of the Cold Desert region to the Mojave Basin and Range of the Warm Deserts (Hard et al. 1996; Vlaisch 2005; Raish 2013). Areas were cleared of existing vegetation and a variety of methods were used to irrigate crops (Vlaisch 2005). Tree removal for fire wood and building was common and was evidenced by reductions in juniper pollen counts from some locations during increases in human populations (Hevly 1988). Extended and repeated droughts in the twelfth and thirteenth centuries likely contributed to crop failures and eventually to community abandonment by these cultures (Benson et al. 2007). However, many of these people continued to subsist off of these lands.

Many western tribes used fire, provided fuel was adequate, to reduce woody plant dominance and encourage desired food plants, wildlife, or access for farming, transportation, or hunting (Keeley 2002). Evidence for such uses comes primarily from Mediterranean California, northern Cold Deserts, and Great Plains ecoregions (Gruell 1985; Keeley 2002), and not the less productive lands of the southern Cold Deserts or Mojave Basin and Range of the Warm Deserts (Brooks et al. 2013).

This brief review indicates that native Americans likely had significant impacts on ecosystems prior to Euro-American colonization, and may have influenced longer-term ecosystem trajectories including the fire-induced reductions in ecosystem resistance to *Bromus* species mentioned above (Keeley et al. 2012). The difference between Native-American and Euro-American land use, especially at the time of *Bromus* invasion, is that Native-American use tended to be more localized, severe disturbances were smaller in extent, and post-disturbance successional processes, before Euro-Americans, took place in the absence of invasive species like *Bromus*.

11.3.2 Role of Land Uses and Regulatory Policies in Exotic Annual **Bromus** *Colonization and Spread*

A common theme between Native American and Euro-American settlements was their associations with lower elevation lands near perennial water sources that typically had deeper soils and warmer temperatures. This is a global theme of people residing in continental interior locations (Small and Cohen 2004) that continues to shape human land use and impacts in the western USA and that often has negative effects on ecosystem resilience and resistance. These lower elevation lands, especially those farther from perennial water sources, are often warmer and drier locales that are least resilient to disturbances and most vulnerable to *Bromus* invasion (Brooks et al. 2015; Chambers et al. 2015).

Land policies from the 1850s through 1916 yielded a variety of homestead acts that contributed to land degradation through their impacts on the least resilient lands. These acts gave federal lands for settlement and required farming or ranching on a portion of those lands, but restricted the amount of land to 259 ha (640 ac) or less (Donahue 1999). Initially, lands with readily available irrigation water were settled. Later, dryland farming opened new lands for settlement on even warmer and drier, less resilient lands. Within these ecoregions, 259 ha were recognized as largely insufficient to sustain a family since productivity was low (Donahue 1999). Some ranchers were able to get around this restriction by owning lands with water and grazing livestock on adjacent public lands to take advantage of the extended forage base. However, these practices led to degradation of these common lands and set the stage for the introduction and expansion of *Bromus*.

Introductions of *Bromus* into the western states were first recorded during the homestead era (Mack 1981; Salo 2005). *Bromus tectorum* and *B.rubens* were first noted in the northern Cold Deserts and Mediterranean California, respectively, at transfer points along transportation corridors such as sea ports, river depots, and train stations (Mack 1981; Salo 2005). Both species, along with *B. madritensis*, are suspected to have been unintentional contaminants of seed grains for crops (Mack 1981, 1986, 1991; Salo 2005). Less is known about introductions of other *Bromus*, but since they increase with disturbance like their congeners, they may have been crop seed contaminants as well. Seeds of *Bromus* that were contaminants with purchased grain seeds also grew along with the crop and were later harvested and planted on the same or other farms (Mack 2000). As lives became more settled, people began ordering plants through seed catalogs for landscaping, ornamental uses, and erosion control. Several *Bromus* were available from these sources (Mack 1991).

By the mid-1900s, *B. tectorum* and *B. rubens* colonized most of their current ranges (Mack 1981; Salo 2005). The human footprint (impact of human presence and their action on ecosystems; Sanderson et al. 2002) across the western USA expanded during this period. By 2000, a minimum estimate of 13 % of the land area in the western USA was impacted by humans (Leu et al. 2008). Nearly 10 % was due to crop production, about 2 % resulted from populated areas, and slightly over 1 % was due to improved roads (excluding unmaintained single or two-track roads). Infrastructures to sustain human life (power lines, irrigation canals, railroads, and energy development in decreasing magnitude of importance) represented 0.01–0.05 % of the land (Leu et al. 2008; Bangert and Huntley 2010). Disturbances related to each land use increase the likelihood of colonization and spread of invasive species, especially in areas of low inherent resilience to disturbance and resistance to *Bromus*.

11.3.2.1 Cropland

Crop growth was encouraged by homestead laws, but failures of dryland farming in the early 1900s resulted in millions of hectares of abandoned land in the Intermountain West (Stewart 1938), where *B. tectorum* was likely already present (Mack 1981). Morris et al. (2011) found differences in shrub and forb cover on previously cultivated and never cultivated lands, but the direction of the difference may depend on the ecological site. Surprisingly, they found little *B. tectorum* on both never cultivated and previously cultivated areas, but noted their result was an anomaly relative to similar studies in the Cold Desert region where *B. tectorum* has dominated previously cultivated sites for up to 50 years.

Technological improvements to current seed-harvesting equipment now prevent most contamination of crop seed with weeds (however, see weed policies below) and thus prevent direct seeding of weeds with crops. Yet, activities associated with croplands, such as livestock grazing, fertilization, or herbicide drift, still increase the likelihood of weeds in lands surrounding crops. Within several kilometers of cropland, *B. tectorum* is more likely to exceed cover levels found in areas not associated with cropland (Bradley and Mustard 2006; Bradley 2010). Bradley and Mustard (2006) found that *B. tectorum* appeared to become more abundant near cultivation between 1973 and 2001, indicating that associated activities in adjacent lands (listed above) might have reduced resistance near these fields. Farmers are required to treat noxious weeds on their property, but those weeds not classified as noxious, including *Bromus*, may remain untreated while nontarget native species might be unintentionally harmed. A common practice to control weeds on roadsides, ditches, and field margins is by using fire. However, this may favor *Bromus* since it responds well to the post-fire environment and to the lack of competitors (Miller et al. 2013).

11.3.2.2 Weed Policies and Exotic Annual *Bromus*

Noxious weeds are plants declared by a government to be injurious to public health, agriculture, recreation, wildlife, or property. Property owners must control noxious weeds or face potential penalties. Generally, these are weeds that have been rarely seen in the locale for which agencies are attempting early detection and rapid response for weed eradication or control. Once weeds become common in an area, they may be excluded from the noxious category because the cost of control may exceed the potential economic threat to an individual or county (county exceptions do occur in Wyoming; Mealor et al. 2013). However, when *Bromus* dominance changes fire regimes, the resulting costs of fire management may exceed a billion dollars annually in the western USA (based on 1/3 of the 2009 appropriation to federal agencies; USGAO 2009). These costs are paid by Federal and State funds and are never considered regarding noxious weed status. A 2015 Department of the Interior Secretarial Order (3336) attempts to shift priorities and begins to examine *Bromus* control and restoration as a means of reducing these costs and combating this threat. Ecoregions where *Bromus* species have the potential to change fire regimes may be treated with fuel management funds and receive higher priority for fire suppression in the future.

Other regulatory programs encourage reductions in the spread of weeds from croplands to new locations. Weed-free forage programs are similar to noxious weed lists because states that participate have a goal of controlling noxious weed dispersal associated with sales of livestock forage. Public land management agencies (US Forest Service and Bureau of Land Management [BLM]) require use of weed-free forage on many of their lands. However, *Bromus* species are not represented as part of the minimum standards for weed-free forage (North American Invasive Species Management Association [NAISM]; http://www.naisma.org/images/WFFStandards.pdfAccessed 06/09/2015). The inclusion of *Bromus* may incur additional costs of inspection and treatment, thus making regulatory programs prohibitive to implement.

11.3.2.3 Land Management Policies Addressing Public Land Uses

Degradation of native ecosystems has resulted in regulatory and legal changes geared at conserving and restoring resilient and resistant native ecosystems. Land uses are regulated to some degree to halt the tragedy of the commons (Hardin 1968) by largely declaring that natural ecosystems are not available for common uses, but also fall under certain rules and regulations to sustain goods and services. The overuse of lands in the West by livestock during the early 1900s was a clear example of the tragedy of the commons (US Department of Agriculture, Secretary of Agriculture 1936).

After the advent of homesteading, those lands not claimed by individuals remained in the public trust, but the USA lacked management policies in the late 1800s and early 1900s to prevent degradation of lands and thus the loss of perennial plants, soils, or water and ultimately resilience. The degradation was recognized at the turn of the twentieth century and some livestock grazing restrictions were implemented on forest reserves in 1902, but non-forested lands largely were unregulated until the passage of the Taylor Grazing Act in 1934. This act was intended to halt the progression of overuse and allow the orderly use and improvement of public rangelands in the west.

Degradation was severe by the time this act was passed and *Bromus* had colonized most of the west, thus filling the void left by the loss of perennial grasses due to overgrazing by livestock (US Department of Agriculture, Secretary of Agriculture 1936; Leopold 1941; Mack 1981; Salo 2005). However, it took until the late 1960s and 1970s for passage of the Federal Land Policy and Management Act of 1976 and the Public Rangeland Improvement Act of 1978. These Acts recognized that (1) public lands should be managed for multiple uses, (2) permits for livestock grazing should be connected with the condition of the land, and (3) land condition should be monitored and reported.

Some legislation during that period led to increases of animal use on rangelands because of the Wild and Free-roaming Horses and Burros Act of 1971. This law provided protection for feral horses and burros and allowed their use on lands year-around. Season of use is regulated for domestic livestock, but not for feral horses and burros which use rangeland at will, regardless of the resilience of the plant community to defoliation or resistance to invasive plants (see grazing tolerance below). Feral horse and burro numbers are regulated through annual roundups of animals, but restricting them to specific areas and maintaining their populations at desired levels are difficult.

More recent legislation has attempted to expand the assessment of land condition beyond the key plants for livestock. Rangeland Reform of 1994 implemented new standards for rangelands that followed recommendations of a National Academy panel of experts (National Research Council 1994) that lands be evaluated relative to the lands' potential to support plant production and composition, and that soil, water, and biological components be included. This recognized that lands dominated by invasive plants, such as *Bromus*, may no longer have the ability to recover even if disturbances are removed since they have essentially lost their resilience and resistance. The dominance of *Bromus*, even if it could be used as livestock forage, was recognized as a degradation of the status of the land.

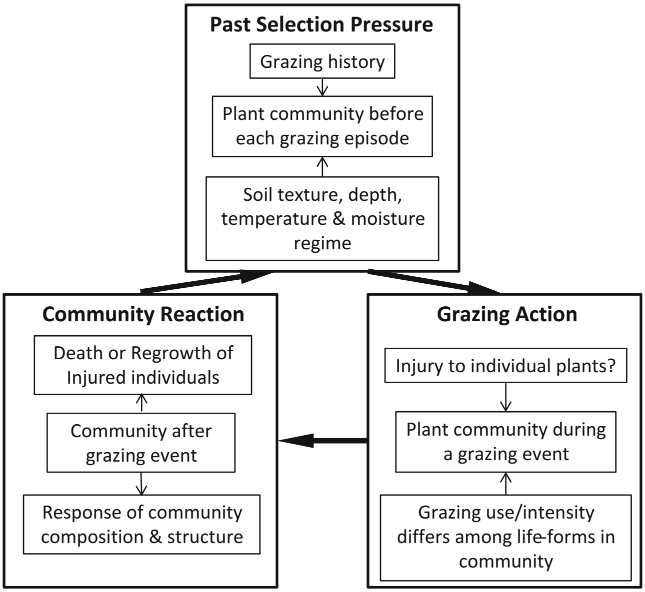
In 2015, Secretarial Order 3336 was released by the Department of the Interior to reduce sizes of fires and the spread of invasive plants like *B. tectorum* in an attempt to sustain sagebrush-grassland ecosystems and *Centrocercus urophasianus* Bonaparte (greater sage-grouse) in the western USA. This is the first Federal policy, to our knowledge, that has directly addressed *Bromus* management.

11.3.2.4 Livestock Grazing

The most ubiquitous land use in the western USA is livestock grazing. This use cannot be ruled out as contributing to the initial range expansion of *Bromus*. In the California Mediterranean ecoregion, The General Colonization Laws of Mexico granted large tracts of land for ranches in California in 1824 beginning overuse of western lands by livestock. For example, governmental reports on the status of rangelands made specific mentions of dominance of *Bromus* and depletion of native perennials as a result of uncontrolled livestock in the Mediterranean California and Cold Desert ecoregions (called California Foothills and Pacific Bunchgrass in the report; US Department of Agriculture, Secretary of Agriculture 1936).

Millions of hectares of rangelands in the Western USA are grazed by wildlife, livestock, and feral horses or burros each year. Grazing responses differ widely among individual plant species and communities largely due to inherent levels of resistance and resilience of plant communities to grazer-induced stresses. Differences in grazing (including defoliation and hoof impacts) by various herbivores, and timing and intensity of grazing, undoubtedly play a large role in the susceptibility of rangelands to invasion by *Bromus* species.

Grazing Tolerance Controlling *Bromus* on lands grazed by livestock requires maintaining perennial plants in sufficient densities and distributions (Chambers et al. 2007, 2014a; Reisner et al. 2013). Grazing tolerance, or a plant's ability to survive and compete for resources with other plants while being defoliated, is formed by adaptations often selected through evolution with grazing animals (Strauss and Agrawal 1999). For native plants, this relates to adaptive traits developed through grazing selection at the location, but for exotic species it depends on the evolutionary adaptations to grazing where they initially evolved. The interactions among the grazing responses of exotic and native species will determine the community's response to current grazing (Fig. 11.2).



Past Selection Pressure

	Annual *Bromus*		Native Herbaceous		Community Reaction
	Environment	Graze	Environment	Graze	
Great Plains	-	+	+	+	NH => AB
Cold Desert	+	+	+	--	AB >> NH
Warm Desert	+	+	+	--	AB >> NH
Med. California	+	+	+	--	AB >> NH

Fig. 11.2 Plant community structure (above) as shaped by grazing during grazing events, by the community's response to the grazing, and by the past selection pressures including the environment and grazing among the grazed plants at the site of evolution (modified from Milchunas et al. 1988). In the table (below), negative (–) and positive (+) signs indicate degree of adaptation for annual *Bromus* species (AB) and native herbaceous species (NH) to environments of four ecoregions and to grazing during the active growing season. Under community reaction, equal than and greater than signs (>) reflect dominance strength of AB and NH based on these adaptations

The geographic center of evolution for the *Bromus* species that are invasive in the Western USA is between the Middle East and eastern Europe (Sales 1994; Atkinson and Brown 2015), the region of origins of plant and animal domestication (about 10,000 years BP; Flannery 1969). *Bromus* seeds were associated with humans from at least 5000 years BP and likely earlier (Sales 1994; Marinova 2003; White et al. 2014). Thus, they had ample time to evolve with both crops and domestic livestock grazing. The annual life cycle is one adaptation that imparts grazing tolerance to these species. As populations of *B. tectorum* decrease in one generation, and in the absence of competition from native perennial plants, the remaining individuals tend to produce more seeds for the next generation compensating for temporary population reductions (Mack and Pyke 1983; Hempy-Mayer and Pyke 2008). Seed banks in soil may not be impacted directly by grazing intensities (Clements et al. 2007); therefore, once *Bromus* becomes abundant within plant communities, their seed densities tend to dominate seed banks (Chambers et al. 2015).

In addition, a morphological adaptation of *B. tectorum* is the ability to develop decumbent tillers by activating new buds after multiple grazing occurrences. This is an avoidance mechanism that results in placement of inflorescences and seeds below the lowest grazing level of many livestock (Hempy-Mayer and Pyke 2008). This combination of grazing avoidance and tolerance makes it difficult to use livestock to eliminate *B. tectorum* without perennial plant competitors to access available resources.

Native grasses in the western USA vary in their evolved traits for climate which may have determined the likelihood of frequent grazing by animals and influenced the evolution of adaptations to tolerate grazing (Mack and Thompson 1982; Milchunas et al. 1988, Fig. 11.2). A gradient in precipitation seasonality exists from east to west and from south to north across the western USA. The Northwestern Great Plains consistently receives higher amounts of summer precipitation than other western ecoregions. In addition, these prairies evolved with large herds of bison that persisted in this area due to the abundance of nutritional forage throughout most of the year. These plants adapted to grazing because they had predictable resources for regrowth and had grazing tolerance mechanisms such as clonal growth. In contrast, most precipitation arrives in winter in the Mojave Basin and Range portion of the Warm Deserts, in the Cold Deserts of the Intermountain West, and in the Mediterranean California ecoregions. In these winter-wet regions, native grasses do not have consistent growing season moisture. This kept plant production and nutrition low especially in the summer which in turn kept populations of grazing animals low and not distributed widely throughout these regions (Mack and Thompson 1982; Milchunas et al. 1988).

Plant communities within all western ecoregions except the Northwestern Great Plains are less grazing resistant and those with suitable climate regimes are subject to *Bromus* dominance once these communities lose deep-rooted perennial grasses. Inappropriate grazing that leads to degradation often entails excessive defoliation repeated over time resulting from overstocking the land with animals (i.e., overgrazing; Briske et al. 2011) or repeated defoliation of perennial grasses between the middle and late growing season weakening the grasses' ability to regrow in the following year (i.e., season of use; Briske and Richards 1995)—both of which are likely related to patchy grazing distribution across the landscape. This may eventually lead to reductions in perennial plants, increases in *Bromus* dominance, and ultimately in a type conversion to annual grasslands, where perennial plants have low grazing tolerance. Some speculate this happened early in the Mediterranean California region due to the early Spanish/Mexican ranches with year-round grazing that was continued when this area became part of the USA. The same levels or timing of grazing may play less of a role in *Bromus* dominance in regions with higher grazing tolerance, such as Great Plains grasslands, but may still contribute to *Bromus* presence within this ecoregion. The full potential of *Bromus* invasion in the Northwestern Great Plains is unknown. *Bromus arvensis* is a persistent component of large areas of the cooler and wetter Northwestern Great Plains (Haferkamp et al. 1992). *Bromus tectorum* and *B. arvensis* are significant components at the intersection of the warm and dry to cool and dry Cold Deserts and Northwestern Great Plains in Wyoming (Mealor, unpublished data). They may both continue to spread and become more dominant as land uses expand in this region (see Energy Development below).

Trampling Impacts Trampling may also affect *Bromus* dynamics. Perhaps one of the most important indirect impacts of livestock trampling that appears to benefit *B. tectorum* is the reduction and fragmentation of biological soil crusts in many Cold Desert plant communities (Warren and Eldridge 2001; Reisner et al. 2013). Biological soil crusts aid in soil stabilization and may reduce susceptibility to invasion by *Bromus* and other weedy species in arid ecosystems (Chambers et al. 2015). Physical damage to crusts, caused by hooves of grazing animals (and recreationalist's shoes or OHVs), increases the number of safe sites (sensu Harper 1977) where annual grasses can emerge and establish (Chambers et al. 2015). This may produce gradients of biological soil crust cover that are negatively correlated with livestock grazing intensity and *B. tectorum* cover as shown in eastern Oregon (Reisner et al. 2013). The degree that this relationship can be extended to other *Bromus* has not been tested, but it appears to be a reasonable outcome since many of the *Bromus* have similar traits (Atkinson and Brown 2015).

Grazing and Exotic Annual *Bromus* Species Invasion and Dominance Mismanagement of livestock grazing in the late 1800s and early to mid-1900s is considered a primary driver in the widespread introduction and dominance of *B. tectorum* into the Cold Deserts (Mack 1981; Young and Clements 2007) and potentially *B. rubens* in California Mediterranean and the Mojave Basin and Range of the Warm Deserts (Salo 2005). However, it is sometimes difficult to disentangle impacts of historic livestock grazing and current grazing practices. Surprisingly, there is a dearth of long-term studies relating livestock stocking rates or grazing seasons to plant compositional changes, especially in the Cold Deserts and the Mojave Basin and Range in the Warm Deserts where *Bromus* continues to be problematic. Briske et al. (2011) only cite three studies from these ecoregions with native plants and none reported data on annual grasses (all lumped them into other grasses). Thus, we lack good studies examining how stocking rates or grazing seasons may influence *Bromus* relative to native perennials.

Increased grazing intensity through livestock trampling and defoliation has been studied once in the Cold Desert (*B. tectorum*) and once in the Mojave Basin and Range of the Warm Deserts ecoregion. Both studies used proximity to watering sites to create grazing gradients that revealed similar effects at the community level, but opposite effects on individual *Bromus* species (Brooks et al. 2006; Reisner et al. 2013). Absolute and relative cover of exotic annual plants increased with proximity to water, whereas cover and species richness of native plants decreased. In the Cold

Deserts, cover of *B. tectorum* and the upright annual forb, *Lepidium perfoliatum* L. (clasping pepperweed), increased with nearness to water (Reisner et al. 2013). In the Mojave Basin and Range, cover of the *B. madritensis* ssp. *rubens* decreased with nearness to water and cover of the exotic rosette-forming forb *Erodium cicutarium* (L.) L'Hér. ex Aiton (redstem stork's bill) and a short-statured, nonnative annual grass *Schismus* spp. P. Beauv. (Mediterranean grass) increased (Brooks et al. 2006). The differences between these annual species may reflect the greater grazing avoidance of *E. cicutarium* and *Schismus* relative to *B. rubens* (Brooks et al. 2006). In the Cold Deserts, *B. tectorum* is rarely competing with plants with traits that avoid livestock grazing. A similarity between both studies was reduction in perennial plant cover nearer to water (Brooks et al. 2006; Reisner et al. 2013). Reisner et al. (2013) found that with this lower cover of perennial plants, distances between perennial plants increased. This distance was the strongest factor relating to *B. tectorum* cover, while biological soil crust cover was the second strongest. These results indicate that although livestock use may not generally promote *Bromus* invasions and dominance, repeated livestock use at high intensity can tip the balance toward *Bromus* species unless other species with better grazing avoidance mechanisms exist to replace *Bromus* if it is grazed by livestock.

Rangeland managers have promoted water developments to better distribute livestock across lands; however, each water location, especially when they are permanently located, creates another gradient such as these noted in the studies above. Heady and Child (1999) recommended placing water no farther than 1.3 km apart. Given the gradient of annual plants, including *Bromus* found near the water, each new water source may enhance *Bromus* spread and dominance. Strategic placement to provide livestock water but minimize the dominance of *Bromus* could use investigations.

Reductions in the biomass or seed production of *Bromus* species with livestock grazing are commonly used as evidence that livestock can control and potentially tip the balance in favor of desired perennial species (Mosley and Roselle 2006). The strongest evidence supports the potential for using livestock to reduce fuel levels and fire behavior of *Bromus*-dominated communities (Strand et al. 2014). However, this use must be repeated annually, since *Bromus* always has plants that produce high numbers of viable seeds (Hempy-Mayer and Pyke 2008). Diamond et al. (2012) used combinations of cattle grazing and fire to reduce *B. tectorum* seed densities, but their results were still two to three times higher than the 330 seeds m^{-2} estimated by Hempy-Mayer and Pyke (2008) that would be necessary to keep *B. tectorum* from competing with seedlings of native perennials. More details on livestock as a control for *Bromus* are provided in Chambers et al. (2015).

11.3.2.5 Urban, Suburban, and Exurban Development

The western USA has increased in population by 60.5 % between 1980 and 2006 with 8 of the 11 fastest growing states found in regions where *Bromus* can dominate lands (Nevada, Arizona, Utah, Idaho, Washington, California; Albrecht 2008). Five of the ten fastest-growing cities between 2000 and 2010 were St. George, Utah (53 % increase), Las Vegas, Nevada (42 %), Orem-Provo, Utah (40 %), Greeley, Colorado (40 %) and Bend, Oregon (37 %) (Mackun and Wilson 2011). A population rise results in increases in use of fossil fuels and changes in atmospheric gases that may potentially impact plant communities and benefit growth of *Bromus*. The annual rate of increase in atmospheric carbon dioxide (CO_2) has doubled since 1975 (data from Mauna Loa Observatory, Hawaii, http://www.esrl.noaa.gov/gmd/ccgg/trends/Accessed 23 March 2015). Elevated CO_2 increases water use efficiency of plants, and may result in slower rates of water depletion, improved plant water relations, and greater biomass production (Polley et al. 2011). These biomass increases may be the greatest in invasive *Bromus* (Nowak et al. 2004). However, advantages to growth and reproduction of *Bromus* due to elevated CO_2 depend on the availability of other key resources, like water and N, and are possibly offset by droughts (Nowak et al. 2004; Smith et al. 2014).

In contrast to increased atmospheric CO_2, atmospheric nitrogen deposition is more localized and tends to increase closer to or downwind from population centers. The greatest source of depositional nitrogen is air pollutants from burning fossil fuels in vehicles or power plants (Galloway et al. 2003). Deposition near cities can be 3.5–10 times higher than away from these centers and this can contribute to high biomass of *Bromus* in Mediterranean California and Warm and Cold Desert ecoregions (Allen and Geiser 2011; Fenn et al. 2011). The higher biomass could lead to higher fuel loads contributing to more or larger fires in these areas of deposition.

Population spread from the city and its suburban communities has led to exurban development that is defined as low-density residential housing outside of city and suburban limits, with one house for each 4–16 ha (Theobald 2003), and that typically results from sale of ranch or farm lands for subdivision development. In northwestern Colorado, *B. tectorum* cover was higher on exurban and wildlife reserves than on existing ranches with similar soils (Maestas et al. 2003). These reserves were highly visited recreational areas with trails and roads that may have contributed to the increase in *B. tectorum*. In addition, 8 of 23 exotic plant species were unique to exurban land uses (Maestas et al. 2003).

Education of urban and exurban populations is important for detection and control of invasive plants. Mealor et al. (2011) found that greater than half of the exurban landowners surveyed in Wyoming correctly identified photographs of *B. tectorum*. In addition, these landowners ranked weeds as a concern on their property and information about those weeds and their control as a desired need (Mealor et al. 2011). However, regulations or incentives for control of *Bromus* generally do not exist except in local areas since regulations are restricted to noxious weed laws discussed above.

11.3.2.6 Transportation Corridors and Vehicles

Transportation corridors for trains and automobiles are potential conduits for invasive species dispersal. Improved roads and railroads cover 1.22 % and 0.02 %, respectively, of the land area in the western USA (Leu et al. 2008). Current construction or maintenance of these routes may also be a source of *Bromus* species dispersal through the gravel used to construct road bases and verges (strips between the road shoulder and the vegetation). Some state and federal agencies are requiring weed-free gravel, yet, similar to weed-free forage, the minimum standard does not preclude *Bromus* species (NAISM; http://www.naisma.org/images/Gravelpit_inspect_stdrs.pdf. Accessed 06/09/2015).

Transportation routes have broader ecological effects on *Bromus* than the direct land area of the route itself. Road density was the greatest human-related predictor of wildfire probability after fuel load and climate across the western USA (Parisien et al. 2012). Sources (e.g., vehicles, equipment, or smoking) of ignition may vary, but roads were a common location associated with the ignition (Syphard and Keeley 2015). Any increase in road density may contribute to wildfires, and provided *Bromus* exists in the plant community, fires may contribute to changes in fire regimes.

Transportation corridors may provide safe sites for establishment and spread of plants. Seeds dispersed along roadsides or railroads, if capable of establishing and reproducing, are likely to colonize surrounding vegetation (Gelbard and Belnap 2003; Gelbard and Harrison 2005). Improved roads increase the probability of *B. tectorum* being found within 500 m of roads in Nevada (Bradley 2010). Improved roads tend to have wider verges with deeper soils and different soil texture and chemistry than surrounding native soils because of road development and maintenance (Brooks and Lair 2009). Runoff from roads carries nutrients that become available for plant growth within and adjacent to verges. Reductions in perennial plants along these verges through maintenance (e.g., grading or herbicides) may also lead to annual grass establishment and growth. A negative correlation between cover of perennial plants and *Centaurea solstitialis* L. (yellow star-thistle), an annual forb, occurs as distance from roads increases (Gelbard and Harrison 2005).

Most state and county highway and transportation departments attempt to manage vegetation along roads for human safety and the control of designated noxious weeds, water pollutants and runoff, and fires (Transportation Research Board 2005). Management includes herbicides or buried root barriers to maintain a plant-free zone between 2 and 10 ft from pavement. Mechanical cutting of vegetation may be applied beyond the vegetation-free zone to reduce fuel loads while maintaining sufficient plant cover for erosion and runoff control. Herbicide spraying for noxious weeds in roadside right-of-ways is conducted as needed in accordance with vegetation management plans. However, *Bromus* are rarely on the list of species for control since they are not considered noxious. Timing of road maintenance is not geared to reducing seed production of *Bromus.* Often this timing is related to maximizing noxious weed controls or lowering vegetation height for fuel reductions both of which typically occur after *Bromus* reproduction. In addition, herbicidal control using dicot-specific herbicides may reduce target weeds, but may allow *Bromus* to fill the void.

Vehicles are common dispersal agents of seeds. The average automobile is estimated to be carrying 2–4 seeds per car at any given time. A systematic review of seed transport found that 96 % of the 626 species on cars were considered weedy, and of those, grasses were the most common life form (Ansong and Pickering 2013). Seeds mixed with soil are common on unimproved roads and driving conditions may influence dispersal distances of seeds. High percentages of seeds stuck to vehicles when they were mixed with soil. If the soil dried on the vehicle and the vehicle was driven under dry road conditions, seeds were retained on vehicles (86–99 %) for a distance of at least 256 km regardless of road surface (Taylor et al. 2012). If driven during wet road conditions, fewer seeds were retained on vehicles when driven on paved relative to unpaved roads, since water on the road tended to wash soil and seeds from the cars (Zwaenepoel et al. 2006; Taylor et al. 2012). Cleaning vehicles moving between areas may be a potential method for reducing spread of weeds (Fleming 2005).

11.3.2.7 Mineral Extraction, Energy Development, and Their Infrastructures

Extracted natural resources (minerals, gas, and oil) and renewable energy development (wind, solar, and geothermal) are subject to a wide variety of regulations. Each type of resource has an immediate footprint that may impact *Bromus* species' colonization and spread. Hard rock or mineral mining is often more localized with roads directly to the mines and then accessing major transportation corridors. Surface mining, where the soil and rock above the mineral is removed to extract the mineral, tends to have a broader footprint, but the post-mining reclamation is regulated (Surface Mining Control and Reclamation Act of 1977). A Montana Greater Sage-grouse Habitat Conservation Advisory Council (2014) recently recommended that control of *B. tectorum* and *B. arvensis* should be added to the reclamation requirements when mines occur in habitat for the *C. urophasianus*. Implementation of these recommendations by Montana still remains.

Other energy developments, however, have the direct footprint associated with well pads, wind power towers, and solar panel arrays, but also include either buried pipelines and cables or electrical transmission towers and corridor rights-of-way. For example, oil and gas wells in the western USA represent 0.01 % of the human footprint, while power lines represent a 3- to 5-fold greater impact (Leu et al. 2008; Knick et al. 2011). The land area impacted by oil and gas wells, relative to their associated pipelines and including their buffers, was nearly 4:1, but this ratio increases to 10:1 if roads to connect wells are included and the potential buffer around these roads is counted in the calculation (Knick et al. 2011). These roads and buffers are likely conduits for the spread of *Bromus* and for fire ignitions (see Transportation above).

Well pads alone may contribute to increased distances of *B. tectorum* seed dispersal. The maximum dispersal distances for *B. tectorum* reported occurred on simulated well pads with dispersal reaching nearly 20 m, nearly 50-fold higher than previously recorded maximum distances in intact sagebrush ecosystems (Johnston 2011). However, Bergquist et al. (2007) found no difference in *B. tectorum* or *B. arvensis* occurrences or cover between coal bed methane sites and similar control sites. They attributed the similarity among treatments of *Bromus* cover to previous disturbances such as livestock grazing as *Bromus* already dominated the sites before coal bed methane development. They did note a lack of perennial plants on well pads and warned that these disturbances would be prone to potential future invasions of *Bromus*.

Power line rights-of-ways and their associated roads tend to have a greater likelihood of *B. tectorum* presence than distant locations (Bradley and Mustard 2006). Vegetation clearing is one of many disturbances found in these corridors; however, it may be difficult to separate the impact of power line corridor maintenance from other impacts associated with corridors such as service roads, livestock grazing, and OHVs. In the Hells Canyon Complex of the Idaho Power Company, a botanical survey found *B. tectorum* was common along with several noxious weeds (Dumas et al. 2003) and listed vehicle use as a likely contributing factor to occurrence of these weeds.

Power lines may directly contribute to fire ignitions when they are located in areas with high winds that may directly damage power lines or cause materials to come in contact with the power line and create an electrical arc. This was recently noted in Mediterranean California (Syphard and Keeley 2015) and was the source of a major Australian fire that began with a downed power line on grazed grassland (Cruz et al. 2012). In Australia, this resulted in a shift to buried power lines to prevent future fires in similar areas.

11.3.3 Interrelated Impacts of Anthropogenic Infrastructure and Exotic Annual **Bromus** *Species on Wildlife*

The expansion of anthropogenic infrastructure is one of the largest impacts to wildlife in the Intermountain West (Copeland et al. 2011). Not only do these infrastructures encourage establishment and spread of invasive species including *Bromus* (Gelbard and Belnap 2003; Bradley and Mustard 2006), they also cause habitat fragmentation and loss (Kirol et al. 2015). In addition, changes to habitat may result in behavioral avoidance of once preferentially used habitat (Buchanan et al. 2014) and in concomitantly reduced vital rates (Dinkins et al. 2014; LeBeau et al. 2014). A related and unintended consequence of increasing infrastructure in native ecosystems is increases in predators. *Corvus corax* L. (common ravens), for example, are provisioned with nesting structure and food resources in formerly unsuitable habitat. They have increased predation on a variety of animals including juvenile *Gopherus agassizii* Cooper (desert tortoise; Boarman 1993) and *C. urophasianus* (Coates and Delehanty 2010) which may also become more visible to predators because of habitat shifts to *Bromus*.

Invasion of annual grasses such as *B. rubens* in the Mojave Basin and Range of the Warm Deserts has led to increased wildfire (Salo 2005), which has direct effects on mortality and loss of cover for *G. agassizii* and other small vertebrates, and hypothetical indirect effects on diet composition and greater exposure to extreme temperatures (Esque et al. 2003). Recreational activities such as target shooting and OHV activity in the Mojave Desert suggest these disturbances may also lead to greater invasion by *B. rubens* and other annuals, along with concomitant impacts to wildlife and habitats in this arid region (Vollmer et al. 1976).

11.3.3.1 Impacts of Land Uses, Exotic Annual *Bromus*, and Fire on Sagebrush-Dependent Wildlife

The sagebrush biome is one of the largest in the USA, but it is threatened by the combination of *Bromus* and wildfires (Noss et al. 1995). Sagebrush communities provide habitat for a diverse assemblage of wildlife (Paige and Ritter 1999; Welch 2005), and it is likely that hundreds of vertebrate species use sagebrush habitats in many landscapes at some point during a year. For example, Wyoming's sagebrush lands provide habitat to nearly 450 avian, mammalian, herptile, and fish species (Wyoming Game and Fish Department 2010: III-9-5), with approximately 6 % (25) of these sagebrush-associated species identified as species of greatest conservation need (Wyoming Game and Fish Department 2010: IV-i-1).

Currently, large contiguous fires pose a significant risk to habitats on which sagebrush-obligate species depend, because they tend to burn uniformly over an area. The dominant sagebrush species do not survive fires (Pechanic et al. 1965) and little suitable sagebrush habitat remains for sagebrush-obligate species (Bukowski and Baker 2013). Nine wildlife species in the western USA are commonly considered sagebrush obligates that depend on sagebrush communities for resources required during critical life stages. These include *Spizella breweri* Cassin (Brewer's sparrow), *C. urophasianus* Bonaparte and *C. minimus* Young, Braun, Oyler-McCance, Hupp & Quinn (Gunnison sage-grouse), *Antilocapra americana* Ord (pronghorn), *Brachylagus idahoensis* Merriam (pygmy rabbit), *Oreoscoptes montanus* Townsend (sage thrasher), *Sceloporus graciosus* Baird and Girard (sagebrush lizard), *Artemisiospiza nevadensis* Ridgway (sagebrush sparrow), and *Lemmiscus curtatus* Cope (sagebrush vole) (Braun et al. 1976; Paige and Ritter 1999; Welch 2005). Sagebrush-associated wildlife tend to decrease while grassland-associated species tend to increase with sagebrush conversion to grassland (Olson et al. 2003; Reinkensmeyer et al. 2007; Larrucea and Brussard 2008; Holmes 2010). Two of these sagebrush-dependent species (*A. americana* and *C. urophasianus*) along with two facultative sagebrush habitat species, *Cervus elaphus* L. (elk) and *Odocoileus hemionus* Rafinesque (mule deer), are of sporting and economic interest in most western states. Further loss of habitat through *Bromus*-fueled fires may directly impact recreation in those states.

Woody plant reductions are often management actions for enhancing wildlife habitat and reducing woody fuels (Heady and Child 1999). Research indicates that prescribed burning as a management tool to achieve either goal should be avoided in *A. tridentata* ssp. *wyomingensis* Beetle & Young (Wyoming big sagebrush) habitats because it encourages spread and increase in *Bromus*, slows recovery of shrubs, and often does not enhance insects and forbs which are often management objectives of prescribed fires (Beck et al. 2009, 2012; Rhodes et al. 2010; Davies et al. 2011; Hess and Beck 2012a, 2014). Hess and Beck (2012a) reported that sagebrush cover and height needed to meet guidelines for nesting and brood-rearing *C. urophasianus* (Connelly et al. 2000) had not recovered as much as 19 years post-burning. Mechanical forms of tree removal may be more beneficial for fuel reduction goals while also improving both shrub and herbaceous components and decreasing the likelihood of *Bromus* becoming dominant (Chambers et al. 2014b). Mowing may be a more promising treatment for enhancing perennial herbaceous plants while reducing but not completely removing sagebrush cover (Hess and Beck 2012a); however, insects and forbs in north-central Wyoming were not more abundant, nor was forb nutritional quality enhanced following mowing in *A. tridentata* ssp. *wyomingensis* (Hess and Beck 2014). Furthermore, mowing *A. tridentata* ssp. *wyomingensis* communities with intact herbaceous understories in several locations had mixed results on perennial herbaceous species cover, density, or biomass. Mowing increased cover, density, and production of annual forbs and grasses compared to untreated sites in some comparisons (Davies et al. 2011; Pyke et al. 2014), but not others (Chambers et al. 2014b). Sagebrush reduction treatments appear to be more promising in *Artemisia tridentata* ssp. *vaseyana* (Rydb.) Beetle (mountain big sagebrush), which are more resilient and resistant and respond to disturbance better than *A. tridentata* ssp. *wyomingensis* (Dahlgren et al. 2006; Beck et al. 2012).

Some recent studies provide insights as to how *C. urophasianus* populations may respond at landscape and micro-habitat scales to invasion of sagebrush habitats by exotic annual grasses. At the micro-habitat scale, *C. urophasianus* nest site selection in south-central Wyoming was negatively correlated with the presence of *B. tectorum*, but positively correlated with *A. tridentata* ssp. *vaseyana* and *A. tridentata* ssp. *wyomingensis* canopy cover (Kirol et al. 2012). At the landscape scale, exotic or introduced grasslands (*B. tectorum* or *Agropyron cristatum* (L.) Gaertn. [crested wheatgrass]) in central Nevada had a negative influence on per-capita recruitment of male *C. urophasianus* to leks where recruitment was consistently low in areas with substantial exotic or introduced grasslands even following years with favorable rainfall (Blomberg et al. 2012). These authors also reported males breeding at leks with substantial exotic grass species had lower annual survival compared to males at leks surrounded by native sagebrush (Blomberg et al. 2012). Abandonment of *C. urophasianus* leks in north-central Wyoming was related to numbers of oil and gas well pads within a 1-km radius of leks, the percent area of wildfire within 1 km, and the variability in shrub height within 1 km of leks (Hess and Beck 2012b). Additive factors stemming from increasing disturbance in this area due to energy development and wildfire were believed to be related to a reduction in habitat quality, at least partially due to establishment and spread of *Bromus*, leading to loss of some leks (Hess and Beck 2012b).

11.4 Management Implications

Human land uses across the western USA have reshaped the structure and function of many ecosystems, especially in the warmer drier ecosystems of the Mediterranean California, the Mojave Basin and Range of the Warm Deserts, and the Cold Deserts. This has led to changes in fire regimes that contribute to feedbacks ensuring the maintenance of annual grass dominance once it occurs. Changes in land use planning, management, and policy may be necessary to impede further loss of native ecosystems to *Bromus* and degradation of wildlife habitats, and to restore native plant communities that are resilient to stresses and disturbances such as fire, land uses, and global changes and that are resistant to increases in *Bromus*. Such changes may require eliminating or mitigating land uses that are incompatible with this goal, while retaining land uses that are compatible or could become compatible with adjustments in land management.

Understanding which lands are more resistant to *Bromus* and resilient to land disturbances provides an opportunity to prioritize land uses relative to the threat of *Bromus* invasion and dominance. The detailed research to determine which ecosystems are more prone to *B. tectorum* dominance in the Cold Deserts has led to ranking of resilience and resistance based on soil temperature and moisture regimes (Chambers et al. 2014c). Similar rankings for other species and regions would improve land use planning and policy development.

A 2015 Secretarial Order from the Department of the Interior (SO 3336 on Rangeland Fire Prevention, Management, and Restoration of 5 January 2015) specifically lists *B. tectorum* as contributing to the "increased threat of rangeland fires." These fires pose "a significant threat to ranchers, livestock managers, sportsman, and outdoor recreation enthusiasts who use sagebrush-steppe ecosystems, and puts at risk their associated economic contributions across this landscape that support and maintain the American way of life in the West." This Secretarial Order is causing reexamination of land use planning and policies relating to management of fire, invasive plants, and restoration of functional, resilient ecosystems in Cold Deserts. This action was a direct response to conserving habitat for *C. urophasianus* and other wildlife species currently threatened by the increasing dominance of *Bromus* throughout the region. Future changes may occur relating to policy and management of these lands with the goal of reducing future fires and a concomitant reduction of *Bromus*.

Planning and policies in other areas of land use and management will likely require similar revamping to stem this tide of *Bromus* increases in response to land uses. For example, weed management policy and planning from national to county levels vary with each successive and finer level of resolution (Ielmini et al. 2015), indicating a need for more consistency among different levels of government, especially related to weed species such as *Bromus* that contribute fuel for fires that may harm wildlife habitats and human safety.

An emphasis on increased communication and education regarding impacts of land uses on *Bromus* could shift the public from the view that "nothing can be done, so why bother," to the view that "our actions, individually and corporately, can focus on activities that do not increase *Bromus*." Education and information regarding potential land use actions that can promote or restrict weeds, including *Bromus*, may aid in changing policies or providing incentives for land managers.

Road and railroad maintenance often uses gravel. Encouraging the use of weed-free gravel will aid in reducing this as a source of weed colonization. But weed-free hay and gravel would need to exclude *Bromus* as well as designated noxious weeds and these may need testing and certification programs. In addition, vegetation treatments along road verges could consider the timing of *Bromus* reproduction, to potentially reduce *Bromus* populations along with other vegetation.

Consideration could be given to closing some roads or to minimizing use to essential vehicles while new road construction is kept to a minimum to reduce new sources of *Bromus* spread. Education of all users of public lands about the benefits of cleaning vehicles as they move from one location to another is important to control the transport of *Bromus.* Courtesy inspections for weed seeds may aid this education similar to courtesy boat inspections done currently in some regions are attempting to reduce the transport of invasive aquatic species. Where practical, consideration could be given to using weed washing technology (e.g., Fleming 2005) for vehicles that must go off-roads to perform their land uses. Some Australian states and territories provide online education on how to wash vehicles and standards for these cleaning facilities to prevent weed spread (Queensland Government 2008).

Livestock grazing management that focuses on increasing resilience of communities by encouraging increased density and cover of deep-rooted perennial grasses while reducing distances among them will likely benefit ecosystem recovery in most ecoregions, except the Mediterranean California system which is now managed as an annual grassland. Grazing systems that encourage light stocking levels and grazing seasons that allow seed and tiller production of perennial species are likely to be complementary with increasing resilience, especially for grass species that did not evolve with repeated grazing.

Maintaining sustainable feral horse and burro populations without degrading habitat is difficult without being able to manage animal stocking rates for both livestock and feral equids. Recommendations for moving forward with an adaptive management study of newly developed contraceptives (Garrott and Oli 2013) may aid in future herd management and halt further contributions to land degradation from equids.

11.5 Research Needs

Resistance to invasion and dominance of *Bromus* coupled with resilience to disturbances such as fire are dependent on the cover, density, and spatial relationships among perennial plants, especially perennial grasses. Understanding the values for these measures for differing ecological sites or plant communities is necessary. These values are most likely related to soil temperature and moisture regimes (Chambers et al. 2015) and, thus, are specific to ecoregions and ecological sites within ecoregions. Progress is being made in using such factors to evaluate the recovery potential of Great Basin ecosystems to management actions and wildfire (Miller et al. 2014). However, our current understanding of these values is inadequate to predict outcomes (e.g., *Bromus* or native plant dominance) of disturbances like wildfire with assurance. In addition, an understanding of these factors may provide managers with early-warning indicators of the potential loss in plant community resilience in areas impacted by *Bromus* or provide quantitative goals for restoration objectives.

BLM and USDA Natural Resources Conservation Service are currently collecting data on these plant measures across the western USA using a standardized protocol with replicated sites in ecoregions (Toevs et al. 2011). These should provide a baseline for relating *Bromus* cover to these factors across a range of sites differing in resilience and resistance.

The rapid expansion of oil and gas wells and renewable energy in the western USA is cause for more study into impacts these types of land uses and their infrastructures have on *Bromus*. We are only aware of one study in one locale in Wyoming that addressed the impacts of these wells on the immediate plant community (Bergquist et al. 2007), but the control sites already had *Bromus*. Is this a consistent finding or an anomaly? Further studies in other energy development sites are needed to confirm or refute this finding.

The surprising lack of research relating livestock grazing intensity and season of use to *Bromus* and perennial grass dominance makes these areas ripe for research. Since long-term grazing studies are expensive and hard to replicate, we suggest using additional studies examining plant compositional changes along grazing intensity gradients. It would be necessary to use a covariate such as ecological sites to begin to tease apart the livestock grazing component from the plant community potential component. Since a complex of factors can impact the results for both *Bromus* and perennial grasses, the use of multivariate statistical procedure will likely be necessary (Reisner et al. 2013, 2015). Examining livestock water placement and *Bromus* cover across the landscape may aid in placing and using water strategically to control *Bromus* spread.

The use of livestock as a tool for reducing fire risk and for controlling *Bromus* has been proposed. The utility of using targeted grazing, especially in locations with varied levels of resistance and resilience and in areas where perennial grasses already exist, warrants further investigation. Studies demonstrating the achievement of goals to reduce *Bromus* while maintaining or increasing deep-rooted perennial grasses are currently lacking. There is no evidence that this goal can be achieved without controlled and replicated studies.

There is a great need to better understand the impacts of *Bromus* to wildlife habitats in many ecosystems in the western USA. Specific information such as predicted changes in cover and dietary resources (e.g., insect availability and forage nutritional quality), as well as population responses for sagebrush obligates such as *C. urophasianus* and other species of concern (e.g., *G. agassizii*), will be useful to assist in developing practical and successful restoration protocols for burned or *Bromus*-dominated habitats. Research is also needed to evaluate vital rates and habitat selection for wildlife during critical life stages (e.g., juveniles) and seasons (e.g., breeding and winter) when wildlife populations are most vulnerable to large-scale habitat changes and restoration practices. These evaluations will be useful to ascertain the effectiveness of restorative actions to improve conditions for wildlife populations in areas impacted by *Bromus*.

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