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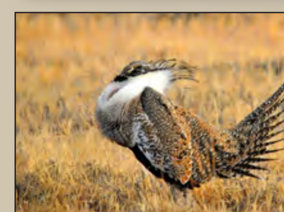
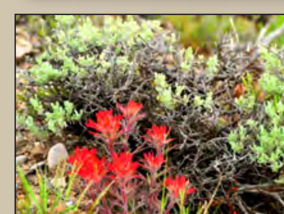
A Conservation Paradox in the Great Basin—Altering Sagebrush Landscapes with Fuel Breaks to Reduce Habitat Loss from Wildfire





Open-File Report 2018-1034

U.S. Department of the Interior
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Cover:
Left: Photograph showing mowed fuel break in southwestern Idaho. Photograph by U.S. Geological Survey.
Right (top to bottom): Brewer's sparrow (*Spizella breweri*), Greater sage-grouse (*Centrocercus urophasianus*), Indian paintbrush (*Castilleja angustifolia*) and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*. Photographs by Tom Koerner, U.S. Fish and Wildlife Service. Wildfire in southwestern Idaho. Photograph by Douglas Shinneman, U.S. Geological Survey, 2010.

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U.S. Department of the Interior
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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

U.S. Geological Survey, Reston, Virginia: 2018

Suggested citation:
Shinneman, D.J., Aldridge, C.L., Coates, P.S., Germino, M.J., Pilliod, D.S., and Vaillant, N.M., 2018, A conservation paradox in the Great Basin—Altering sagebrush landscapes with fuel breaks to reduce habitat loss from wildfire: U.S. Geological Survey Open-File Report 2018–1034, 70 p., https://doi.org/10.3133/ofr20181034.

ISSN 2331-1258 (online)

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°F=(1.8\times°C)+32$$

Datums

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

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A Conservation Paradox in the Great Basin—Altering Sagebrush Landscapes with Fuel Breaks to Reduce Habitat Loss from Wildfire

By Douglas J. Shinneman[1], Cameron L. Aldridge[1], Peter S. Coates[1], Matthew J. Germino[1], David S. Pilliod[1], and Nicole M. Vaillant[2]

Abstract

Interactions between fire and nonnative, annual plant species (that is, “the grass/fire cycle”) represent one of the greatest threats to sagebrush (*Artemisia* spp.) ecosystems and associated wildlife, including the greater sage-grouse (*Centrocercus urophasianus*). In 2015, U.S. Department of the Interior called for a “science-based strategy to reduce the threat of large-scale rangeland fire to habitat for the greater sage-grouse and the sagebrush-steppe ecosystem.” An associated guidance document, the “Integrated Rangeland Fire Management Strategy Actionable Science Plan,” identified fuel breaks as high priority areas for scientific research. Fuel breaks are intended to reduce fire size and frequency, and potentially they can compartmentalize wildfire spatial distribution in a landscape. Fuel breaks are designed to reduce flame length, fireline intensity, and rates of fire spread in order to enhance firefighter access, improve response times, and provide safe and strategic anchor points for wildland fire-fighting activities. To accomplish these objectives, fuel breaks disrupt fuel continuity, reduce fuel accumulation, and (or) increase plants with high moisture content through the removal or modification of vegetation in strategically placed strips or blocks of land.

Fuel breaks are being newly constructed, enhanced, or proposed across large areas of the Great Basin to reduce wildfire risk and to protect remaining sagebrush ecosystems (including greater sage-grouse habitat). These projects are likely to result in thousands of linear miles of fuel breaks that will have direct ecological effects across hundreds of thousands of acres through habitat loss and conversion. These projects may also affect millions of acres indirectly because of edge effects and habitat fragmentation created by networks of fuel breaks. Hence, land managers are often faced with a potentially paradoxical situation: the need to substantially alter sagebrush habitats with fuel breaks to ultimately reduce a greater threat of their destruction from wildfire. However, there is relatively little published science that directly addresses the ability of fuel breaks to influence fire behavior in dryland landscapes or that addresses the potential ecological effects of the construction and maintenance of fuel breaks on sagebrush ecosystems and associated wildlife species.

This report is intended to provide an initial assessment of both the potential effectiveness of fuel breaks and their ecological costs and benefits. To provide this assessment, we examined prior studies on fuel breaks and other scientific evidence to address three crucial questions: (1) How effective are fuel breaks in reducing or slowing the spread of wildfire in arid and semi-arid shrubland

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ecosystems? (2) How do fuel breaks affect sagebrush plant communities? (3) What are the effects of fuel breaks on the greater sage-grouse, other sagebrush obligates, and sagebrush-associated wildlife species? We also provide an overview of recent federal policies and management directives aimed at protecting remaining sagebrush and greater sage-grouse habitat; describe the fuel conditions, fire behavior, and fire trends in the Great Basin; and suggest how scientific inquiry and management actions can improve our understanding of fuel breaks and their effects in sagebrush landscapes.

Introduction

The Threat of Wildfire to Sagebrush Ecosystems and Wildlife in the Great Basin

Sagebrush (*Artemisia* spp.) ecosystems are highly imperiled throughout North America (Noss and Peters, 1995), largely due to agricultural conversion, energy development, livestock grazing, nonnative species invasions, and altered fire regimes (Knick and others, 2011; Chambers and others, 2016). There has been an estimated 45 percent loss in sagebrush area relative to its historical distribution (Miller and others, 2011), which once likely covered more than 1 million km^2 of the Western United States (Beetle, 1960; McArthur and Plummer, 1978). Roughly one-half of the sagebrush biome is located in the Central and Northern Basin and Range and adjacent Snake River Plain ecoregions, collectively referred to hereinafter as the “Great Basin” and comprising 506,000 km^2 of land dominated by arid and semi-arid shrublands interspersed with isolated mountain ranges (fig. 1). Much of the sagebrush biome in the Great Basin was historically dominated by big sagebrush (*A. tridentata*). Big sagebrush has three primary subspecies: Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*), basin big sagebrush (*A. t.* ssp. *tridentata*), and mountain big sagebrush (*A. tridentata* ssp. *vaseyana*). Other widespread or dominant sagebrush species in the region include low sagebrush (*A. arbuscula*), silver sagebrush (*A. cana*), and black sagebrush (*A. nova*). Although fire is a natural process that plays an important ecological role in the Great Basin, it is now a primary threat to many sagebrush ecosystems in the region (Chambers and Wisdom, 2009; Baker, 2011; Miller and others, 2011), and numerous Federal and State agencies are focused on limiting future losses (Pellant and others, 2004; Wisdom and Chambers, 2009; Havlina and others, 2014; Doherty and others, 2016).

Figure 1. Big sagebrush (*Artemisia tridentata*) landscape, Great Basin, northern Nevada. Photograph by U.S. Geological Survey.

The threat of fire to sagebrush landscapes largely comes from interactions with nonnative ("exotic") annual grasses and forbs, especially cheatgrass (*Bromus tectorum*) (fig. 2), which can promote increased fire frequency and fire spread across extensive areas (Brooks and others, 2004; Balch and others, 2013; Pilliod and others, 2017). Historically, average fire return intervals in sagebrush landscapes likely ranged from a few decades (Miller and Heyerdahl, 2008) to hundreds of years (Baker, 2006; Bukowski and Baker, 2013). Post-fire recovery to mature sagebrush conditions after fire was probably a slow process that typically required several decades or more, similar to post-fire recovery trends observed in contemporary sagebrush stands without substantial invasion by nonnative species (Lesica and others, 2007; Ellsworth and others, 2016; Shinneman and McIlroy, 2016). Warmer and drier sagebrush landscapes, especially those dominated by Wyoming big sagebrush and basin big sagebrush, often have sparse perennial grass cover and low resistance to nonnative species invasion (Chambers, Bradley, and others, 2014; Chambers, Pyke, and others, 2014; Taylor and others, 2014; Brummer and others, 2016). As cheatgrass and other fire-prone annual species invade these ecosystems, they fill interspaces between native perennial plants (Reisner and others, 2013), senesce early in the growing season (Chambers and others, 2016), and provide contiguous swaths of dried, fine fuels that facilitate fire spread and increase ignition rates (Brooks and others, 2004; Pilliod and others, 2017). Following fires, exotic annuals establish more readily and competitively displace native perennials, further intensifying nonnative plant dominance and future fire risk (Chambers and others, 2016). These conditions can lead to a self-perpetuating “grass/fire cycle” (D’Antonio and Vitousek, 1992) characterized by greatly reduced fire-free intervals that promote further dominance and spread of invasive, annual plant species (Brooks and others, 2004; Brooks, 2008) and prevent reestablishment of the native sagebrush community (Laycock, 1991; Brooks and others, 2016) (fig. 3).

Figure 2. Cheatgrass (*Bromus tectorum*). Photograph by U.S. Geological Survey.

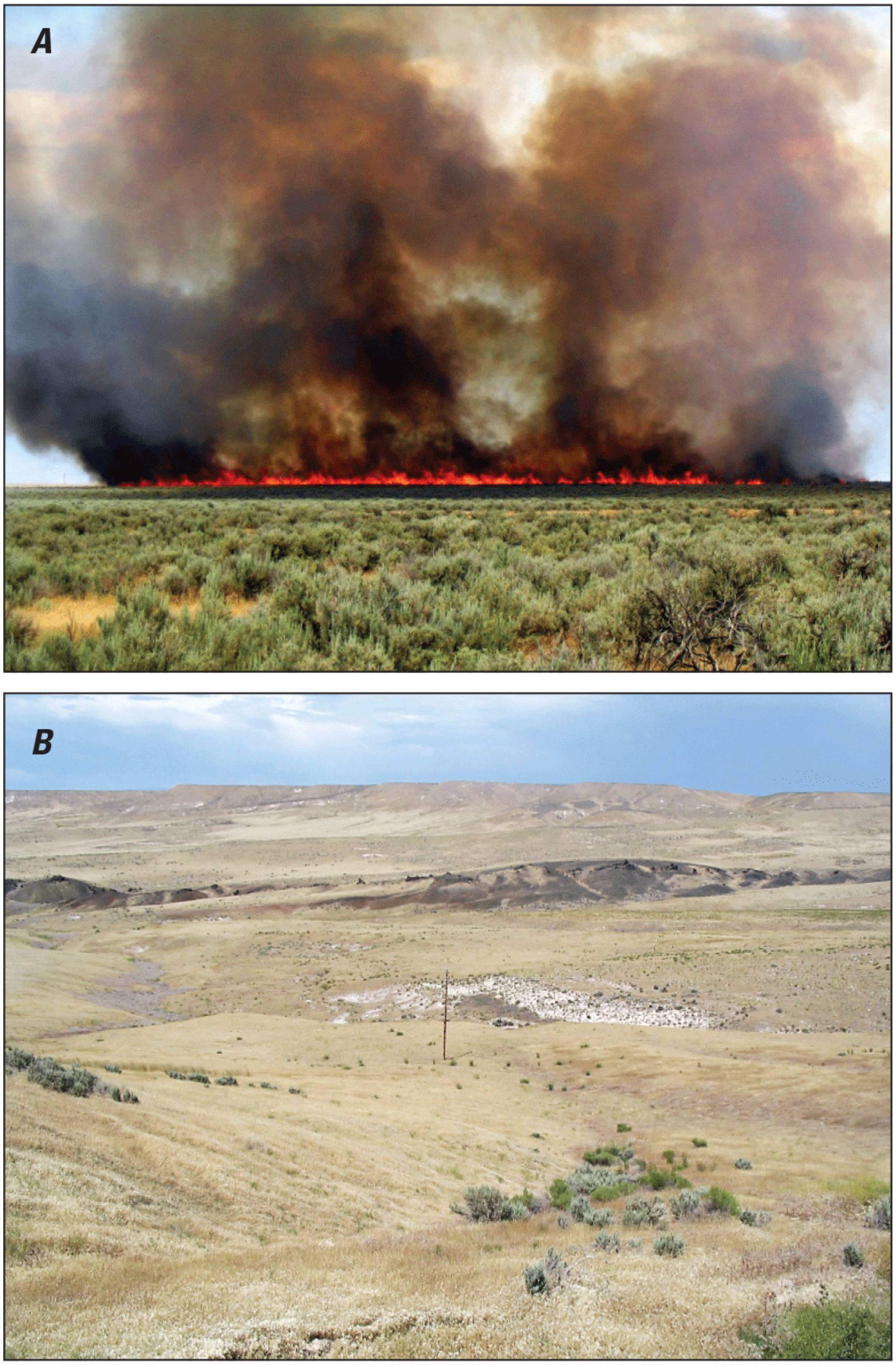

Figure 3. Examples (from southwestern Idaho) of ecological conversion via the grass/fire cycle: (a) fire burning in sagebrush landscape with dried cheatgrass fuels dominant in the understory, and (b) a landscape that formerly supported sagebrush-steppe but, after burning multiple times in recent decades, became dominated by cheatgrass and other fire-prone, annual species. Photographs by U.S. Geological Survey.

Protecting sagebrush ecosystems from the threat of the grass/fire cycle is critical for the myriad species they support. At least 350 plant and animal species depend on sagebrush ecosystems (Wisdom and others, 2005). The greater sage-grouse (*Centrocercus urophasianus*) (fig. 4) is a key sagebrush-obligate and potential umbrella species (Rowland and others, 2006) that is considered at risk throughout its range (Connelly and others, 2004, 2011). The steady loss and fragmentation of sagebrush habitat due to the grass/fire cycle, among other factors, is considered a primary threat to the species' remaining habitat, especially in the Great Basin (Miller and others, 2011; Balch and others, 2013; Brooks and others, 2015; Coates and others, 2016). Indeed, during 2015–17 alone, more than 1.3 million ha (about 3.3 million acres) of greater sage-grouse habitat burned in the U.S., and over two-thirds of that area was within the Great Basin (U.S. Department of the Interior, 2017). Loss of sagebrush habitat from increased wildfire activity has had negative effects on greater sage-grouse populations over the past 30 years, and may reduce the current population size by more than one-half over the next 30 years (Coates and others, 2015, 2016). Effects of exotic plant invasions and altered fire regimes on other sagebrush obligate and associated species are likely similar, but for most species the effects are largely unknown or relatively poorly studied (as reviewed by McAdoo and others, 2004; Litt and Pearson, 2013; Rottler and others, 2015).

Figure 4. Greater sage-grouse (*Centrocercus urophasianus*). Photograph by Tom Koerner, U.S. Fish and Wildlife Service.

In response to wildfire threats to sagebrush-dependent wildlife and other rangeland resources in the Great Basin, land management agencies rely heavily on a variety of pre-fire fuel treatments, fire suppression, and post-fire rehabilitation and restoration strategies aimed at increasing resistance to invasion by annual grasses and resilience from future wildfire disturbances. Implementing networks of linear fuel breaks has become a particularly strategic pre-fire management tool intended to enhance fire suppression effectiveness and limit ecological damage from unwanted wildfire (Green, 1977; Ager and others, 2013; Maestas, Pellant, and others, 2016; U.S. Department of the Interior, 2016a). A "fuel break" is defined by the National Wildfire Coordinating Group (2018) as “a natural or manmade change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled.” Land management agencies are increasingly planning and utilizing linear fuel break networks across much of the Great Basin to conserve sagebrush and greater sage-grouse habitat (Moriarty and others, 2016). However, despite the potential for fuel breaks to help slow the loss of sagebrush caused by fire, relatively little scientific information is available to assess either their effectiveness (that is, to control wildfire) or their ecological effects (that is, on plant and wildlife communities), especially in arid and semi-arid landscapes. In the only other review of fuel breaks for sagebrush ecosystems that has been compiled, the authors state, “Fuel break effectiveness continues to be a subject of much debate yet relatively little research has been conducted evaluating their role in constraining wildfire size and frequency” (Maestas, Pellant, and others, 2016, p. 4). Similarly, there is insufficient research regarding the effects of fuel breaks on rangeland ecosystems in general and the effects on wildlife populations specifically.

Objectives and Approach

This report is intended to serve as an initial assessment of fuel breaks in sagebrush landscapes of the Great Basin, including their potential effectiveness in altering fire behavior and reducing area burned (by facilitating fire suppression and containment), their ecological costs and benefits, and the need for further science. To accomplish these objectives, we examined prior studies, agency databases, and other scientific evidence for three crucial questions:

1. How effective are fuel breaks in reducing or slowing the spread of wildfire in arid and semi-arid shrubland ecosystems?
2. How do fuel breaks affect sagebrush plant communities?
3. What are the effects of fuel breaks on the greater sage-grouse, other sagebrush obligates, and sagebrush-associated wildlife species?

Before addressing these questions, we provide an overview of recent federal policies and management directives aimed at protecting remaining sagebrush and greater sage-grouse habitat, and discuss how the potential use of fuel breaks to help achieve these objectives also underscores the need for better scientific understanding of their potential effects. We then describe the fuel conditions, fire behavior, and fire trends in the Great Basin to set an operational context for the different types and designs of linear fuel breaks commonly used in the region. In light of the information provided, we close this report by summarizing what is known and not known about fuel breaks, and suggest how scientific inquiry and management actions can improve our understanding of fuel breaks and their effects in sagebrush landscapes.

The primary geographic focus of this review encompasses the sagebrush-dominated landscapes of the Great Basin (fig. 5), with an ecological focus on greater sage-grouse habitat and the sagebrush steppe and shrubland communities that are typically dominated by big sagebrush or low sagebrush. However, many of our findings are applicable to sagebrush ecosystems throughout the western half of the greater sage-grouse range, particularly where sagebrush community composition and climate conditions are similar to that of the Great Basin. These findings also may be pertinent to other shrubland ecosystems (for example, salt-desert shrublands, mountain shrublands) that are typically adjacent to, or intermixed with, sagebrush.

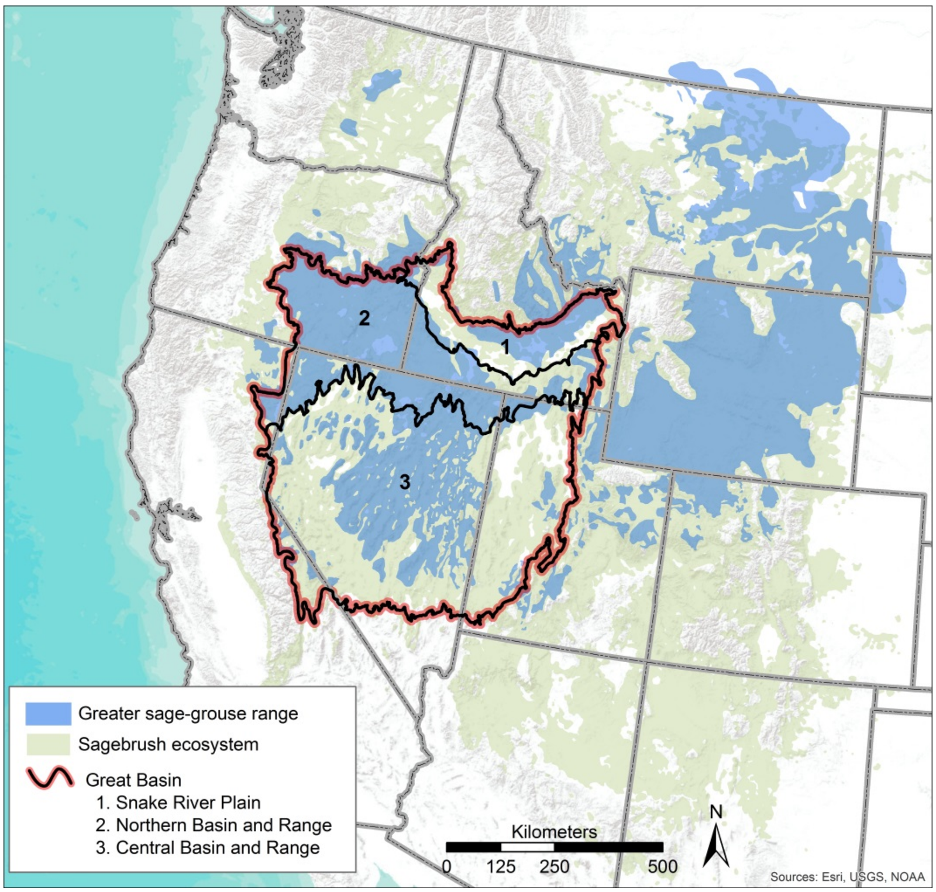

Figure 5. Location of the sagebrush ecosystem and distribution of greater sage-grouse in the Western United States. The Great Basin consists of the Central Basin and Range, Northern Basin and Range, and Snake River Plain ecoregions (Level III; U.S. Environmental Protection Agency, 2013). Sagebrush ecosystem data from U.S. Geological Survey (2018b); greater sage-grouse distribution data from U.S. Geological Survey (2018a).

To accomplish these objectives, we reviewed the scientific literature directly related to fuel breaks, but also considered research pertaining to the effects of other types of fuel treatments on sagebrush communities, as well as from other anthropogenic disturbances (especially linear landscape features, such as roads). Assessments of fuel break effects also were considered within an operational understanding of sagebrush ecosystem dynamics, including plant community function, disturbance ecology, fire behavior, nonnative species invasions, and wildlife population dynamics and habitat needs. We considered articles in peer-reviewed science publications, but also examined “gray” literature (for example, graduate theses and agency reports). Our objective did not include analytical review approaches (for example, a “meta-analysis”), largely due to the current paucity of data and quantitative research regarding the effects of linear fuel breaks in sagebrush ecosystems. Additionally, we assessed the utility of relevant agency databases that contain information on fuel treatment effects and effectiveness (for example, the Fuel Treatment Effectiveness Monitoring database) to help guide strategic fuel break plans moving forward.

Fuel Breaks to Protect Greater Sage-Grouse Habitat—Policy, Management, and Science Directives

In light of recent decisions regarding the legal status of the greater sage-grouse, rangeland fire suppression and sagebrush conservation have become dominant land management priorities in the Great Basin, and fuel breaks have been identified as an important strategy to help achieve these goals. The greater sage-grouse was first considered for listing under the U.S. Endangered Species Act (ESA) by the U.S. Fish and Wildlife Service (USFWS) in 2005. Listing for the greater sage-grouse was determined not to be warranted, but the official decision document recognized fire as significant threat, especially in the western part of the species’ range (U.S. Fish and Wildlife Service, 2005). A subsequent 2010 decision by the USFWS concluded that listing under the ESA was warranted but precluded by higher priorities, and it again emphasized the increasing role of fire in threatening greater sage-grouse habitat (U.S. Fish and Wildlife Service, 2010). Under court-order in 2015, the USFWS determined that the greater sage-grouse did not warrant protection under the ESA and would be removed from the candidate list (U.S. Fish and Wildlife Service, 2015). The agency cited the effectiveness of ongoing conservation partnerships that were benefitting greater sage-grouse over 90 percent of its 7-million-hectare range.

Despite this legal outcome, land management agencies were tasked with implementing policies that would conserve and benefit sagebrush ecosystems, in large part to ensure continued protection of greater sage-grouse habitat. In January 2015, U.S. Department of the Interior Secretarial Order 3336 called for a “science-based strategy to reduce the threat of large-scale rangeland fire to habitat for the greater sage-grouse and the sagebrush-steppe ecosystem” (U.S. Department of the Interior, 2015a, Section 6a). Two companion reports were subsequently published to reinforce and facilitate the Secretarial Order: “The Integrated Rangeland Fire Management Strategy” was intended to specifically identify effective actions to prevent and suppress rangeland fire, and to restore fire-affected sagebrush landscapes, while the “Actionable Science Plan” (hereinafter, IRFMS-ASP) identified key science needs and research priorities that would promote more efficient and effective use of specifically identified management strategies (U.S. Department of the Interior, 2015b, 2016a). Fuel breaks were identified as a key strategy in these documents.

Although the IRFMS-ASP suggested that the design of fuel breaks should use existing spatial information to help protect sagebrush focal areas and greater sage-grouse priority habitats (U.S. Department of the Interior, 2016a), it also pointed out that little is known about the effects of fuel breaks on greater sage-grouse populations, habitat use, and movement across the landscape. Moreover, the IRFMS-ASP outlined other potential negative effects of fuel breaks that are poorly studied, including spread of invasive plants, effects on other sagebrush-obligate species, increased habitat fragmentation, expanded access for off-highway vehicles, and increased potential for human-caused ignitions. Given such knowledge deficiencies, two of the eight "Fire Science Needs" that are described and prioritized in the IRFMS-ASP identify fuel breaks as high priority areas for scientific research. Specifically, Fire Science Need #5 stresses the need to determine how to minimize the potential deleterious ecological consequences of fuel breaks, similar fuel treatments, and resulting landscape patterns that are ostensibly designed to benefit greater sage-grouse and their habitats by reducing wildfire spread (U.S. Department of the Interior, 2016a, p. 21). Fire Science Need #8 seeks to determine the characteristics of fuel breaks that are effective in preventing fire spread or intensity, including through "…synthesis of the literature, critical evaluation of techniques and plant materials used in fire breaks (species, structure, placement, and native versus nonnative species), and economic tradeoffs" (U.S. Department of the Interior, 2016a, p. 26). The IRFMS-ASP additionally recommended various complementary steps designed to encourage assessment, research, and monitoring to determine the effectiveness of different types of fuel breaks in changing fire behavior, their potential ecological effects, and prospects for long-term maintenance.

Fire Regimes, Patterns, and Trends in the Great Basin

Recent studies have demonstrated that fire regimes across large portions of the Western United States have changed over the past several decades, with longer fire seasons, more area burned, and shorter fire return intervals on average over time (for example, Westerling and others, 2006; Littell and others, 2009; Dennison and others, 2014). Although fire has always been an integral natural process in most ecosystems and fire regimes are dynamic over time, anthropogenic factors such as changing climate, land use effects (for example, grazing, fire suppression), and nonnative species invasions are likely increasing fire activity in some ecosystems and pushing them beyond their historical ranges of variability (for example, Westerling and others, 2006; Abatzoglou and Kolden, 2013; Higuera and others, 2015). Of the major ecosystem types in the Western United States, sagebrush ecosystems have among the most clearly altered fire regimes due to these human-induced factors (Keane and others, 2008; Abatzoglou and Kolden, 2011; Balch and others, 2013; Bukowski and Baker, 2013).

A recent report by the U.S. Geological Survey (Brooks and others, 2015) documented that about 8.4 million ha burned in the western portion of the greater sage-grouse range (which is largely located in the Great Basin) over a recent 30-year period (1984–2013). Roughly 88 percent of that burned area was in sagebrush vegetation types. During that same 30-year period, about 1.2 million ha burned two or more times, and the vast majority (about 85 percent) of this "recurrent fire" area was also in sagebrush vegetation types, including cheatgrass invaded areas. Moreover, the annual area burned by fires in the western portion of the greater sage-grouse range has likely increased over the 30-year period, in large part driven by trends in the Snake River Plain, where recurrent fire is contributing to average fire return intervals of less than 7.5 years in some areas. The report also demonstrated that fire sizes have been increasing over the 30-year period in portions of the Great Basin (see also Balch and others, 2013), with “mega-fires” greater than 40,000 ha not uncommon, and with some individual fires exceeding 200,000 ha (fig. 6). Finally, the primary fire season in the Great Basin, which typically starts in May and often extends into September (as defined by the start dates of large fires), is the longest in the Snake River Plain, and there is statistical evidence that it has lengthened over the past 30 years in the southern portion of the Great Basin (Brooks and others, 2015). Although the fire area patterns and trends outlined in Brooks and others (2015) were derived from the best available data on large fires (>405 ha, which comprise about 95 percent of total area burned), small fires (comprising about 5 percent of the area burned) are not included, and some large fires are potentially missing from the earlier portion of the 30-year record (Short, 2015).

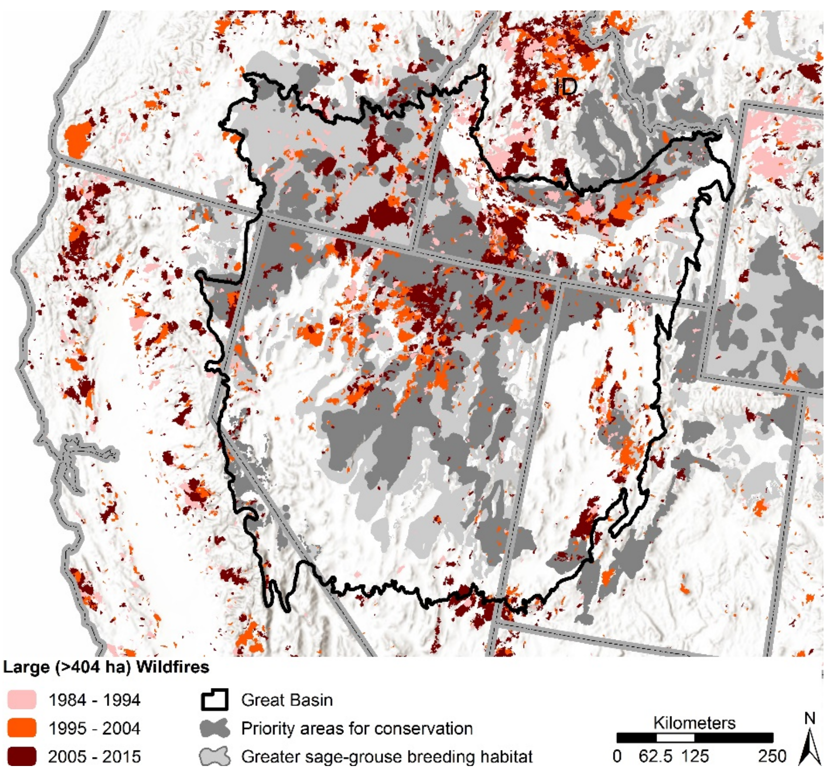

Figure 6. Large fires in and around the Great Basin, 1984–2015. Data from Monitoring Trends in Burn Severity (2018).

The number and extent of wildfires in the Great Basin (or any region) are influenced by ignition sources, climate and fire weather, fuel availability, and topography (DeBano and others, 1998). Historically, these factors contributed to infrequent occurrences of large fires in sagebrush landscapes of the Great Basin (Bukowski and Baker, 2013). However, fire trends of the past several decades have been influenced by human-altered fire regimes, largely due to interactions among ignition sources, invasive plants, and climate variability. Within the Great Basin, lightning accounted for 58 percent of all fires and 84 percent of area burned between 1992 and 2015 (Short, 2017) (fig. 7). However, human-caused ignitions in the U.S. generally are increasing the number of wildfires, the area burned, and the fire season length (Balch and others, 2017). In the Great Basin, the area burned by both lightning and human-caused fires is enhanced by the widespread availability of herbaceous fine fuels, especially in areas with substantial cover of nonnative annual grasses that dry early in the fire season and accumulate as litter over several years (Balch and others, 2013; Pilliod and others, 2017). In a recent remote-sensing mapping effort in the northern Great Basin, about 82 percent of the area in lower-elevation (<2,000 m) rangelands had some cheatgrass cover, about 33 percent had greater than 10 percent cover, and some areas (especially in the Snake River Plain) were at or near 100 percent cover (Boyte and Wylie, 2016) (fig. 8). Cheatgrass-dominated areas have been shown to be approximately two to four times more likely to burn compared to other rangeland community types (Balch and others, 2013).

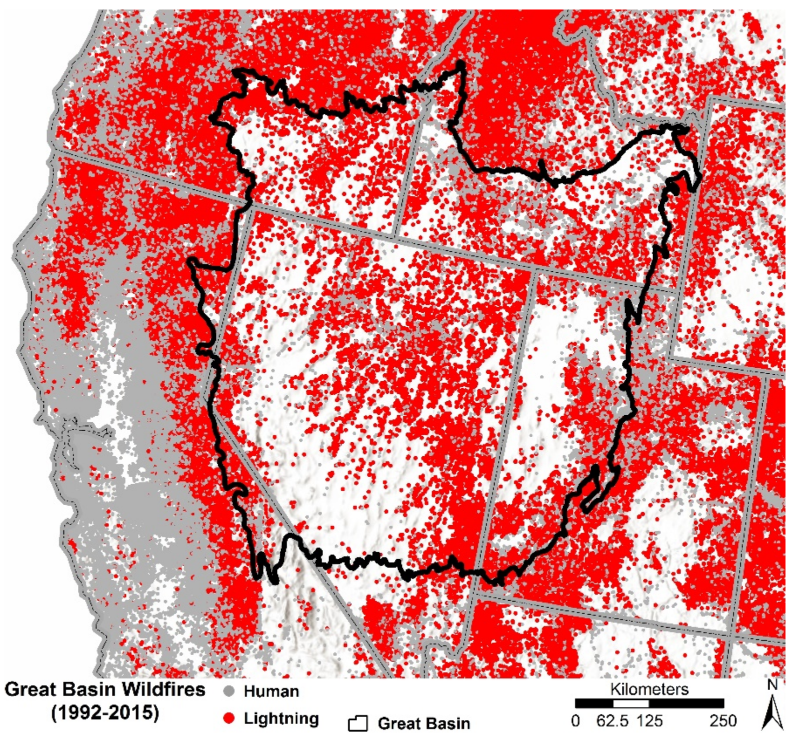

Figure 7. Wildfire ignitions by source (human and lightning) in and around the Great Basin, 1992–2015. Data from Short (2017).

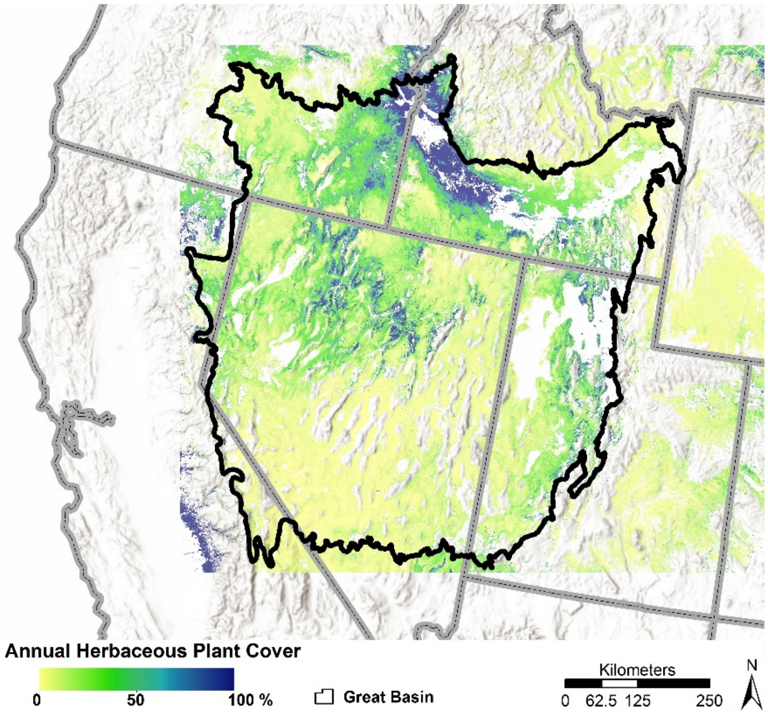

Figure 8. Near-real-time cover (June 19, 2017) of annual herbaceous grasses in the Great Basin. Data from Boyte and Wylie (2017).

Climate and fire weather influence fuel and fire dynamics but act at different spatial and temporal scales. Fire weather includes precipitation, wind speed, temperature, and relative humidity at temporal- and spatial-scales relevant to behavior of individual fires (Schroeder and Buck, 1970; Brown, 1982; Wright, 2013). Climate is a long-term phenomenon of annual cycles of precipitation and temperature that drive plant growth and phenology, fuel accumulation, desiccation of biomass (vegetation and litter), and lightning patterns that influence fire patterns and trends across broad spatial- and temporal-scales (Westerling and others, 2003; Minnich, 2006; Pilliod and others, 2017). Though climate conditions vary along elevational and latitudinal gradients, most of the Great Basin is typified by cold winters and warm-to-hot summers that receive relatively little precipitation. Because summer conditions are typically hot and dry enough to support fire in the Great Basin, there is no strong connection between contemporaneous moisture deficits alone, fuel drying, and wildfire activity in the region (Westerling and others, 2003; Davies and Nafus, 2013). Rather, fuel loading is typically the limiting factor that drives fire activity in Great Basin shrublands, and studies have demonstrated that higher precipitation during the winter and early growing season results in greater amounts (cover, biomass) of grasses and forbs, including nonnative species such as cheatgrass (Pilliod and others, 2017). Moreover, these fuel loads increase fire risk over several years because of nonnative forb and cheatgrass litter accumulation (Pilliod and others, 2017), resulting in the well-established phenomenon of increased fire activity (more fires and area burned) 1–3 years following above-normal moisture (Billings, 1994; Knapp, 1998; Westerling and others, 2003; Littell and others, 2009; Abatzoglou and Kolden, 2013; Balch and others, 2013). Modeled projections suggest that future climate could enhance both fuel production and fire-weather conditions, potentially making these ecosystems even more fire-prone in coming decades (Stavros and others, 2014; Barbero and others, 2015; Liu and Wimberly, 2016).

Fuel Break Objectives, Types, and Design Considerations

Within the fire environment (fig. 9), fire weather and topography cannot be altered, but fuels can be modified. A *fuel treatment* is a type of pre-suppression activity intended to manipulate or reduce fuels and modify fire behavior in an effort to mitigate potential negative wildfire impacts. The types and spatial pattern of fuel treatments can vary depending on the fire regime, fire management objective, and values at risk (Ager and others, 2013). A "fuel break" is a type of fuel treatment that involves the removal or modification of vegetation in strategically placed strips or blocks of land, specifically to disrupt fuel continuity and reduce fuel loads and accumulation. Fuel breaks target removal or control of plants with low-moisture or high volatile oil content that are more likely to carry fire, increase fire residence time, promote longer flame lengths, or encourage spotting (Weatherspoon and Skinner, 1996; Agee and others, 2000; Maestas, Pellant, and others, 2016). The strategic spatial configurations of fuel breaks are intended to enhance firefighter access, improve response times, provide safe and strategic anchor points for wildland firefighting activities (for example, back-burning), and compartmentalize wildfires to constrain their growth (Green, 1977; Maestes, Pellant, and others, 2016). A key point among these objectives is that fuel breaks are designed to facilitate fire suppression operations, and are not intended to stop fire activity unaided (though they occasionally do). Indeed, after interviewing 15 experienced fire managers in the northern Great Basin, Moriarty and others (2016) found wide agreement that the purpose of fuel breaks is to “…allow firefighters to actively engage in fire suppression in a safe, strategic manner without committing exhaustive resources to control or contain the spread of wildfire.” Limited systematic analysis of fuel break effectiveness in forest and chaparral ecosystems also suggests that the main way in which fuel breaks effectively help to constrain fire size is by facilitating fire suppression activities (for example, Syphard and others, 2011a, 2011b).

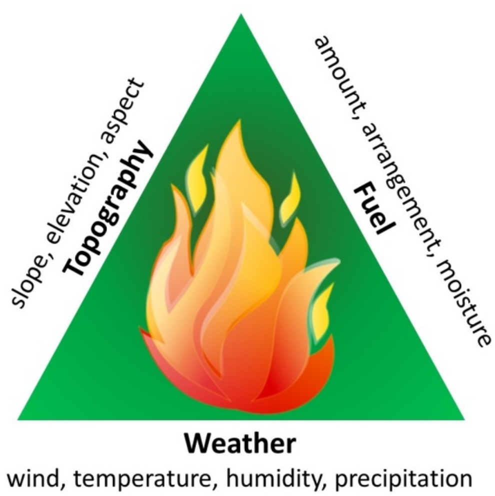

Figure 9. Fire environment triangle. Once combustion is sustained, the fire environment (weather, topography, and fuels), influences the growth and behavior of a fire. Within the fire environment the three factors are interrelated and vary with both space and time.

The three main types of linear fuel breaks used in the Great Basin include green strips, brown strip*s*, and mowed linear fuel breaks, and these are often employed along with other treatments, including modifying existing roadbeds, herbicide use, or targeted grazing. Linear fuel breaks are often dispersed among other broad-scale treatments designed to disrupt fire spread and help facilitate fire containment, including use of prescribed fire or thinning and removal of piñon (*Pinus* spp.) and juniper (*Juniperus* spp.) trees. In the following section, we describe the three primary types of linear fuel breaks used in the Great Basin. We later discusss potential ecological effects and limitations of each fuel break type in more detail, as we address fuel break effectiveness and effects on plant and animal communities.

Green Strips

The goal of constructing a green strip is to replace more flammable and contiguous plant communities (particularly those dominated by exotic annual grasses, such as cheatgrass) with perennial plants that retain moisture later into the growing season, often by using plants that grow as widely spaced, low-statured individuals that result in large, bare interspaces (fig. 10). Green strips are typically constructed in widths of 30–90 m along both sides of a road, although they can be wider and may result in a combined width of 180 m or more when including the road (Pellant, 1990, 1994, 2000; St. John and Ogle, 2009). In green strips, vegetation is typically first removed or altered with a plow, harrow, or chain, and often in combination with application of a broadly effective herbicide (for example, glyphosate) to control existing vegetation, with additional herbicide treatments (for example, Imazapic) to reduce invasive annual grasses (Maestas, Pellant, and others, 2016). New species are then sown into the prepared strips, with ideal seeded species having relatively deep roots, forming persistent stands that provide some competitive pressure against exotic annual invasion, and having relatively inexpensive seeds that germinate reliably. Not many species have these criteria, and they include the nonnative perennial crested wheatgrass (*Agropyron cristatum*, also *A. desertortum* and their varieties and hybrids) and the subshrub/semi-evergreen forage kochia (*Bassia prostrata*), as well as a few others (Monsen, 1994; Pellant, 1994; St. John and Ogle, 2009) (fig. 10). These vegetation type conversions are designed to result in reduced fuel loads, discontinuous fuels, and less-flammable vegetation that can slow rates of spread and wildfire intensity (Davison and Smith, 1997). Replacing cheatgrass or other annual species with more fire resistant vegetation breaks the continuity of fuels across the landscape, reducing the rate of spread and aiding in suppression success (Pellant, 1994). Early in the fire season, the increased fuel moisture of the vegetation alone can delay or limit burning (Monsen, 1994). Additionally, increasing the proportion of plants with higher moisture content during peak fire season can reduce the potential for ignition and rate of spread (Pellant, 1994).

Figure 10. Great Basin green strips. (a) Forage kochia (*Bassia prostrata*) in southwestern Idaho; (b) forage kochia; and (c) crested wheatgrass (*Agropyron cristatum*). Photographs by U.S. Geological Survey.

If established under ideal conditions, green strips may require relatively little maintenance, especially if planted species are drought resistant, tolerant of grazing, able to survive fire, or have competitive advantages over more fire-prone species. However, in many cases, the ability of a green strip to alter fire behavior generally diminishes over time without regular maintenance, and the treated areas may be prone to litter accumulation or invasion by annual species (Monsen, 1994; Gray and Muir, 2013; Meastas and others, 2016a). Thus, the effectiveness of a green strip to alter fire behavior can reduce over time without maintenance, and they typically need to be mowed or grazed to reduce the buildup of fine fuel between the desired plants (Monsen, 1994; Maestas, Pellant, and others, 2016).

Brown Strips

The two-fold objective of a brown strip (fig. 11) is firstly to limit fire starts within the fuel break and secondly to provide a place for firefighters to engage in suppression activities. A brown strip is typically installed along major thoroughfares (for example, paved highways) using a harrow or plow to completely remove vegetation (that is, all fuels) down to bare mineral soil, typically in widths of 3–6 m (and sometimes wider). Brown strips are the most simplistic of the linear fuel breaks in regards to potential fire behavior, because they are devoid of vegetation and thus cannot burn. Brown strips function as anchor points for direct-attack fire suppression or as a line for indirect attack tactics (for example, burnout operations) ahead of the approaching fire front. However, because of the narrow width that brown strips are typically constructed, they are breached under higher intensity fire events where flame length or spotting exceed the width (Green, 1977; Wilson, 1988; Pellant, 2000). Moreover, the effectiveness of a brown strip is short-lived (for example, single fire season) without continued maintenance (for example, re-disking or herbicides), as they are prone to weedy plant invasion (Pellant, 1990).

Figure 11. Brown strip that stopped a fire that started along an adjacent highway. Photograph by Bureau of Land Management.

Mowed Linear Fuel Breaks

The primary goal of creating a mowed fuel break is not to reduce the total fuel load but rather to compact and limit the vertical extent of the fuel bed, which results in lower flame lengths and reduced rates of spread. Effectively, mowing redistributes fuel loadings by reducing vegetation to 15–30 cm in height and by leaving the cut plant material on site (Maestas, Pellant, and others, 2016) (fig. 12). Mowed fuel breaks are typically at least 30–90 m wide and constructed along both sides of a road (they may be substantially wider, depending on fuel conditions and fire suppression needs). Mowed fuel breaks are the preferred method of treatment within patches of intact sagebrush because they are relatively easy to implement and, if wide enough, can help to disrupt large, wind-driven fires and limit wildfire spread (Maestas, Pellant, and others, 2016). However, reducing the canopy cover can increase herbaceous plants in the short-term, necessitating further intervention (Davies and others, 2011; 2012a), and treated areas require regular mowing or targeted grazing to maintain the desired fuel height (Schmelzer and others, 2014).

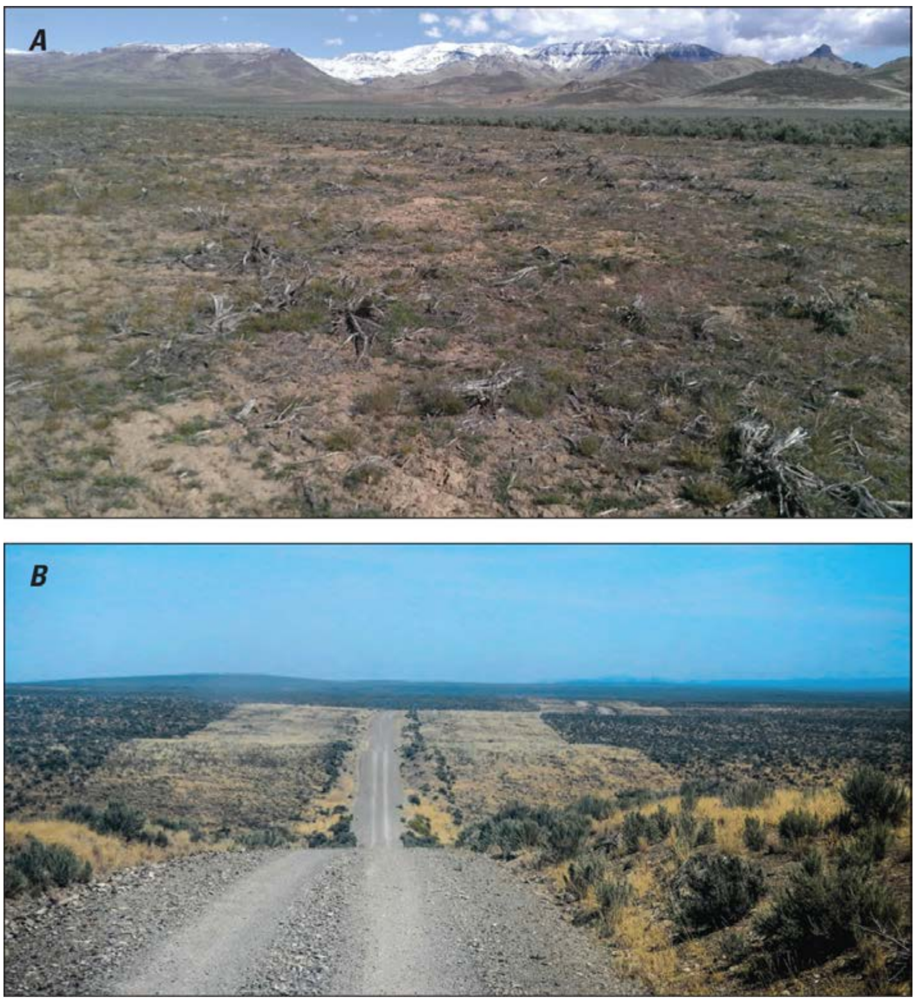

Figure 12. Example of (a) recent mowing in northern Nevada and (b) mowed linear fuel breaks along both sides of a gravel road in southwestern Idaho. Photographs by (a) Bureau of Land Management and (*b*) U.S. Geological Survey.

Other Fuel Break Treatments

One additional category of fuel break treatment worth mentioning that is relatively new, but now in limited use, is targeted grazing. In this approach, fuel reduction is accomplished by prescribing livestock utilization to specific levels and grass heights (Diamond and others, 2009; Schmelzer and others, 2014). Appreciable logistic challenges lie in the contractual constraints of grazing permits, economic costs or benefits to permittees, practical challenges of concentrating livestock into linear features, and other issues. Targeted grazing has occurred primarily on degraded sites with low resistance to invasion and existing high cover of exotic annual grass–that is, sites and landscapes that may have little ecological value to lose (Strand and others, 2014). Because of its rather limited and novel usage, the effects of targeted grazing are not explored further in this report.

Fuel Break Spatial Design and Strategic Placement Considerations

In addition to directly altering fuel characteristics within the break itself, the ability of fuel breaks to limit fire ignition and spread also depends on spatial design, particularly the width of individual breaks and the configuration of a fuel break system (that is, a network of individual fuel breaks) on the landscape. Depending on the type, individual fuel breaks are often constructed in widths ranging from just a few meters to over 100 m along roadsides, typically along roadways that provide reliable firefighter access (fig. 13). However, linear fuel breaks are also sometimes constructed along other human features on the landscape that may require protection or that can facilitate access (for example, power-lines, fences, and housing developments). Although wider fuel breaks are generally considered better for effectively altering fire behavior under more extreme conditions, it is not practical or realistic to create excessively wide fuel breaks that extend over many linear kilometers. As a result, different analytical approaches have been used to suggest efficient widths and shapes of individual fuel breaks. For instance, Finney (2001) used predicted fire shape and rates of spread to determine that the width and length of a rectangular fuel treatment unit could be considered optimized when the resulting shape caused the portion of the fire burning through the unit and the portion burning around it to bypass the unit at the same rate. Wilson (1988) used grassland fire experiments to determine that the flame length of an approaching fire can be used as a rough approximation for the necessary width of a brown strip to stop the spread of fire via flame contact. Using a more operational approach, federal agencies have recently promoted fuel break widths of about 90 m on both sides of a road, using both flame length considerations and the need for establishing enough fire-free space to provide adequate safety zones for firefighting activities (U.S. Department of the Interior, 2016b) (fig. 14).

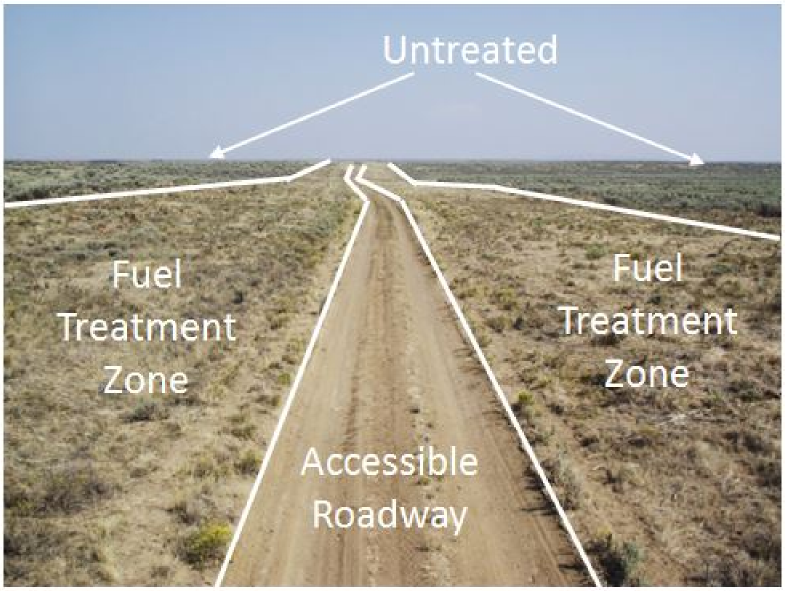

Figure 13. Conventional fuel break design along an accessible roadway. Photograph by Bureau of Land Management.

Figure 14. Example of how fuel type impacts flame lengths, with approximately 30-foot-long flames in sagebrush stands versus approximately 7-foot-long flames along mowed roadside. Figure by U.S. Department of the Interior (2016b).

Other spatial and strategic placement considerations include positioning fuel breaks on the landscape to most effectively influence patterns of fire ignition, probability, intensity and spread (based on prevailing wind direction). Simulation studies in both North American forests and Mediterranean woodland-shrublands have shown that optimizing the spatial pattern of fuel treatments is more effective at limiting fire spread than random or non-strategic placement (Finney, 2001; Duguy and others, 2007; Parisien and others, 2007; Schmidt and others, 2008; Bar-Massada and others, 2011; Oliveira and others, 2016). There has been relatively little spatially explicit fire behavior or fire-connectivity modeling done to help plan more effective fuel break networks in non-forest landscapes. Gray and Dickson (2016) used circuit theory simulations on rangelands in the Kaibab Plateau in Arizona to test the effectiveness of green strips to reduce overall fire spread between patches of cheatgrass within a landscape of piñon-juniper and sagebrush. Their models suggested that strategic placement of green strips at locales where fire is most likely to spread to surrounding areas, representing just 1 percent of the study area landscape, could decrease overall area burned. Recently, federal agencies and their partners have also been using landscape simulation models to help design fuel treatments more effectively across large landscapes in the Great Basin, to demonstrate the utility of modeling to improve the targeting of fuels reduction projects, and to minimize potential impacts on greater sage-grouse habitat (Rideout and others, 2017). However, we are aware of only a few such modeling studies for the Great Basin (Welch and others, 2015; Opperman and others, 2016) and, to our knowledge, these have not undergone external, scientific peer-review. Experimentally testing various fuel break designs that are supported by modeling analysis is a logical next step to ensure their efficacy. In the only such study we are aware of in the Great Basin, the Bureau of Land Management (G. Dustin, written commun., April 20, 2017) tested a spatially strategic fuel break configuration as suggested by Finney (2001), and results indicated that rate of fire spread and flame length could be effectively reduced by using parallel, overlapping disc lines in a cheatgrass dominated landscape in northern Utah. However, such designs are not likely to be practical in intact sagebrush habitat, due to wildlife habitat fragmentation concerns (as discussed later).

When it is not feasible to complete spatially explicit fire behavior simulations for local planning, nationally produced maps of fire and fuels data may still provide useful information for the placement of fuel breaks within landscapes. Here, we highlight a few examples of national-scale datasets, some with fairly comprehensive (gridded) spatial coverage. Fire data from the Monitoring and Trends in Burning Severity program (Monitoring and Trends in Burning Severity, 2018) uses a consistent methodology to provide fire perimeter and severity information for all fires 405 ha (1,000 acres) or larger that have burned since 1984 (Eidenshink and others, 2007). This comprehensive and spatially explicit dataset can help to target fuel break locations; for instance, by identifying fire spatial patterns and temporal trends that indicate changing fire extent or frequency. The smallest fires–especially those less than 40 ha (about 100 acres)–are often only reported as point locations (that is, not fire boundaries) in other available fire datasets, and are less reliable due to missing or inaccurate information and redundancy errors (Brooks and others, 2015). However, there are now relatively comprehensive datasets that contain fires of all sizes and that attempt to reconcile problematic small fire records (Short, 2017; Welty and others, 2017). Small fires are more numerous than large fires and, although they account for only about 5 percent of area burned over time (Eidenshink and others, 2007), may be particularly relevant for locating areas with high rates of ignition and for assessing fuel break effectiveness (for example, to determine if fuel breaks influenced fire size).

The LANDFIRE program (LANDFIRE, 2018) is a source of gridded geospatial information available for the entire United States. It can be used to assess potential fire threats based on disturbance history, vegetation type, and fuel characteristics (Rollins, 2009; Ryan and Opperman, 2013). The LANDFIRE program provides fuel model grids for predicting fire behavior (for example, spread and intensity) and has recently offered dynamic fine fuel measurements for the Great Basin and Southwest based on current fire season herbaceous cover (currently available as provisional data [LANDFIRE, 2017]). These dynamic fuels data are meant to better reflect the seasonal and inter-annual variability in fine fuel loadings that are common in desert and semi-desert ecosystems (Gray and others, 2014; Pilliod and others, 2017).

Other highly pertinent products include mapped analyses of wildfire likelihood, intensity, and risk (using comprehensive fire and fuels data for the conterminous United States). These analyses are intended to inform evaluations of wildfire risk or prioritization of fuels management needs across large landscapes. Short and others (2016) developed mapped estimates of annual likelihood of a fire burning (that is, "burn probability," fig. 15a) and associated intensity (under current landscape conditions and fire management practices, fig. 15b) by simulating tens of thousands of hypothetical contemporary fire seasons (Finney and others, 2011). Recently, Chambers and others (2017) combined the fire probability maps developed by Short and others (2016) with greater sage-grouse breeding habitat probability and resilience/resistance maps to indicate where sagebrush and greater sage-grouse habitats are at highest risk from fire across the sagebrush biome (fig. 16). More specifically for Great Basin rangelands, Pilliod and others (2017a) developed a model of wildfire risk on the basis of established relationships between seasonal precipitation data and wildfire characteristics in Major Land Resource Areas. Finally, there are myriad other fire-relevant datasets that contain dynamic (fuel moisture and fire danger rating), static (fuel models), and historical (ignition location/source) information of varying geographic coverage, resolution, and utility (U.S. Forest Service, 2018) that could also aid fuel break design, but assessing each of these is beyond the scope of this review.

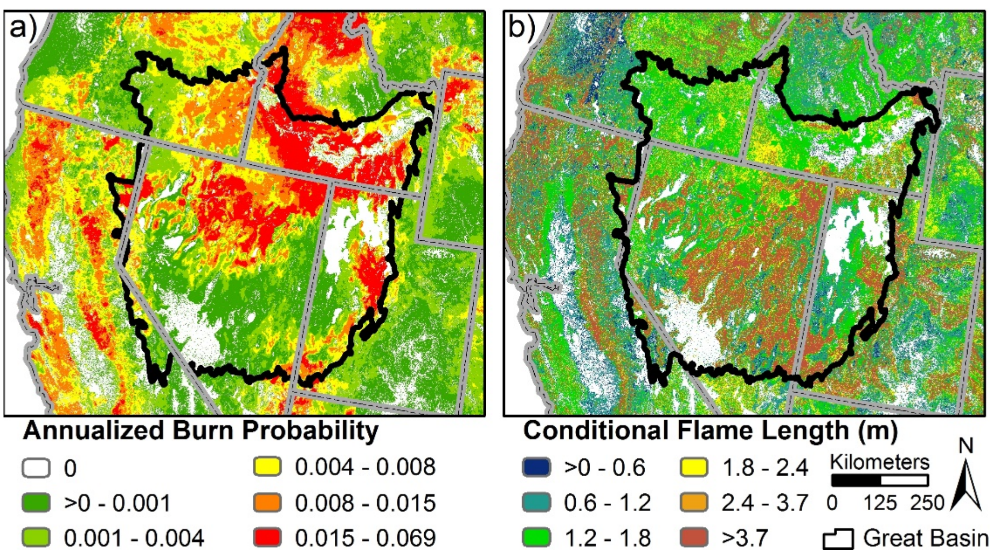

Figure 15. Nationally available maps of (a) simulated fire probability and (b) intensity for the Great Basin. Data from Short and others (2016).

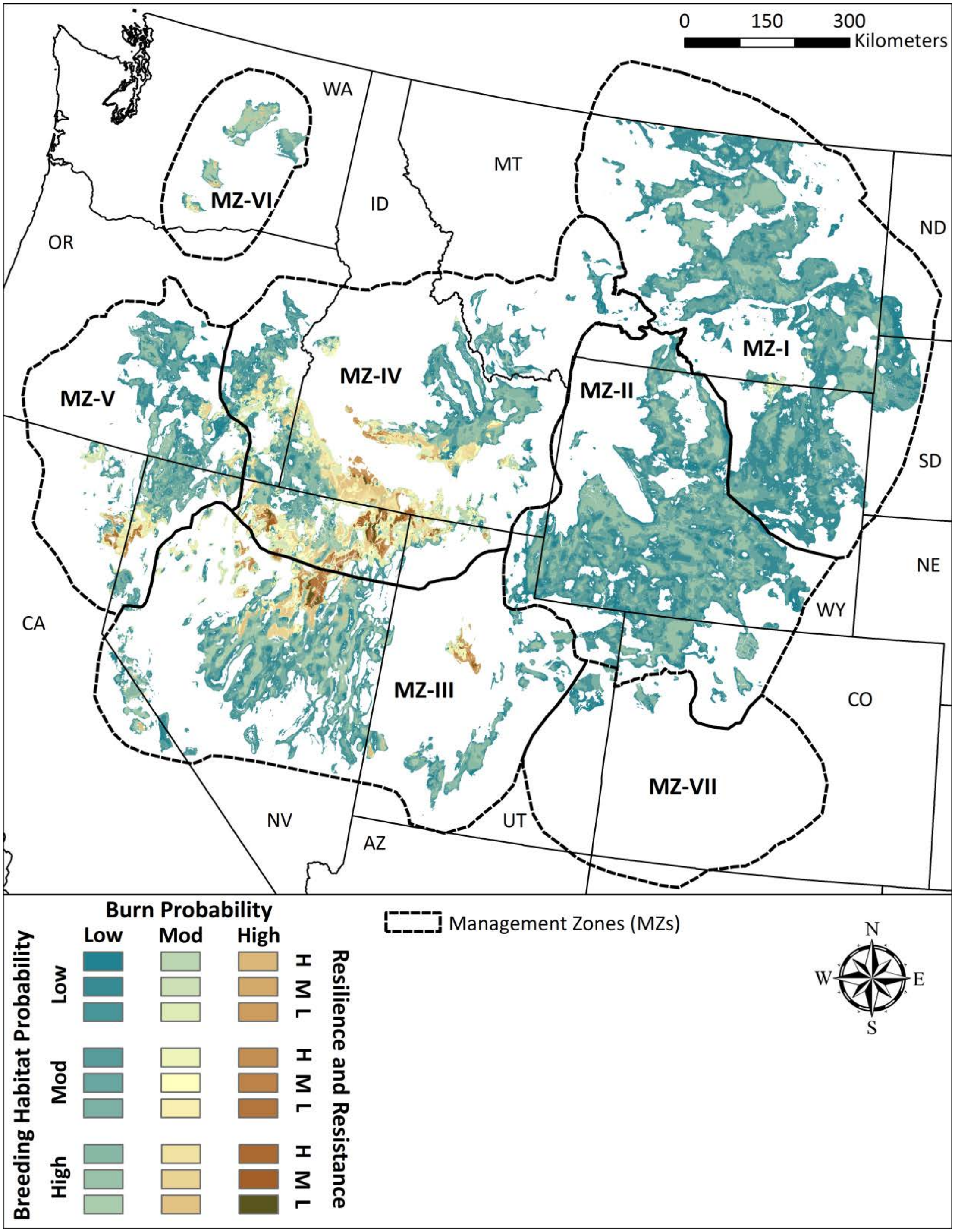

Figure 16. Wildland fire risk map for greater sage-grouse, in which Chambers and others (2017, fig. A10.1) depicted 27 different combinations of burn probability and threats to sagebrush ecosystems, using greater sage-grouse breeding habitat probability (Doherty and others, 2016), resilience and resistance classifications (Maestas, Campbell, and others, 2016), and large wildland fire probability (Short and others, 2016). Effectively, wildfire risk increases as colors on the map transition from blue-green to brown, reflecting combinations of increasingly greater fire probability, lower resistance and resilience, and more valuable greater sage-grouse habitat.

Using Wildfire Simulation to Model Fuel Treatment Effects on Fire Behavior

Modeling is another important tool that can be used to design and maintain fuel breaks, by projecting their effectiveness in altering fire behavior and assessing their ability to provide utility and safety for firefighting activities. Fire modeling systems (that is, "fire simulators") are important tools in fuels management because they can be used to predict the effect of fuel treatments on potential fire behavior, including flame length, rate of spread, fireline intensity, fire growth, and burn patterns that affect the ability to safely use suppression activities (Miller and Landres, 2004; Varner and Keyes, 2009). Fire modeling systems exist for both stand- (that is, typically <40 ha) and landscape-level assessments (>40 ha).

Commonly used stand-level (or point-based) fire systems are non-spatial models that give a “snapshot” of potential fire behavior for a given fire environment (that is, with uniform fuel, topography, and fire weather conditions in time and space), as specified by the modeler. Thus, model users can alter inputs (for example, by changing fuel types or wind speed) among simulations to compare fire behavior under different environments (as in fig. 17). Recently, such models have been used by land management agencies in the Great Basin to assess the likely effectiveness of treated fuel conditions in proposed fuel break projects for Great Basin rangelands (U.S. Department of the Interior, 2016b). Behave Plus (Andrews, 2014) is the most frequently used non-spatial fire behavior system among fire and fuel management professionals (Miller and Landres, 2004).

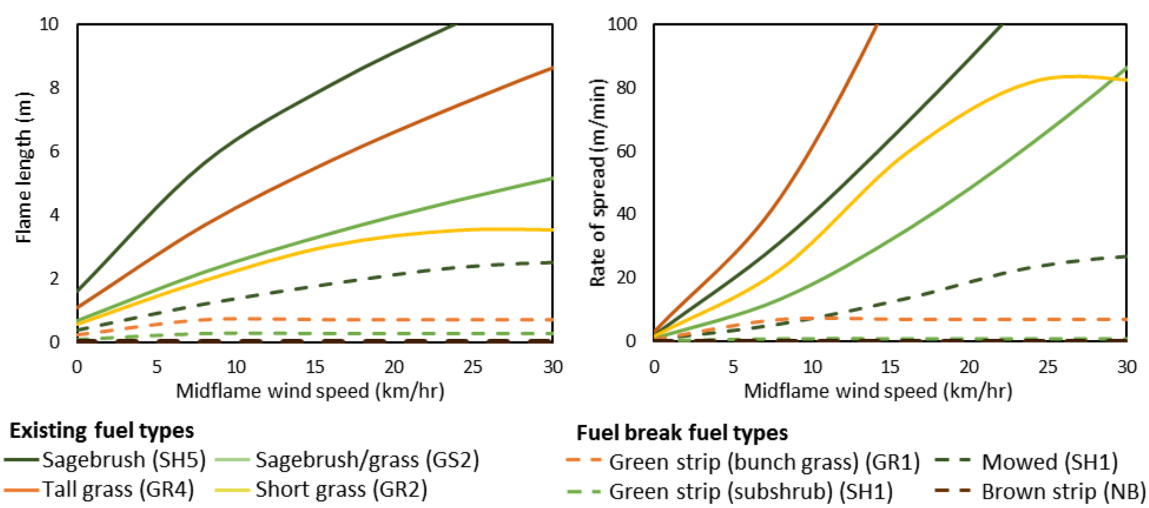

Figure 17. Predicted flame length and rate of spread for common existing and treated fuel types within the Great Basin using BehavePlus (Andrews, 2014), a stand-scale, fire-behavior model. Fuel models are from Scott and Burgan (2005), where GR is "grass," GS is "grass shrub," SH is "shrub," and NB is "non-burnable." Fuel moisture levels were different for mowed and green strip ("subshrub") modeling with the same fuel model. These simulations indicate that fairly rapid fire movement could still occur across mowed fuel breaks, although more resolute modeling is needed (see appendix 1 for model parameters).

In contrast to stand-level models, landscape-level wildfire systems simulate the spread of fire across a landscape under variable fire environments. In the fuel management context, these models are used to determine the effectiveness of landscape fuel treatments in reducing fire size (that is, reduce rate of spread), changing intensity (that is, flame length), and predicting fire likelihood (that is, burn probability) for known and random ignitions. To assess fire behavior for pre-determined ignition points, FARSITE is among the most widely used, typically to simulate the growth of a single wildfire over time under heterogeneous fuels and terrain, as well as under dynamic fire-weather conditions (Finney, 2004). To project potential fire behavior of multiple fires across landscape scales, FlamMap (Finney, 2006) and its derivatives (for example, the large fire simulator, FSim; Finney and others, 2011) are among the most commonly used wildfire simulation systems for management and planning purposes (for example, determining where to apply fuel treatments). In FlamMap, for example, fire-weather is held constant for any particular model run and the spread of one to many fires is simulated across spatially heterogeneous landscapes and fuel conditions.

However, it is worth pointing out that these landscape-scale fire behavior models have largely been developed and used for forested landscapes, and they have rarely been used in the sagebrush ecosystems of the Great Basin or other dryland landscapes (and mostly for non-research purposes). Moreover, inputs for landscape-scale fire behavior models may not adequately capture the influence of cheatgrass and other nonnative annuals that drive seasonal and interannual variability of fine-fuel loadings and continuity that greatly influence ignition rates, fire probability, and rates of spread (compare Gray and Dickson [2016]); and LANDFIRE dynamic fine fuel measurements [LANDFIRE, 2017]). Moreover, whether using spatial or non-spatial fire behavior models, the inputs required to represent fuel conditions are generally derived from standard *fuel models* (Anderson, 1982; Scott and Burgan, 2005) that specify surface fuel attributes (for example, fuel loading) among different fuel types. These standard fuel models are derived from a priori fuel type classifications that may not adequately capture key fuel attributes found in the Great Basin, particularly in fuel break treatments (for example, forage kochia monocultures or recently mowed sagebrush), and custom fuel models may need to be developed to obtain more accurate fire behavior predictions (in the sense of Keane [2015]).

Question 1. How Effective Are Fuel Breaks in Reducing or Slowing the Spread of Wildfire in Arid and Semi-Arid Shrubland Ecosystems?

Historically, most empirical evidence for the effectiveness of fuel breaks has been largely anecdotal, based on previous wildland firefighting experience or occasional agency reports for specific projects. Despite the extensive use of fuel breaks in sagebrush landscapes, especially since the 1990s, the IRFMS-ASP points out that “no specific research within the sagebrush ecosystem has been conducted to evaluate their effectiveness” (U.S. Department of the Interior, 2016a, p. 25). Moreover, the IRFMS-ASP also suggests that fires often occur 10 or more years after a fuel break is constructed, when effectiveness may have reduced if lack of maintenance resulted in conversion to vegetation types that more readily carry fire. Moreover, fire managers acknowledge that, under extreme fire weather conditions, fuel breaks are unlikely to adequately reduce fireline intensity, flame length, or rate of spread (Moriarty and others, 2016). These factors make it challenging to assess the relative effectiveness of properly maintained fuel breaks under different fire environments.

Examples of effectiveness of fuel breaks in the Great Basin have been reported in various agency publications to highlight the success of fuel treatments. For example, the combination of wildfire suppression efforts and a 60-m wide green strip stopped a wildfire along 10 of 11 km of the contact zone (the breach was along a rocky ridge surrounded by pockets of sagebrush) near Grasmere, Idaho in 1988 (Pellant, 1994). Similarly, green strips adjacent to a highway contributed to limiting a wildfire in 1990 near Mountain Home, Idaho to 6 ha relative to the 10-year average of about 725 ha for that location (Pellant, 1994). Forage kochia green strips in Utah and Nevada reduced flame lengths and even stopped fires completely in places (Harrison and others, 2002). However, over-reliance on hand-picked examples of success underscores the difficulty in accurately assessing fuel break effectiveness, as such cases represent anecdotal reporting with a lack proper study controls. Even studies that have used simulation modeling to assess fuel break influence on fire dynamics tend to lack empirical validation of results.

Despite these individual reports and studies, consistent record-keeping and monitoring of fuel treatment effectiveness has not historically been a priority for fire and land management agencies. Until recently, there was no central repository to store information specifically regarding the efficacy of fuel breaks. This has been partially remedied by the Fuel Treatment Effectiveness Monitoring (FTEM) program. The FTEM was initiated in 2006 with the goal of demonstrating the utility of hazardous fuels reductions by verifying that fuel treatments encountered by wildfire worked as intended. The FTEM database has become the primary source of information for qualitatively assessing the effectiveness of fuel treatments to alter fire behavior. Initially, the FTEM included only voluntary reporting of treatment effects on U.S. Forest Service lands, but reporting became mandatory for the U.S. Forest Service in 2011 and for the Department of the Interior in 2012. For each treatment burned in a wildfire, two “yes/no” questions are required in the FTEM: (1) “Did the fire behavior change as a result of the treatment?” and (2) “Did the treatment contribute to the control of the fire?” Using FTEM data, Moriarty and others (2016) found that of the 58,000 ha of fuel treatments reported by the Bureau of Land Management in Oregon, Idaho, and Nevada, 97 percent of the treatment area was considered to have altered fire behavior, and 95 percent aided in the control of the fire. Although these findings are encouraging, a “yes” response in the FTEM database is relatively subjective. For example, what criteria constitute a significant change in fire behavior? Moreover, although the FTEM database provides fields for supplying important additional information, many records lack adequate descriptions of the fuel treatment, how fire behavior was changed, or the specific fire-environment. Generally, more recent FTEM records contain more of this critical information than older records, and they are often cross-linked to other databases containing fuel treatment details. However, based on our assessment of recent fire and known fuel break locations extracted from the Land Treatment Digital Library (Pilliod and Welty, 2013), it is not clear that all fire interactions with fuel breaks are entered into the FTEM. We found that between 2012 and 2016 there were 114 fires that intersected (that is, burned through) mapped linear fuel breaks in the Great Basin, and many of these incidents do not match locational information provided in the FTEM (see example landscape in fig. 18). Thus, we do not know how the behavior of these fires may have been affected by fuel breaks.

Additionally, agencies within the U.S. Department of the Interior lack a single comprehensive database for storing fuel treatment locations, their spatial extent, or conditions over time (that is, by monitoring species composition, cover, biomass). Thus, it is uncertain how many fuel breaks currently exist in the Great Basin, let alone their spatial configurations or fuel loadings. This further confounds our ability to systematically determine where and when fuel breaks work. Recently developed agency-wide databases (for example, the Land Treatment Digital Library [LTDL]) are intended to remedy these previous record-keeping deficiencies, but they are still not entirely inclusive, in large part because older records are incomplete or missing, and many record entries lack critical information. Based on our assessment of available records of linearly shaped treatments that contained information indicating a fuels reduction focus (for example, “green strip,” “fuel break”), we estimate that there are at least 10,000 linear kilometers of fuel breaks already in the Great Basin, and about 130,000 ha contained within them (table 1). Small (generally <1 km) linear treatments, non-linear fuel treatments, and linear features with no associated treatment information were not included in table 1, and it is likely some fuel breaks remain unmapped. Thus, undoubtedly, additional fuel breaks exist for which we lack records entirely or that have not yet been properly entered into agency databases.

In short, anecdotal evidence, sporadic project monitoring, and limited record-keeping indicate that fuel treatments do accomplish their intended goals under certain conditions. However, a history of incomplete and insufficient record-keeping has resulted in a lack of systematically collected data on fuel treatments in general, and fuel breaks specifically, that would allow us to readily and objectively analyze how often and under what conditions linear fuel breaks are effective. We simply lack spatially and temporally comprehensive datasets on fuel breaks, including locations, treatment types, maintenance history, fire environments (for example, fire-weather conditions, fuel loadings), and firefighting response (for example, whether or not used for suppression activities, and in what manner) to accomplish such an analysis at this time. However, as agency-wide databases continue to be compiled and improved, such analyses may become prudent, at least for portions of the Great Basin with consistent record keeping.

Table 1. Known and likely linear fuel break distance and area in the Great Basin by Bureau of Land Management (BLM) district office.

[Values are approximate, based on incomplete mapping and database entries, and probably underestimate actual totals. **Data sources:** Land Treatment Digital Library: Pilliod and Welty (2013), and (2) The Vegetation Treatment Area database (Bureau of Land Management, 2010). Data accessed: October 13, 2017. This is an initial assessment that will eventually be reconciled with other agency databases, especially the National Fire Plan Operations and Reporting System (NFPORS). See appendix 2 for methods.]

BLM District Office	State	Hectares	Kilometers
Battle Mountain	Nevada	19,803	567
Boise	Idaho	3,518	2,431
Burns	Oregon	7,996	777
Carson City	Nevada	1,639	65
Color Country	Utah	18,656	250
Elko	Nevada	18,355	1,124
Ely	Nevada	6,106	318
Idaho Falls	Idaho	8,657	702
Lakeview	Oregon	1,814	774
Northern California	California/ Nevada	7	2
Prineville	Oregon	867	59
Twin Falls	Idaho	11,190	962
Vale	Oregon	17,467	649
West	Utah	7,511	570
Winnemucca	Nevada	10,356	1,273
Totals		**133,942**	**10,523**

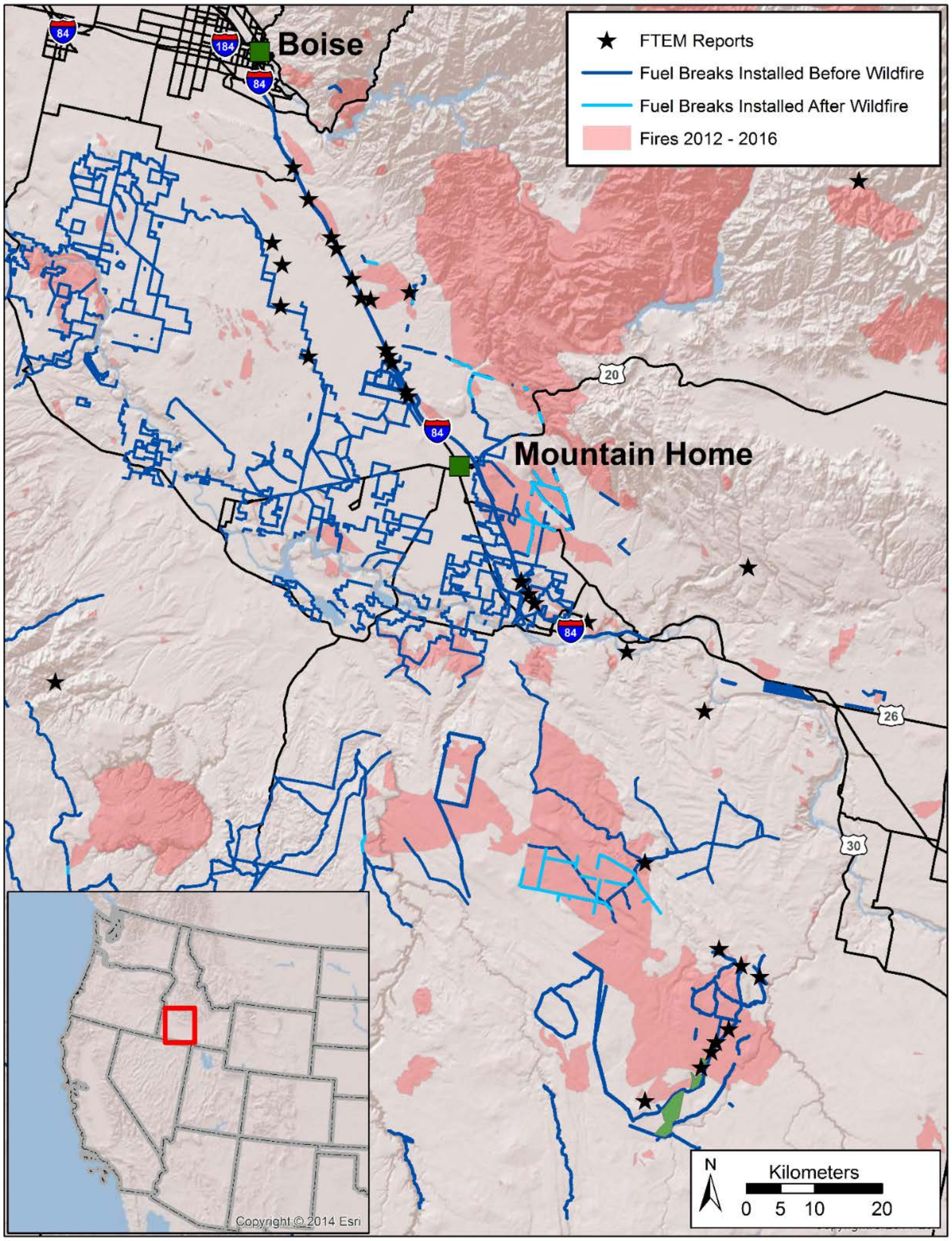

Figure 18. Reports of fire interaction with fuel treatments recorded in the Fuels Treatment Effectiveness and Monitoring (FTEM) database. All existing FTEM records are shown relative to fires that burned from 2012–16 (after reporting to the FTEM became mandatory for the Bureau of Land Management) for a portion of the northern Great Basin. In this landscape, it is apparent that many FTEM records are for smaller fires that started along roads, while some larger fires clearly intersected existing fuel breaks but were not reported in the FTEM. The multiple FTEM records in and around the large fire at the bottom of the map include some fuel breaks, as well as other fuel treatment types, but they lacked comments to describe how they contributed to suppression objectives or changed fire behavior. Fire data compiled by U.S. Geological Survey (2017) (see table 1 for fuel treatment data sources).

Question 2. How Do Fuel Breaks Affect Sagebrush Plant Communities?

Different types of fuel breaks can affect plant communities directly through modification or conversion of the existing plant community, and indirectly through the spread of invasive species and changes in soil conditions. Here, we characterize potential plant and soil responses to fuel break treatments across plant community types and their climates over short, intermediate, and long time periods. We also discuss implications for different management and maintenance scenarios with an emphasis on fuel breaks in intact shrublands versus herbaceous annual grasslands, and across landscapes with varying resistance to cheatgrass and resilience to disturbance. We focus on dominant plant communities and do not cover sensitive species because we assume fuel breaks would be diverted around them. The limited empirical evidence for plant community responses to green stripping, brown stripping, and mowing treatments is then reviewed. A summary of key effects of fuel breaks on plant communities are in table 2.

Table 2. Summary of potential fuel break effects on plant communities.

Fuel break type	Maintained?	Vegetation condition	Wildfire potential	Risks
Green strip	Yes	Widely spaced and more fire resistant species; typically nonnatives introduced through seeding	Shortened period for combustibility; in some cases less contiguous fuels (for example, forage kochia [*Bassia prostrata*])	Stand failure (maladaptation), risks of emigration or invasive spread of seeded species into surrounding landscape
	No	Potential attrition of desirable species and gain of undesirable species (for example, annual grasses, invasive forbs)	Fine fuels accumulate, enhancing ignition and fire spread	Fuel break becomes invaded (or re-invaded), affecting surrounding landscape
Brown strip	Yes	Bare soil	Does not burn	Herbicide risks, soil erosion
	No	High potential for annual species invasion	Increased ignition and rates of spread	Increased fire hazard, spread of exotic species
Mowing	Yes	Reduced height (15–30 cm)	Reduced flame height	“Bushout” could increase fuel continuity, potential for exotic invasion
	No	Height is regained	Flame height reduction lost; potential for enhanced ignition and fire spread	Initial condition regained, potential for exotic invasion

We note that while the effects of fuel breaks have been evaluated in Mediterranean-like climates of California (for example, Syphard and others, 2011a, 2011b), there are limits to the transferability of the information into sagebrush steppe. Merriam and others (2006) and Potts and Stephens (2009) reported increases in bare soil and exotic plant abundances (up to 40 percent increases or more) on fuel breaks applied across a diverse array of habitats in California, a number of which have similar exotic species and winter-wet conditions that have favored conversion of native shrublands to nonnative annual grass communities in the Great Basin. However, there are limitations to transferring information from habitats such as chaparral to sagebrush ecosystems, due to different life forms and growing season patterns (for example, there is generally less grass cover in chaparral). Similarly, there is substantial literature on cutting, masticating, and prescribed burning of piñon-juniper, oak woodland, and chaparral habitats; however, these systems contain much greater biomass in standing woody species than most sagebrush sites. The removal of larger and more dominant trees or shrubs would be expected to result in greater resource release (for example, that could be exploited by exotic annuals) than in sagebrush ecosystems.

Plant-Community Trajectories and Their Relationship to Soil Resources within Fuel Breaks

Plant community responses within fuel break treatments are determined by both biophysical setting (for example, elevation, topography, precipitation, temperature, and soils) and type of fuel break installed. Fuel breaks in the Great Basin are applied in many different plant communities over a wide range of elevations that receive different amounts of precipitation annually, from less than 120 mm at lower elevations to greater than 500 mm at upper elevations. Precipitation combined with soil properties strongly influences vegetation communities, as well as what can grow successfully in a fuel break and how a fuel break might need to be maintained. For example, the warm and dry salt desert at the lowest elevations support shrub species with unique adaptations to salt, drought, or toxic minerals, including shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus* spp.), and winterfat (*Krascheninnikovia lanata*). Middle elevations support sagebrush steppe, a cold desert perennial grassland characterized by the presence of shrubs, particularly sagebrush. Mountain shrub communities, characterized by big sagebrush (*A. t. subsp. vaseyana*), snowberry (*Symphoricarpos* spp.), and curlleaf mountain mahogany (*Cercocarpus lediofolius*), dominate at higher elevations where precipitation is less limiting but still inadequate to support coniferous forests. These plant communities all are structurally heterogeneous in their intact condition, co-dominated by woody (shrub) or herbaceous perennials interspersed with bare soil “canopy gaps” that provide discontinuity in wildfire fuels. Invasion of these canopy interspaces by nonnative annual grasses can lead to nearly complete replacement of perennials by a homogeneous canopy of annuals, that results in a high-continuity, fine-textured fuel bed that senesces with low water content for about 80–90 percent of each year (Brooks and others, 2004; Germino and others, 2016).

Although there are few reports of sagebrush or other rangeland vegetation response to fuel break treatments, the treatments used to create fuel breaks are similar to treatments that are commonly applied as part of rehabilitation or restoration actions to large tracts of land in the Great Basin (Pyke and others, 2014). Thus, the general paradigms and concepts currently used to predict vegetation change (see section, “General Concepts for Plant Community Responses”) are usually also applicable to fuel breaks, although scale and edge effects are anticipated to be relatively important landscape factors for fuel breaks due to their extensive linear configurations. However, one of the most basic concepts represented by classic plant succession models (that is, an orderly transition from early, to mid, and late series of species assemblages) may have only marginal or sometimes no utility in explaining or predicting the plant communities of interest after a treatment. For example, the species that successfully establish after a fuel break treatment are likely to be the species that will persist into the mid- to long-term, unless invasions by nonnative plant species, grazing, or subsequent fire cause further change. Notable exceptions are when ruderal species become established and undergo apparent seral replacement, such as replacement of Russian thistle (*Salsola kali*) by exotic annual mustards (for example, *Sisymbrium altissimum*) and then cheatgrass (Piemeisel, 1951). Also, native species such as Sandberg bluegrass (*Poa secunda*) or 6-weeks fescue (*Vulpia* spp.) can have a clear early-successional, colonizing role compared to other native species.

Below, we extend state-and-transition and resistance and resilience concepts (as described in section, “General Concepts for Plant Community Responses”) to the three types of fuel breaks, focusing on the relationship of the potential plant community outcomes of the treatments to wildfire risk, site conditions, and soil stability. Traditional state-and-transition models (STMs) do not account for the surrounding landscape of a subject site; however, edge effects and species immigration and emigration (that is, invasion of fuel breaks, or invasion of species seeded onto fuel breaks) are primary concerns for fuel breaks. By design, fuel breaks have a high perimeter-to-area ratio, and movement of species from or to the surrounding landscape is of primary concern. Generally, the habitat fragmentation and edge-effect impacts of fuel breaks on the plant communities surrounding them will usually relate to spread of seeded/planted or volunteer (invasive) species from fuel breaks into the surrounding landscape (Gray and Muir, 2013). For instance, any resulting increase of exotic annuals on the fuel break “strip” would likely increase the potential for invasion of the surrounding landscape.

General Concepts for Plant Community Responses

State-and-transition theory and the resistance and resilience paradigm are two alternative theories to classic plant successional models that are considered more effective constructs for understanding changes in plant communities following disturbance, invasion, or treatment (Allen-Diaz and Bartolome, 1998). Vegetation changes at mid-elevations, specifically within sagebrush steppe, have become an archetype for state-and-transition concepts and modeling (Laycock, 1991). State-and-transition models (STMs) for Wyoming big sagebrush communities generally suggest that exotic annual grasses, such as cheatgrass or medusahead (*Taeniatherum caput-medusae*), invade and promote wildfire occurrence in ways that further favor their dominance and inhibit perennials. The outcome of this grass/fire cycle is that perennial communities are converted to (that is, transition to) annual grasslands, which is an alternative, stable state from which it is difficult or impossible to redirect the plant community towards the native perennial state (Bagchi and others, 2013; Chambers, Miller, and others, 2014). Additional alternative states can include near monocultures of introduced perennial grasses (for example, crested wheatgrass) that are seeded to stabilize soils and preempt exotic annual grasses (Hull and Klomp, 1966; Marlette and Anderson, 1986; Hulet and others, 2010). Transitions among the three dominant states (that is, native mixed woody/herbaceous, exotic annual, or introduced perennial) are caused by disturbances such as fire, grazing, or management actions or treatments. These state changes are relevant to fuel breaks because the intent is to leverage them to render the treatment area in a stable state that has consistently lower hazardous fuels. The National Resources and Conservation Service Ecological Site Descriptions (Natural Resources Conservation Service, 2018) contain STMs for plant communities.

A more contemporary view of invasion and recovery in these ecosystems uses the terms "resistance" to annual grass invasion and "resilience" from disturbance (Chambers, Bradley, and others, 2014). These concepts are operationalized in the Fire and Invasives Assessment Tool (FIAT), which is used to prioritize areas for land treatments. Areas with moderate amounts of resistance and resilience are deemed most suited for treatment, because they can benefit from intervention and they have enough growth potential to respond to treatment.

Communities with high resilience have a high recovery potential for many or most native plant species (for example, Seefeldt and others, 2007), which limits the available space and soil resources that exotic annuals require for invasion and thus confers resistance to invasion. From a rehabilitation or restoration perspective, areas with high resistance and resilience have a high likelihood of recovering without intervention.

Conversely, at the lowest elevations, in or near salt desert or low-elevation Wyoming big sagebrush, resistance and resilience is low with longer recovery rates, making restoration challenging in these sites. At the core of the resistance and resilience concepts is the hypothesis that re-sprouting perennial grasses can quickly control soil water and nutrients and competitively displace exotic annuals, and that minimum temperatures also inhibit exotic annuals at higher elevations. An emphasis of the resistance and resilience concept is placed on promoting deep-rooted perennial bunchgrasses, as they are considered to confer greater drought resilience and thus longer-term competition against exotic annuals than shallow-rooted and ephemeral grasses such as Sandberg bluegrass (Reisner and others, 2013). Healthy stands of perennial bunchgrasses have smaller and less connected bare-soil patches that are considered to minimize available microsites for annual grass invasion, particularly if biological soil crusts cover the interspaces and inhibit establishment of annual grasses (Deines and others, 2007; Reisner and others, 2015). Biological crusts prevented germination of exotic annuals in a greenhouse study (Serpe and others, 2006). These biological and physical elements that increase resistance to annual grass invasion also confer soil stability, which is another major management concern in the affected plant communities. Erosion following disturbances such as fires or stand failure can be extensive, strongly affecting ecosystem properties and feeding back on annual grass communities (Germino and others, 2016). The duration of bare soil exposure is a major factor affecting erosion risks.

Potential Effects of Green Strips on Plant Communities and Soils

The purpose of green stripping is to provide vegetation that will likely prevent the growth and spread of annual invasive vegetation (for example, *Bromus* spp.) but will also consist of relatively shorter vegetation with higher moisture content and, thus, reduced fuel loading (Davison and Smith, 1997). Plants that are commonly used for green stripping include crested wheatgrass and forage kochia (Monsen, 1994; Pellant, 1994), although other species are also used (Davison and Smith, 1997; Harrison and others, 2002; St. John and Ogle, 2009; Maestas, Pellant, and others, 2016). Crested wheatgrass has shown some effectiveness as a strong competitor against less desirable nonnative annual forbs and grasses, such as halogeton (*Halogeton glomeratus*) and cheatgrass, and is considered fire tolerant (Hulet and others, 2010; Nafus and others, 2016; Svejcar and others, 2017). However, its ability to spread into nearby undisturbed sagebrush environments and outcompete native bunchgrasses and other desirable plants has been a subject of valid concern (Pyke, 1990; Bakker and Wilson, 2004). To prevent further disruption of the surrounding sagebrush ecosystems, crested wheatgrass may require careful management and frequent maintenance (Hansen and Wilson, 2006) because, once established, it can be difficult to remove (Hulet and others, 2010; McAdoo and others, 2017; Svejcar and others, 2017). Forage kochia is also used widely in fuel break construction (as well as in a few experimental applications) (Graham, 2013). This medium-sized sub-shrub, originally from central Asia and Europe (McArthur and others, 1990) typically contains greater moisture content than crested wheatgrass, which helps to better prevent the spread of fire compared to crested wheatgrass (Graham, 2013). Forage kochia has relatively high resilience after wildfire and various case studies suggest it can be competitive with cheatgrass (McArthur and others, 1990; Harrison and others, 2002). However, forage kochia is subjected to similar concerns as crested wheatgrass regarding potential spread into adjacent sagebrush environment. Kochia has the potential to spread at least 700 m beyond the original planting areas (Gray and Muir, 2013) and might hinder attempts to maintain or recreate proper functioning of original sagebrush communities (Graham, 2013).

Areas converted to green strips are usually first treated with herbicides to remove competition and then drill seeded with vigorous species known to confer high resistance and resilience as described above. Establishment success varies with method of seeding, generally increasing if applied with a rangeland drill than by aerial broadcast, and is typically greater at higher elevations receiving more precipitation (Knutson and others, 2014) (fig. 19). In contrast, seeding crested wheatgrass or forage kochia on sites having only 200 mm/year of precipitation did not appear to increase those species on treatment areas, while many-fold increases were evident in areas receiving 400 mm/year. Unsuccessful seedings in sites that are less resistant or resilient are more likely to degrade into annual grasslands, whereas successful seedings typically lead to monospecific stands (Beyers, 2004), which could influence stand development over time. For instance, although both crested wheatgrass and forage kochia are moderately deep rooted and likely use soil nutrients thoroughly, resulting in relatively vigorous growth, these species generally do not use soil water as efficiently as a diverse stand of woody and herbaceous perennials in native communities (for example, Kulmatiski and others, 2006). This dynamic can result in greater duration of available soil water and potentially facilitate invasion by exotic tap-rooted forbs (for example, Hill and others, 2006; Prevéy and others, 2010) or cheatgrass. Invasion of interspaces maybe somewhat controllable if biological soil crusts can become established (Serpe and others, 2006), and research is underway to determine how to facilitate that process (Condon and Pyke, 2016). It is likely that dispersal of moss and other biological soil crust life forms (from persisting remnant patches) can be used to “seed” areas like green strips in the near future (Bowker, 2007), increasing abundance of soil crusts and stabilizing the soils and plant community to the desirable seeded plant species.

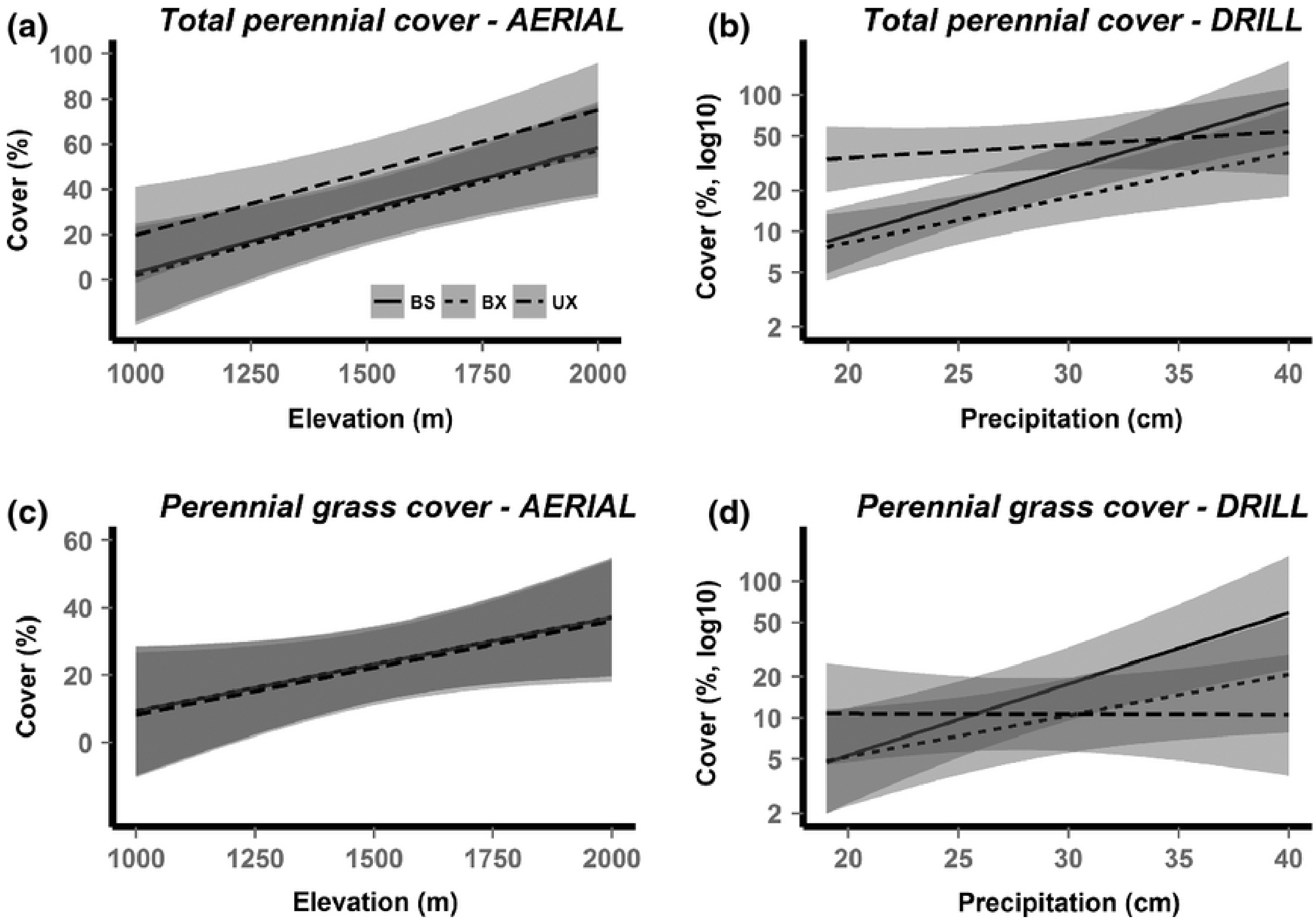

Figure 19. Cover of all (*a, b*) perennial life forms and (*c, d*) perennial grasses in burned-seeded (BS), burned-unseeded (BX), and unburned (UX) treatments at aerial and drill projects. Other significant model covariates not shown were held constant at intermediate values (precipitation: 28 cm; age: 12 years; elevation: 1,400 m; heat load: 0.94). Shaded bands are 95-percent confidence intervals, and darker areas represent overlap. Used with permission from Knutson and others (2014).

Potential Effects of Brown Strips on Plant Communities and Soils

Brown strips involve the removal of above-ground biomass and exposure of bare mineral and organic soil, leading to high potential for recolonization by early seral native or naturalized perennial species following treatment (for example, Sandberg bluegrass, crested wheatgrass) or invasion of exotic, annual herbs with propagules present. Recolonization and invasion potential necessitates intensive annual (or more frequent) treatments to eliminate plant cover. Any trace vegetation that evades herbicide treatment would likely have abundant soil moisture and nutrients available, due to the lack of plant community usage. If brown strips are maintained, there will be no carbon inputs by plants and soil carbon would likely decrease. Brown stripping likely reduces biological crusts, eliminating the nitrogen fixation potential they confer and increasing the potential for physical crusts (reducing aeolian but increasing water erosion), as could be verified with slaking tests. There can be a substantial time lag between the construction of brown strips and the formation of physical crusts, as days to months may elapse for wetting and drying cycles to trigger the crusting. In the interlude, soils may be unconsolidated and aeolian erosion risks are greatly increased. Disturbances to crusts from hooves or intense precipitation events could reduce transient soil aggregation and increase the availability of erodible soil. Depending on the orientation of brown strips to water and wind flow (that is, runways), erosion risks could increase, although catastrophic wind erosion (>about 2 cm of surface soil removal) generally requires much larger disturbance area-to-perimeter ratio than fuel breaks typically provide (Miller and others, 2012). In the absence of plant transpiration, soil water storage would increase, as evaporation is the only means for water loss until potential saturation and runoff occur (on slopes). If brown strip maintenance ceases, recolonization will be affected by which species' seeds are present; however, species that are expected to be favored include those that have seeds capable of anchoring onto hard soil crusts (for example, awns on cheatgrass seeds, Hoover and Germino [2012]), that rapidly germinate and grow (for example, many exotics, in addition to cheatgrass, such as burr buttercup [*Ranunculus testiculatus*] or mustards [for example, *Sisymbrium altissimum*]), or that can capitalize on abundant deeper water supplies (for example, tap-rooted forbs that include many exotics, such as skeletonweed [*Chondrilla juncea*], thistles [for example, *Cirsium* spp.], and knapweeds [*Centaurea* spp.]). The rate at which plant community cover and height develop, as herbs recolonize or invade unmaintained brown strips, will vary considerably with climate, weather, and species involved.

Even with diligent brown strip implementation and maintenance, vegetation could evade initial or follow-up treatments in several ways. The timing of treatments relative to weather patterns is an important determinant of post-treatment plant emergence. Blading the soil surface may not remove all meristems of perennials, and some seed may remain. Without herbicides, plant establishment is expected in spring or fall following blading, contingent on sufficient rain and suitable temperatures. Pre-emergent herbicides such as imazapic can be expected to reduce or eliminate new seedling establishment following blading for about 1 year (Owen and others, 2011). Herbicide applications in the years following fire is expected to be most effective if timed to precede germination events, and predicting these and applying treatments in a timely fashion can be challenging (allowing for some residual cover of early seral species).

Potential Effects of Mowed Fuel Breaks on Plant Communities and Soils

Mowing Wyoming big sagebrush reduced sagebrush cover, density, canopy volume, and height for at least 20 years in a study by Davies and others (2009), and Pyke and others (2014) found that woody biomass was reduced by at least 85 percent for 3 years in sites with high resistance and resilience. The degree of transformation achieved by mowing will be determined in part by the large height differences that exist for adult or mature plants between the different plant communities of interest. Shrubs in salt desert communities can range from about 1.5 m for four-winged saltbush (*Atriplex canescens*) and greasewood (*Sarcobatus vermiculatus*) to less than 50 cm for winterfat or shadscale. Low sagebrush species are generally less than 30 cm high, yet Wyoming and mountain big sagebrush can vary from about 30 cm to nearly 1 m high, and basin big sagebrush is frequently 1 to about 3 m high. In big sagebrush communities, some bunchgrass species are generally small statured (for example, <about 15 cm for Sandberg bluegrass, with most foliage just a few cm above ground), while others may have leaf heights greater than 1 m (for example, Great Basin Wildrye [*Leymus cinereus*]). After mowing vegetation to 15–30 cm in height (to reduce flame length), grasses, herbs, and some shrubs will have meristems at the soil surface that are able to resprout and regain height loss the following growing period, provided that moisture and temperature conditions are adequate.

Clipping off apical meristems (that is, the top of the plant, which regulates primary growth) causes many woody species to “bush out” due to release of apical dominance controlled by hormone interactions. Sagebrush and several other woody species have meristems above ground and their regrowth potential following clipping will depend strongly on how clipping height relates to the location of their meristems. Regrowth of sagebrush heights can vary substantially depending on subspecies, topographic position, and elevation effects. Basin big sagebrush, for example, grows much taller and faster than does Wyoming big sagebrush (McArthur and Welch, 1982), and topographic depressions are often more fertile and support greater growth. Basin big sagebrush in their fifth to seventh year following planting grew 10–15 (mean=12) cm/yr compared to 6–11 (mean=8) cm/yr in mountain and Wyoming big sagebrush in a deep-soil site (26.8 cm/yr of precipitation; 1,700 m in elevation; McArthur and Welch, 1982). However, no meristems would typically be left following mowing of basin big sagebrush to 15 cm height. Low sagebrush species may be intermixed with big sagebrush communities, and have slower vertical growth following mowing compared with big sagebrush subspecies. Based on these annual growth rates, sagebrush plants could be expected to vary from no recovery to nearly a doubling of height in the year following mowing, depending on the species and its initial height. For instance, minimal growth following mowing would be expected for a low-sagebrush whose height is near or below cutting blades, and for a mature basin big sagebrush that has a thick singular trunk and no meristems above blade height. In contrast, if younger basin big sagebrush are cut, then large incremental growth would be expected (about 12 cm added to a mowed base height of 15 cm).

Mowing of herbaceous vegetation or other woody species that have meristems at or near ground (for example, rabbitbrush [*Chrysothamnus* and *Ericameria* spp.]) will initially reduce the standing litter, but regrowth to pre-cutting heights or potentially more (due to compensatory responses) is expected in the year following treatment (provided weather is suitable). Additionally, soil disturbance and release of resources after mowing in sagebrush stands may further benefit herbaceous species in subsequent years. Pyke and others (2014) found mowing to have no beneficial reduction of herbaceous fuels, and instead observed at least a 36 percent increase in herbaceous fuels (biomass) over 3 years following mowing. Indeed, increased production of herbaceous plants following mechanical (and sometime chemical) removal of big sagebrush is also well-documented elsewhere (Hedrick and others, 1966; Wambolt and Payne, 1986; Swanson and others, 2016) and raises issues about the efficacy of mowing as a fuel treatment. Moreover, bunchgrasses must be present prior to mowing to reduce or prevent exotic grass invasion after mowing as demonstrated by a series of studies in eastern Oregon. Researchers found that mowing of degraded sagebrush steppe, where exotic annual grasses were already fairly dominant, did not increase perennial herbs, but did increase exotic annual grass and annual forb biomass production by as much as 7–9 times, respectively, by the third post-treatment year (Davies and others, 2011; see also Davies and others, 2012a; Davies and Bates, 2014). In northern and central Nevada, mowing resulted in more cover of litter, perennial grasses, cheatgrass, and exotic forbs over a span of 1–10 years (Swanson and others, 2016). However, mowing high-elevation mountain big sagebrush where exotic annual grasses were less common enhanced native herbs, including desirable bunchgrasses, but did not increase exotic annuals (Davies and others, 2012b).

Erosion risks would be minimal for mowed fuel breaks, and the soil fertility and hydrology effects of mowing are likely substantially different than for brown strips. Mowing often causes foliar shoots that have relatively high nutrients, such as nitrogen, to be deposited to soil (depending on phenology of species at the time of clipping), especially compared to leaves that drop to soil after normal translocation of nutrients into the plant. Thus, we can hypothesize that litter resulting from mowing would have greater decomposition rates than normally senesced foliage. Unlike brown strips, the mowed plant community would continue to use available soil moisture and nutrients, providing resistance to annual invasion; though the ratio of soil resources per remaining leaf unit area would likely increase. However, in a study by Davies and others (2009), sagebrush leaves that evaded cutting did not have enhanced foliar nutrition.

Plant Community Responses Adjacent to Fuel Breaks

Fuel breaks also may influence surrounding, untreated plant communities by providing a seed source of species that were seeded into or inadvertently colonized fuel breaks, as well as potential indirect effects of altered microclimates, wind velocity, soil movement and deposition, surface and soil-water hydrology, and snow deposition patterns. For example, both crested wheatgrass and forage kochia have been reported to emigrate from areas they were seeded into the surrounding landscapes (Marlette and Anderson, 1986; Gray and Muir, 2013). However, that process may take considerable time to develop and may not occur everywhere, as in a recent study that found forage kochia did not disperse outside of treated areas for the first 5 years after seeding (Satterwhite, 2016). In 24 fuel breaks (similar to unmaintained brown strips) across California, blading (bulldozing) in chaparral habitat resulted in increased nonnative cover (relative), density, and richness, especially 0–20 m from brown strip edges (Merriam and others, 2006). Grazing and time both also influenced these invasion rates. Careful research investigating where and why fuel breaks become corridors for weed invasion in surrounding landscapes is needed.

The low vegetation cover or low vertical height of linear fuel breaks may result in unintended climatological effects within the fuel breaks and this could have ecological consequences for surrounding plant communities. In areas that have winter snow accumulation and significant wind, redistribution of snow off of fuel breaks and into the surrounding taller vegetation would be likely. Sagebrush and other tall perennials also affect radiation regimes, which feedback to affect snow retention and soil microclimate. Greater bare soil exposure could result in warmer soils (with less canopy shading of soil) and could impact species like cheatgrass that are active in early spring and late fall. The increases in soil moisture that would accompany vegetation reduction on fuel breaks would likely increase effective water availability for surrounding, un-treated vegetation along and outside the treatment boundaries, potentially enhancing plants outside the border of fuel breaks.

Question 3. What Are the Effects of Fuel Breaks on Greater Sage-Grouse, Other Sagebrush Obligates, and Sagebrush-Associated Wildlife Species?

Fuel breaks have the potential to directly affect populations of greater sage-grouse (hereinafter sage-grouse) and other sagebrush-associated species across multiple spatial-scales. In this section, we examine habitat needs and conservation requirements for sage-grouse and other key species relative to the potential for fuel breaks to directly modify habitat, fragment habitat, disrupt seasonal habitat use, impede movement of individuals between populations, influence predator-prey relationships, or cause other deleterious effects on species of concern.

Fuel breaks in shrublands may influence animals across multiple levels of biological organization (individuals, populations, and communities) and across a range of temporal and spatial scales. This ecological complexity often makes it difficult to understand fully the effects of habitat alterations. Some changes increase mortality conspicuously (for example, higher predation rates), whereas other habitat changes have negative effects on animals that are difficult to observe or measure. These subtle effects, such as lower fecundity resulting from increased stress or poor body condition, may result in responses at the population level that are not detectable for several years. Furthermore, habitat treatments may alter prey populations, such as rodents (McAdoo and others, 2006), which could result in delayed population response by their predators. Changes in predator populations can have ecological consequences far outside an area of disturbance because predators tend to be more wide-ranging than prey.

We begin our assessment of the potential effects of fuel breaks on wildlife by first examining several issues that may be common across different types of fuel breaks in sagebrush landscapes: habitat fragmentation and loss, edge effects, and linear features (see section, “General Concepts for Wildlife Considerations”). We then evaluate the empirical evidence for potential effects of green stripping, brown stripping, and mowing treatments on wildlife.

General Concepts for Wildlife Considerations

Wildlife habitats are characterized by the structure and composition of vegetation and various abiotic elements in a landscape, some of which have direct relation to fuel break design and function. Habitat structure has three dimensions, measured typically as two-dimensional ground cover and height. Habitat composition encompasses plant species richness or functional group diversity (for example, perennial grasses), as well as the relative amounts of cover types across a landscape. Cover types can be defined at the species level, functional group level, or broader ecological classes (for example, riparian, grassland, shrubland), depending on level of information needed or available. Abiotic elements, such as amount of rock and bare mineral soil (that is, usually measured as bare ground) and size of interspaces (that is, canopy gaps) among plants, are important components of habitats because they influence movements and cover. Subsurface aspects of habitats, particularly soils, influence burrowing animals as well as plant communities.

Most terrestrial vertebrates respond to habitat structure and composition because of the strong influence on development, growth, survival, and production (that is, number of offspring or fitness). Habitat structure and composition have direct influences on an animal's ability to find food, identify locations to reproduce and raise young, avoid predators, and shelter from stressful or life-threatening environmental conditions. Animals also are aware of the spatial and temporal (that is, diel or seasonal changes) characteristics of their habitats. Whether evaluating their environments from above, such as a bird, or from the ground, animals are adept at navigation and spatial recognition of the distribution of critical resources in their environments. In many cases, animals can perceive potential threats, using habitat resources to minimize those risks, but in anthropogenically modified landscapes, novel risks may not be recognized. Any rapid changes to the structure or composition of habitats can be stressful to animals and may reduce individual fitness and population viability.

Habitat Fragmentation and Loss

Although the effects of fuel breaks on wildlife habitat remains largely unstudied, there is a rich scientific literature on the effects of other anthropogenic landscape features that result in direct habitat loss and subdivide continuous habitats into smaller components, such as happens with development of roads, power-lines, agriculture, and housing (Wilcox and Murphy, 1985; Robinson and others, 1995; Hill and Caswell, 1999; Fahrig, 2002). Most research on the effects of habitat fragmentation in sagebrush shrublands has focused on passerine bird species, which tend to be negatively affected by reduction in the size of sagebrush patches or core habitat (Knick and Rotenberry, 1995; Knick and Rotenberry, 2002; Hethcoat and Chalfoun, 2015b). Core habitat, or habitat that is relatively large and contiguous, contains environmental conditions and resources needed to sustain an individual or a population. The requisite size of core habitat patches is relative for each species, but large patches of habitat that extend beyond individual home ranges (Knick and Rottenberry, 2002) tend to support higher abundance of individual species and greater diversity (Rodewald and Vitz, 2005). For example, the abundance of pygmy rabbits (*Brachylagus idahoensis*) in Utah increased significantly with distance into sagebrush stands, particularly greater than 100 m from the edge created by mechanical treatment (Pierce and others, 2011). Similarly, sage-grouse leks are more likely to be abandoned when contiguous patches of sagebrush are smaller (Wisdom and others, 2011), and entire populations have even disappeared where landscape cover of sagebrush falls below 65 percent (Aldridge and others, 2008). Occupied leks have approximately twice the amount of sagebrush habitat as those leks that have been extirpated (46 versus 24 percent, respectively) and 10 times the size of sagebrush patches (4,173 versus 481 ha, respectively; Wisdom and others, 2011).

Subdividing or fragmenting once-continuous sagebrush habitats may be problematic for some species (Coates and others, 2014a), but our lack of understanding of the mechanisms causing population-level effects (Fletcher and others, 2007) makes it difficult to adapt fuel breaks to minimize negative consequences. For example, Knick and Rotenberry (2002) assessed how landscape composition, configuration, and change influenced passerine bird population dynamics in sagebrush steppe and hypothesized that fragmentation (from any given cause) of otherwise intact native habitat might influence productivity through differences in breeding density, nesting success, or nest predation or parasitism. They concluded that fragmentation was important in determining the distribution of shrubland-obligate species like Brewer's sparrows (*Spizella breweri*), sage sparrows (*Amphispiza belli*), and sage thrashers (*Oreoscoptes montanus*), but the causal mechanisms were unresolved. In other cases, it has been shown that loss in the amount of habitat surrounding populations (for example, degraded habitat at larger spatial scales) is most influential in affecting fitness outcomes of wildlife species in sagebrush ecosystems (for example, for sagebrush-obligate songbirds; Hethcoat and Chalfoun 2015a), perhaps by disrupting meta-population dynamics. Loss of habitat from energy development has been correlated with increased nest predation of sagebrush-obligate songbirds, especially by rodent species that increased in abundance with loss of sagebrush (Hethcoat and Chalfoun, 2015b).

We suspect that habitat disturbances (such as fuel breaks) that subdivide the landscape into isolated patches will make it more difficult for animals to migrate seasonally among complimentary habitats (Harris and Reed, 2002), but the empirical evidence for sagebrush-associated wildlife is lacking. For less vagile animals, such as some small mammals and lizards, it is plausible that fuel break systems could have an isolating effect.

Edge Effects

Because fuel breaks typically create sharp transitions with surrounding habitats, they increase the amount of edge within a landscape, and thus also increase edge effects. Here, we define edge as the interface between two or more adjacent ecological communities or land cover types. Although fuel breaks are often built along existing roads, where edges already exist, there may still be increased edge effects caused by both the road improvement or widening (that often accompanies fuel break construction), as well as the addition of parallel edges adjacent to roads created by the fuel break treatment. Edge effects might resemble natural ecotones or have considerably different environmental characteristics (that is, atypical for a given landscape), including changes in species composition and relative abundance (Woodward and others, 2001; Rodewald and Vitz, 2005); changes in biotic interactions, such as predation (Winter and others, 2000; Vander Haegen and others, 2002), parasitism (Vander Haegen and Walker, 1999), and competition (Ingelfinger and Anderson, 2004); and changes in environmental gradients.

Changes in composition and relative abundance of wildlife species in fuel breaks may result from novel environmental conditions associated with edges or ecotones, but understanding these causal factors is difficult because of confounding effects of biotic interactions and fragmentation. Empirical data on the effects of edges on sagebrush-associated wildlife are lacking, although ecotones between sagebrush stands and sagebrush removal areas (that is, similar to fuel breaks) are thought to attract some species that forage in open habitats, but use adjacent shrubs as cover (McAdoo and others, 2004; Beck and others, 2012). Other species, such as pygmy rabbits (fig. 20), may avoid habitat edges if competitors (for example, cottontails [(*Sylvilagus* spp.] and jackrabbits [(*Lepus californicus*]) prefer these ecotones (Pierce and others, 2011).

Figure 20. Pygmy rabbit (*Brachylagus idahoensis*). Photograph by H. Ulmschneider (Bureau of Land Management) and R. Dixon (Idaho Fish and Game).

Biotic interactions, especially predator-prey, are better documented than other edge effects. Some predators prefer edges; thus, fuel breaks may increase vulnerability of grassland or low-cover species that colonize fuel breaks or species that are moving along or attempting to cross fuel breaks. For example, nesting probability of common ravens (*Corvus corax*) increases near edges, specifically where sagebrush shrubs interface areas dominated by crested wheatgrass or cheatgrass (Coates and others, 2014b; Howe and others, 2014). Edge not only positively influences breeding pairs of ravens but also influences occurrences of non-breeders that are often numerous and transient (Coates and others, 2015). Ravens use visual cues while hunting and edge-dominated areas may offer greater opportunity to detect their prey than those areas with contiguous stands of sagebrush. Edges likely provide ravens the opportunity to more readily locate and depredate nests of other bird species. In areas with ravens, a 1 percent decrease in shrub cover can increase the odds of predation by as much as 7.5 percent (Coates and Delehanty, 2010). Ravens are attracted to edge environments largely associated with lack of shrub canopy. Fuel breaks that intersect shrublands may result in increased ravens and other predators.

The attraction of edges to predators has consequences for prey. For example, greater sage-grouse nests located in fragmented habitats (that is, remnant patches of sagebrush within an agricultural matrix) were approximately nine times more likely to be depredated than those in contiguous habitats, and the majority of nests in fragments were depredated by ravens and other corvids (Vander Haegen and others, 2002). Similarly, increased habitat loss and creation of edges due to natural gas development has been associated with decreased nest survival and increased rodent nest predation rates on sagebrush songbirds (Hethcoat and Chalfoun, 2016a, 2016b). Studies have shown that ravens are important predators of eggs and nestlings of multiple species of birds (Andren, 1992; Luginbuhl and others, 2001), including sage-grouse in the Great Basin (Coates and others, 2008; Coates and Delehanty, 2010; Lockyer and others, 2013). Fuel breaks in nesting habitat might put sage-grouse at relatively higher risk of nest loss, which can influence population growth (Taylor and others, 2012). Sage-grouse tend to avoid nesting in sagebrush environments with relatively high densities of ravens (Dinkins and others, 2012), and raven abundance has been associated with changes in sage-grouse incubation patterns (Coates and Delehanty, 2008) and their nest survival, while other predators have been found to be less important within the Great Basin (Coates and Delehanty, 2010). Although corvids have been influential nest predators in the Great Basin, additional studies within and outside the Great Basin are needed to help clarify spatial variation in the impacts to prey communities. Lastly, increased edge has positive effects on other generalist predatory birds that likely impact sage-grouse adult and juvenile survival, particularly red-tailed hawks (*Buteo jamaicensis*) and Swainson’s hawks (*B. swainsoni*), both of which are effective predators of adult and juvenile sage-grouse (Conover and Roberts, 2017).

Although the line between fuel break and surrounding vegetation may be sharp, environmental changes of a fuel break are likely to extend into the surrounding vegetation. This environmental gradient will have varying effects on animals depending on their environmental tolerances, but with decreasing effects with distance from edge. Compared to the core of surrounding habitats, conditions at the edge are usually warmer, drier, windier, and have more diel and seasonal variability. Thus, these disturbances can influence the remaining native vegetation by altering resource availability and species composition; particularly at the edge between cover types (Saunders and others, 1991). Within sagebrush ecosystems, surrounding habitats that are immediately adjacent to fuel breaks, likely often consist of less shrub canopy cover than those areas located within contiguous core habitat. Total shrub cover is one of the most critical microhabitat factors related to nest site selection and survival across sage-grouse range (Connelly, Reese, and others, 2000; Connelly, Schroeder, and others, 2000b; Connelly and others, 2004) and most notably within the Great Basin (Kolada and others, 2009; Lockyer and others, 2015; Gibson and others, 2016), where the large majority of fuel breaks have been proposed. Overstory shrub cover is also important for pygmy rabbits (Larrucea and Brussard, 2008; Lawes and others, 2013), black-tailed jack rabbits (*Lepus californicus*) (Johnson and Anderson, 1984), ground squirrels (Yensen and others, 1992; Steenhof and others, 2006), and several passerine birds (Baker and others, 1976; Knick and Rotenberry, 1995; Chalfoun and Martin, 2007). These edge effects could be resulting in "functional" habitat loss (Aldridge and Boyce, 2007), where otherwise suitable sagebrush habitat adjacent to roads (or proposed fuel breaks) are avoided, as has been shown for greater sage-grouse (Aldridge and Boyce, 2007). Functional habitat loss for sage-grouse in otherwise suitable sagebrush habitats may extend out at least as far as about 2 km in winter habitat (Carpenter and others, 2010).

Linear Features

A feature of fuel breaks that is different from other forms of wildlife habitat alteration is their linearity. Few natural features in the environment are as linear as those that are anthropogenic (for example, transmission lines, fences, roads, fuel breaks). Variation likely exists in how wildlife perceive these linear features within a landscape compared to natural irregularly shaped features and, as such, these linear features are likely to have different consequences among species. Sage-grouse showed strong avoidance of edges in Canada during nesting (Aldridge and Boyce, 2007). Others have shown that, while on the ground, sage-grouse tend to move along topographic features and to avoid areas without sagebrush cover (Dunn and Braun, 1986). These behaviors are fairly typical of wildlife in general, which often spend time in close proximity to, or avoid crossing (including flying over), non-vegetated areas (for example, brown strips), and will instead attempt to cross in areas that offer at least some protective cover (Richard and Armstrong, 2010). As such, we suspect that some species might move unusually long distances as they attempt to locate an area to transit the fuel break. If fuel breaks reduce successful dispersal, there could be consequences for colonization of new habitats, metapopulation dynamics, or gene flow.

Within sagebrush ecosystems, newly created fuel breaks might impose travel corridors allowing terrestrial predators to readily access sagebrush habitats and operate at much larger spatial scales. For example, mammalian predators, including coyotes (*Canis latrans*), badgers (*Taxidea taxus*), and red foxes (*Vulpes vulpes*), have been shown to use anthropogenic corridors as travel routes while hunting, presumably improving functional response by easier access to prey (Crête and Larivière, 2003; Frey and Conover, 2006). However, potential mechanisms of such effects also have been debated (Larivière, 2003), despite the observed increased in predation rates along edges. Badgers in British Columbia displayed a preference for both roads and general linear corridors (Apps and others, 2002). Common ravens (*Corvus corax*) and other predatory birds are attracted to roads and cleared linear right of ways within shrublands (White and Tanner-White, 1988; Knight and Kawashima, 1993; Coates and others, 2014b; Howe and others, 2014). In sagebrush habitats in Idaho, raven occurrence declines exponentially with the distance from transmission lines and roads (Howe and others, 2014). The authors indicate that ravens were often observed flying over roads, particularly in the early morning hours, presumably searching for prey. Reports of similar observations of ravens flying along linear networks have been reported elsewhere (Bui and others, 2010). Direct removal of overstory shrubs within fuel breaks likely helps to increase movement speeds of predators traveling from one point to another. This effect may diminish in green strips when seeded species reach maturity.

Many fuel breaks are associated with roads, and there is considerable empirical evidence that roads have negative effects on wildlife through vehicle collisions, noise, pollutants, and habitat alteration. For example, Ingelfinger and Anderson (2004) examined how unpaved roads constructed for natural gas extraction in Wyoming big sagebrush habitats influenced passerine birds. They found that Brewer’s sparrow and sage sparrow numbers within sagebrush stands were reduced by 39–60 percent within 100 m of the road despite little traffic (<12 vehicles per day). They concluded that the bird responses were unrelated to vehicles and were likely caused by edge effects, habitat fragmentation, and arrival of other passerine species along the road corridor. Some animals are attracted to roads, such as snakes using road surfaces for thermoregulation, which can further increase probability of vehicle-related mortality. In southeastern Idaho, a road survey through sagebrush steppe revealed that most road mortality was associated with gophersnakes (*Pituophis catenifer*) and rattlesnakes (*Crotalus oreganus*), especially where roadsides were dominated by nonnative grasses (Jochimsen and others, 2014). Horned Larks (*Eremophila alpestris*) are attracted to roadways where they forage on windblown seeds that collect on dirt roads (Ingelfinger and Anderson, 2004).

Roads and other linear right of way features can have varying effects on sage-grouse populations (Manier and others, 2014). These linear features may simply be avoided by both greater and Gunnison sage-grouse (*Centrocercus minimus*) (Aldridge and Boyce, 2007; Carpenter and others, 2010; Aldridge and others, 2012), or are thought to alter productivity and survival of local sage-grouse populations, and even result in local extirpations of leks, as has been observed along Interstate-80 in Wyoming (Connelly and others, 2004). However, smaller, less-frequently used trails may be selected by brooding greater sage-grouse during the summer, possibly for the abundance of succulent invasive forbs that are associated with these disturbed sites (Aldridge and Boyce, 2007). If fuel breaks similarly provide succulent food resources, sage-grouse could be drawn into these habitats, possibly increasing predation risk.

Although one study of very coarse road density did not support impacts to sage-grouse range-wide persistence (Aldridge and others, 2008), roads did correlate with lek extirpations (Wisdom and others, 2011). Other studies done at local scales have demonstrated negative associations with roads and both greater and Gunnison sage-grouse avoidance or productivity (Braun, 1986; Lyon and Anderson, 2003; Holloran, 2005; Aldridge and Boyce, 2007; Aldridge and others, 2012; Kirol and others, 2015). Perhaps the discrepancy between these studies was the differences in data collection, where the range-wide presence analyses (Aldridge and others, 2008) was unable to consider numerous secondary roads and underrepresented total road density.

Potential Effects of Green Strips on Wildlife

The sowing of nonnative species into green strips will influence wildlife habitats and use. A study of crested wheatgrass seedings, for example, revealed that these areas supported fewer nesting bird species and lower densities of birds, mammals, and reptiles compared with intact stands of sagebrush (Reynolds and Trost, 1980). Also, some species seeded into green strips may act as an attractant to wildlife because of higher moisture content, chemical composition, or other characters. Butterflies, for example, could take advantage of seeded areas that provide abundant (or even unique) nectar resources (McIver and Macke, 2014). Other sown species, however, may be unpalatable or undesirable to pollinators or grazers. Forage kochia, for example, has been found to share similar dietary characteristics as sagebrush for sage-grouse, but a recent study indicated that sage-grouse do not tend to consume forage kochia and instead continue to eat the native sagebrush (Graham, 2013). Herbicide use to create green strips could potentially have negative effects on wildlife, though very little research has evaluated these consequences (Freemark and Boutin, 1995).

Green strips may also create ecological traps (Remes, 2000; Bock and Jones, 2004) that reduce survival for some wildlife if they are attracted to an area for food resources but in the process get exposed to higher rates of mortality. For example, sage-grouse maybe drawn into these more risky open areas to seek potential food resources, as long as they have suitable escape cover provided by near-by patches of sagebrush (Dahlgren and others, 2006; Aldridge and Boyce, 2008). However, predators, like burrowing owls (*Athene cunicularia*) and badgers, are also attracted to these open areas within shrublands because their prey (for example, deer mice [*Peromyscus maniculatus*], ground squirrels) favor these open habitats (Rich, 1986; Holbrook, Arkle, and others, 2016).

Potential Effects of Brown Strips on Wildlife

We found no literature examining the effects of brown strips on wildlife species or habitats. However, brown strips essentially involve the removal of wildlife habitat, and many of the same dynamics discussed elsewhere in this section (for example, the addition of edge effects) are likely applicable to brown stripping.

Potential Effects of Mowing Fuel Breaks on Wildlife

Mowing in shrublands may be an attractive fuel break alternative from a wildlife perspective because it reduces fuel loads and height without significantly changing plant species composition, unless exotic annuals are present (Davies and others, 2011, 2012a; Swanson and others, 2016). As such, some wildlife species could benefit from mowing treatments, especially those species that prefer disturbed areas, early successional vegetation, open grasslands, or habitat mosaics. For example, Beck and others (2012) reviewed the literature for the effects of mechanical treatments (as well as herbicide applications and prescribed burning) to identify whether these treatments are beneficial for greater sage-grouse, elk (*Cervus Canadensis*), mule deer (*Odocoileus hemionus*), and pronghorn (Antilocapra americana) in sagebrush habitats. They found some evidence that small-scale treatments (≤60-m width) in mountain big sagebrush may create suitable foraging conditions for brooding sage-grouse. Mowing Wyoming big sagebrush may also increase nutritional quality of remaining sagebrush, suggesting some benefits to wildlife (Davies and others, 2009). However, across the Great Basin, butterfly richness and abundance did not increase for 4 years after mowing or herbicide in Wyoming big sagebrush habitats, with the exception of Becker's white (*Pontia beckerii*), which were lower in mowed plots for at least 4 years relative to other plot types (McIver and Macke, 2014). Similarly, mowing Wyoming big sagebrush stands in north-central Wyoming resulted in no detectable effects on ants, beetles, or grasshoppers relative to reference sites (Hess and Beck, 2014). Mowing can also have direct and indirect consequences for wildlife. If mowing or removal of vegetation takes place during sensitive times of nesting or brood-rearing for birds (grouse, songbirds, ducks, etc.) or denning mammals, mechanical equipment could result in direct mortality. Indirectly, removal of existing vegetation creates a structurally less diverse vegetation community, which is a direct habitat loss for some species that use the shrub structure, negatively affecting wildlife, as was the case for nesting shrub-obligate songbirds when habitat was mowed (Carlisle, 2017). Other types of sagebrush removal techniques, such as use of a Dixie Harrow, have been shown to reduce pygmy rabbit abundance (based on fecal pellet counts) while increasing cottontail and black-tailed jackrabbit abundance (Pierce and others, 2011; fig. 21).

Mowing may also have direct and indirect adverse impacts on sage-grouse and other wildlife. Mowing in sage-grouse winter habitat may be particularly harmful to some populations (Eng and Schladweiler, 1972; Beck, 1977). Noise associated with mowing in sensitive sage-grouse areas also is likely to share similar detrimental effects as other types of noise on sage-grouse populations (Blickley and others, 2012). Timing of mowing in relation to sensitive areas for sage-grouse merits further investigation.

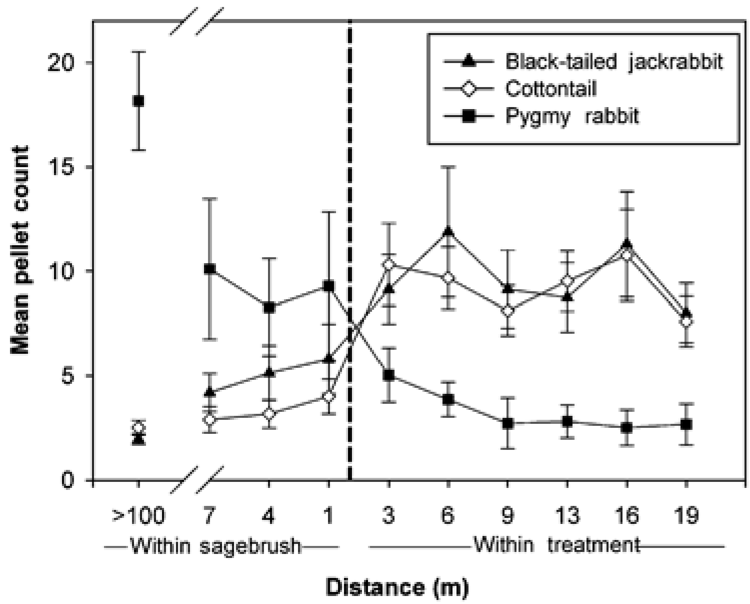

Figure 21. Mean pellet counts (±95-percent confidence interval) by leporid species in control areas in sagebrush near habitat edge, and in mechanically treated areas devoid of sagebrush. (Fig. 4 from Pierce and others [2011], used by permission of John Wiley & Sons, Inc.).

Conclusions and Recommendations

Fuel breaks serve as an important strategy for fire and land management agencies to reduce the risks and negative ecological impacts of wildfire in the Great Basin. Indeed, the Bureau of Land Management has currently identified and prioritized locations for a region-wide network of fuel breaks aimed at collectively minimizing future loss of remaining high priority habitat for sage-grouse that will include both existing, planned, and future fuel break projects (fig. 22). Ideally, these projects will be designed to help minimize future loss of key sagebrush habitat from wildfire, and to reverse recent trends in which hundreds of thousands of hectares of sagebrush habitat are degraded or destroyed each fire season (on average). However, these projects could also add thousands of kilometers of new fuel breaks to the region over the next decade or two, directly altering hundreds of thousands of hectares through habitat conversion, and indirectly affecting sagebrush plant and animal communities through creation of new edge effects and habitat fragmentation.

Enhancing the record-keeping, monitoring, and scientific assessment capacities of the Bureau of Land Management and its science partners (for example, U.S. Geological Survey, university researchers) will be critical for designing, implementing, and maintaining an effective fuel break system into the future. Various types of scientific investigation are likely to be instructive, including retrospective ("space for time") studies of the ecological effects of existing fuel breaks (both maintained and unmaintained); study designs that incorporate comparative analysis of pre- and post-treatment conditions for planned fuel breaks; and modeling exercises that identify opportunities to minimize ecological costs, while maximizing wildland fire suppression potential to protect important natural resources and wildlife habitat. Importantly, it should be recognized that implementation of fuel break systems by land managers is a grand experiment that is not feasible for researchers to replicate or emulate at the appropriate scales; thus, integrating scientific assessment in the form of adaptive management of fuel breaks may also be a key path forward. Finally, we acknowledge that there are other aspects of fuel breaks not addressed in this report that may also be considered, including the potential for increased human impacts (for example, greater ignition rates) in remote areas, as a result of improving roads for fuel break construction and access.

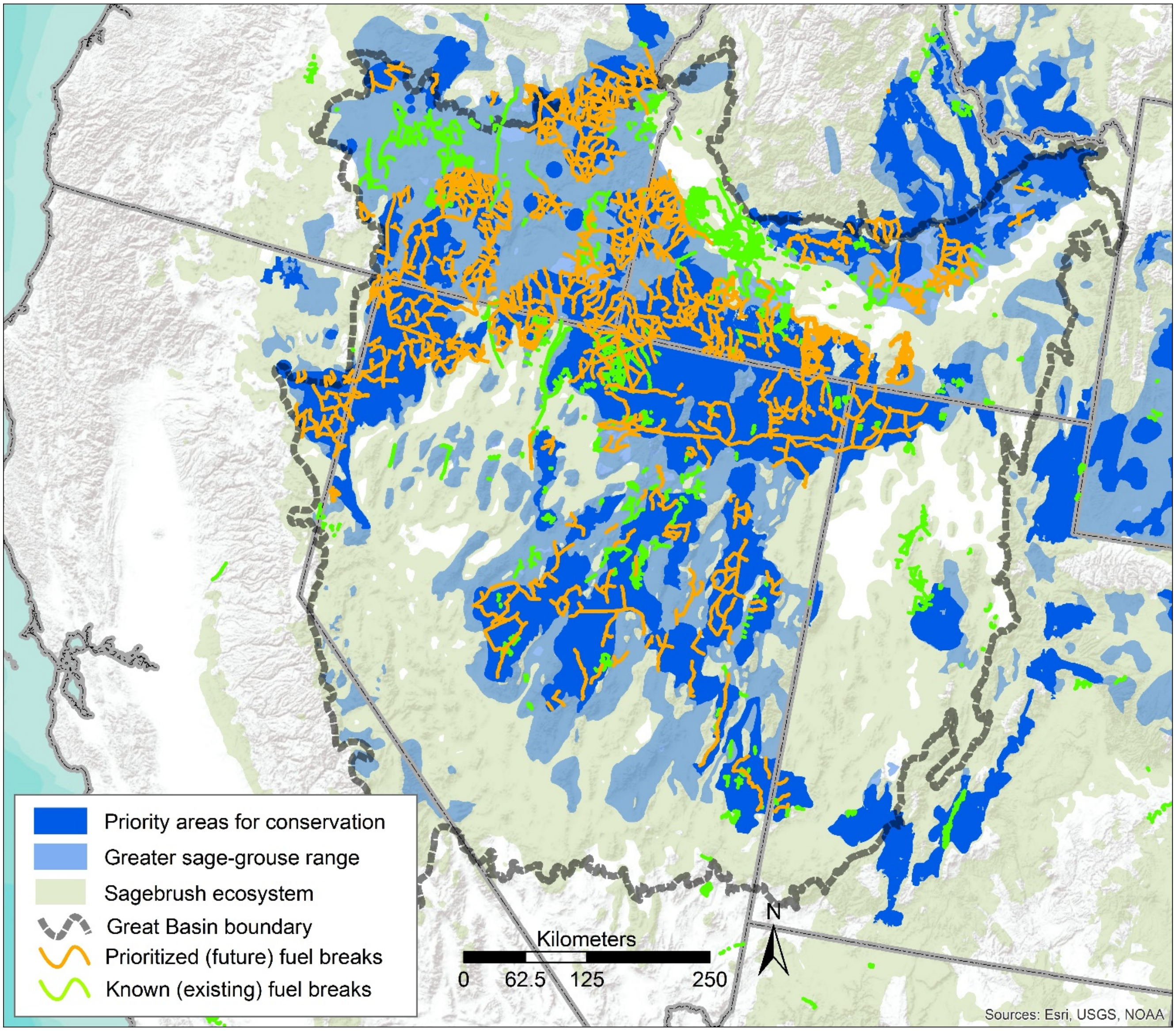

Figure 22. Existing and prioritized locations for future fuel breaks in the Great Basin relative to sage-grouse (*Centrocercus urophasian*us) habitat and priority areas for conservation. Existing fuel breaks include known linear fuel breaks (data sources as described in table 1) based on treatment information and mapped locations. Numerous unmapped fuel breaks also likely exist. Priority future locations for fuel breaks are based on conservation values derived from the Fire and Invasives Assessment Tool (Bureau of Land Management, 2017) that provides the BLM and other agencies a framework to prioritize wildfire management and conservation of sage-grouse habitat. Implementation of priority fuel breaks will require further agency planning and review, and includes both new fuel break construction as well as maintenance and enhancement of existing fuel breaks. Sagebrush ecosystem data taken from U.S. Geological Survey (2018b); greater sage-grouse distribution data taken from U.S. Geological Survey (2018a).

Fuel Break Effectiveness at Reducing Wildfire Impacts

Using wildfire simulation systems and other modeling tools to better plan the spatial configuration of landscape scale treatments would enhance strategic planning efforts to mitigate wildfire spread across the Great Basin and to use fuel breaks most effectively. Although modeling systems already exist to assist with this effort, there is concern within land and fire management communities about the lack of standard surface fuel models (that is, representing more precise fuel conditions) to characterize vegetation types typical of the Great Basin, as well as a lack of data available to validate modeled outputs of potential fire behavior. These concerns are not unique to the Great Basin; as with any application of models and fire behavior systems, fire behavior outputs are probabilistic representations of very complex phenomena which are subject to sources of errors not limited to input data, applicability of use, and model accuracy (Albini, 1976; Alexander and Cruz, 2013a, 2013b). These sources of error can lead to both under- and over prediction of potential fire behavior. However, with careful calibration of both input data and the simulation parameters, an experienced user can minimize these errors (Varner and Keyes, 2009). Various data sources can be used to better fit standard fuel models or develop custom fuel models for use in fire behavior simulations (for example, Stebleton and Bunting, 2009; Bourne and Bunting, 2011). New techniques are also available to obtain dynamic fuel conditions across large regions (for example, Li and others, 2017; Anderson and others, 2018) that could help to quantify fuel parameters for spatially-explicit, landscape-scale, modeling applications. Moreover, other vegetation-based models are being developed to aid in planning and predicting how rangeland fuel loadings might change over time under different climate and management scenarios (for example, the Rangeland Vegetation Simulator; Reeves and Frid, 2016).

The ability of agencies to weigh the potential costs and benefits of implementing extensive networks of fuel breaks would also aid in their efficient and strategic use. Modeling can help to locate fuel breaks where ecological costs may be minimized while simultaneously maximizing wildland fire suppression efforts to protect human development, important natural resources, and wildlife habitat (for example, Bar-Massada and others, 2011; Gray and Dickson, 2016; Opperman and others, 2016). However, these analytical models would benefit from more consistent record-keeping and enhanced information regarding fuel break conditions, ecological effects, and effectiveness over time and space. Although the FTEM program is a step in the right direction regarding effectiveness, there is a need for more quantitative monitoring of fuel break ability to alter fire behavior. For instance, the effectiveness of linear fuel breaks to aid in fire suppression and therefore limit fire size could be assessed across the Great Basin using different metrics of success (for example, containment). Mapped wildfire data coupled with documented wildfire suppression tactics, fuel treatment locations and maintenance history, and fire environment conditions (for example, fuels within and outside of fuel breaks, fire weather) could be used to better assess if fuel breaks aided suppression efforts and, if so, whether they were useful in controlling fire spread or meeting other fire management objectives (for example, reducing severity). Such information could also be valuable to evaluate and determine optimal and cost effective fuel break maintenance strategies. However, the lack of well-mapped historical linear fuel breaks makes a retrospective analysis difficult for many applications. Additionally, better and more comprehensive information is needed from programs that specifically and systematically monitor fuel and other vegetation conditions in fuel breaks over time, as well as their ecological effects (as described below).

Fuel Break Design Considerations for Plant Communities

In plant communities, the effectiveness and potential collateral impacts of fuel breaks mainly depend on (1) the spread of nonnative species that are seeded onto breaks or which invade the breaks, and (2) if and how fuel breaks are maintained. The impact of fuel breaks will depend on the condition, resistance, and resilience of the land converted into a fuel break, as well as in the surrounding landscape. With such little research done on fuel break impacts on plant communities, and yet with expansion of fuel breaks underway, it is vitally important to learn from the actual implementation of fuel breaks. This opportunity to learn would only be possible with carefully designed experiments and (or) comprehensive monitoring that includes species composition and biomass measured before and in the years after implementation of fuel breaks. Monitoring and analyses will be most effective if done for both the direct area on the ground converted to fuel breaks, as well as at different distances from the edge of fuel breaks into surrounding landscapes.

It is also worth pointing out that native species that do not contribute substantially to fuel accumulation and are more drought tolerant than nonnative wheatgrasses (Frank, 1994) may also have potential utility within fuel breaks in some cases. For instance, although Sandberg bluegrass senesces early in the growing season, it is drought and fire tolerant, low-statured, and competitive with cheatgrass (Howard, 1997; Goergen and others, 2011), and it has recently been used in fuel breaks in sensitive species habitats in the northern Great Basin (fig. 23; Mark Williams, Bureau of Land Management, oral commun.).

Figure 23. Native species fuel break, northern Nevada. Photograph by Bureau of Land Management.

Fuel Break Design Considerations for Wildlife

Managing the effects of fuel breaks on wildlife might build upon historic literature of sagebrush removal for purposes of forage production for domestic grazers. In 1976, the Conservation Committee of The Wilson Ornithological Society reviewed available data on the effects of reducing sagebrush on birds and came to the following conclusion: “Sagebrush alteration should be confined to relatively small areas of 16 ha, preferably less. These should be in irregular strips which would give a maximum amount of edge for wildlife and maintain habitat diversity, and be aesthetically most pleasing. Such strips should be alternated with undisturbed strips of sagebrush about twice as wide, or more, and preferably at right angles to the prevailing wind and/or the slope of the land” (p. 169, Baker and others, 1976). Such well-intentioned recommendations to maintain the integrity of sagebrush habitat could be modified to be consistent with the science some 40 years later, especially given our improved understanding of invasive and generalist species that capitalize on habitat disturbance and edge, and the ecological benefits of protecting contiguous tracts of habitat from the irreversible impacts of wildfire.

The width of fuel breaks is an important aspect of their design when considering potential effects on wildlife. Some of the earliest work on passerine birds recommended herbicide treatments of no more than 30 m to avoid negative effects on sagebrush-dependent species such as the Brewer’s sparrows (Best, 1972). Others recommended mechanical or chemical removal of sagebrush in 100-m-wide strips with untreated strips 100–200 m wide to provide sufficient nesting habitat for sagebrush-dependent species such as sage thrashers (Castrale, 1982). Castrale (1982) also recommended retaining scattered shrubs in treated strips “because they are frequently used by all species as perches” (p. 951). McAdoo also suggested retaining at least 10 percent shrub cover in treated areas to maintain bird diversity (McAdoo and others, 1989). More recently, studies suggest treatments less than 60 m wide may be beneficial to wildlife, such as brood rearing sage-grouse, by creating attractive foraging conditions (Pyle and Crawford, 1996; Dahlgren and others, 2006). In a recent review, however, Beck and others (2012, p. 452) stated that “relying on dogmatic beliefs rather than the best available data to support management programs is premature at best for some species and irresponsible at worst for sage-grouse and possibly other species, especially given the stressors currently affecting sagebrush steppe habitats” and “more research is needed to understand the associations between sagebrush wildlife and patch size of treatments better.” For instance, recent studies that demonstrate lower songbird nest survival with a decrease of surrounding habitat (Hethcoat and Chalfoun, 2015a) suggest a likely a trade-off between implementing effective fuel breaks and habitat loss for some wildlife.

The risks of a no-action alternative are unknown, but there is mounting evidence that both fire and conversion of shrublands to invasive grasslands following repeated fires can have strong effects on animal communities, including insects (Ostoja and others, 2009; Holbrook, Pilliod, and others, 2016), mammals (Ostoja and Schupp, 2009; Holbrook, Arkle, and others, 2016; Holmes and Robinson, 2016), birds (Knick and others, 2005; Earnst and others, 2009), and reptiles (Hall and others, 2009). Hence, efforts to protect intact sagebrush may have long-term benefits to sagebrush-associated wildlife even if fuel breaks have mixed effects for individual species and populations at local scales. The lack of correlative or, more importantly, experimental studies, that assess the effects of different types of fuel breaks for most wildlife species (and at relevant spatial scales) is a severe limitation for design and implementation recommendations for fuel breaks in sagebrush ecosystems landscape. A conservative “first do no harm” approach may be warranted to restrict fuel break implementation until this research is completed, but we also recognize that, by waiting, it may be too late to act given current trends in wildfire across the Great Basin.

Acknowledgments

We thank Anna Chalfoun, Michele Crist, Mike Ielmini, Susan McIlroy, Sue Phillips, and Karen Riley, who provided helpful reviews of this report. We also thank Justin Welty and Robert Arkle for helping to prepare and quantify fuel break data and other fuels data that were used in this report, especially in table 1, figure 22, and appendix 2.

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Glossary

All definitions (except 'Sagebrush Focal Area') obtained from the National Wildfire Coordinating Group (2018).

Fine Fuels: Fast-drying dead or live fuels, generally characterized by a comparatively high surface area-to-volume ratio, which are less than 1/4-inch in diameter and have a timelag of 1 hour or less. These fuels (grass, leaves, needles, etc.) ignite readily and are consumed rapidly by fire when dry.

Fire Regime: Description of the patterns of fire occurrences, frequency, size, severity, and sometimes vegetation and fire effects as well, in a given area or ecosystem. A fire regime is a generalization based on fire histories at individual sites. Fire regimes can often be described as cycles because some parts of the histories usually get repeated, and the repetitions can be counted and measured, such as fire return interval.

Fireline Intensity: (1) The product of the available heat of combustion per unit of ground and the rate of spread of the fire, interpreted as the heat released per unit of time for each unit length of fire edge. The primary unit is Btu per second per foot (Btu/sec/ft) of fire front. (2) The rate of heat release per unit time per unit length of fire front. Numerically, it is the product of the heat yield, the quantity of fuel consumed in the fire front, and the rate of spread.

Fireline: The part of a containment or control line that is scraped or dug to mineral soil.

Fire Weather: Weather conditions which influence fire ignition, behavior, and suppression.

Fuel Bed: An array of fuels usually constructed with specific loading, depth, and particle size to meet experimental requirements; also, commonly used to describe the fuel composition.

Fuel Break: A natural or manmade change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled.

Fuel Loading: The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel (consumable fuel) or total fuel and is usually dry weight.

Fuel Moisture Content: The quantity of moisture in fuel expressed as a percentage of the weight when thoroughly dried at 212 °F.

Fuel Type: An identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics that will cause a predictable rate of spread or resistance to control under specified weather conditions.

Sagebrush Focal Area or "SFA": The U.S. Fish and Wildlife Service has identified important landscape blocks with high breeding-population densities of greater sage-grouse (*Centrocercus urophasianus*), existing high quality sagebrush habitat, and a preponderance of Federal ownership or protected area that serves to anchor the conservation value of the landscape.

Spotting: Behavior of a fire producing sparks or embers that are carried by the wind and which start new fires beyond the zone of direct ignition by the main fire.

Appendix 1. Behave Plus Modeling Parameters

BehavePlus (version 5.0.5, Heinsch and Andrews, 2010; Andrews, 2014) was used to model potential flame lengths and rates of spread for existing and treated fuel types within the sagebrush ecosystem of the Great Basin (fig. 17). Fuel model selection (Scott and Burgan, 2005) and description for each fuel type is shown in table 1-1. All runs were completed assuming: (1) a 15 percent slope; (2) 29 °C (85 °F) air temperature; and (3) very low dead and live fuel moisture conditions[1] as defined by Scott and Burgan (2005). For each model run, midflame wind speed was stepped by 8 km/hr (5 mi/hr) increments.

Table 1-1. Fuel model section for each fuel type modeled with BehavePlus (Heinsch and Andrews, 2010; Andrews, 2014).

Fuel type	Fuel model type	Fuel model	Fuel model description
Sagebrush	Shrub	SH5	Heavy shrub load about 1.2–1.8 m (4–6 ft) tall
Sagebrush/grass	Grass-shrub	GS2	Shrubs are 03.–0.9 m (1–3 ft) tall with moderate grass load
Tall grass	Grass	GR4	Moderately coarse continuous grass about 60 cm (2 ft) tall
Short grass	Grass	GR2	Moderately coarse continuous grass about 30 cm (1 ft) tall
Green strip (bunch grass)	Grass	GR1	Grass is short and patchy
Green strip (subshrub)	Shrub	SH1	Low shrub fuel load about 30 cm (1 ft) tall and some grass may be present
Mowed	Shrub	SH1	Low shrub fuel load about 30 cm (1 ft) tall and some grass may be present
Brown strip	Non-burnable	NB	Insufficient wildland fuel to carry wildland fire under any condition

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[1] For all scenarios, fuel moisture was set to 3, 4, 5, 30 and 60 percent for 1-hr, 10-hr, 100-hr, live herbaceous and live woody, respectively, with the exception of green strips. For the green strip model runs, live fuel moistures were low or two-thirds cured (that is, 60 and 90 percent for live herbaceous and live woody, respectively).

Appendix 2. Methods to Map and Quantify Linear Fuel Breaks (Distance and Area) in the Great Basin

Data Sources

Data were acquired from the LTDL, a legacy database of Bureau of Land Management (BLM) land treatments entered by USGS personnel, and the Vegetation Treatment Method (VTRT), a spatial record of treatments uploaded to the VTRT by BLM field offices. The LTDL and VTRT data sources were accessed on October 13, 2017, and are available at Pilliod and Welty (2013) and by contacting the BLM, respectively. These data sources are incomplete (especially pertaining to older treatments), contain duplicate records, and typically have inconsistent and non-standardized field entries for past treatment records making identification of linear fuel breaks within these datasets difficult. Thus, we used a series of automated and manual steps to conservatively identify and measure linear fuel breaks, as described below.

This is an initial assessment of fuel breaks in the Great Basin that will eventually be reconciled with other agency databases, particularly the National Fire Plan Operations and Reporting System (NFPORS) and additional information from BLM state offices.

Identifying Fuel Breaks

First, a query function was developed to search records in both the LTDL and VTRT for terms that would identify potential fuel breaks. For example, "green strip" fuel breaks were searched using many possible variations of the term (for example, "greenstrip", "green strip", etc.). These records were then flagged and standardized in a newly created field identifying them as "green strip" record. The same process of looking for variations on terms was used to identify other types of fuel breaks (for example, mowed or brown strip), as well as other potential treatment terms (and their variations) that could be potentially later verified as linear fuel breaks (for example, kochia, WUI, fuel break, fuelbreak, highway, tumbleweed) after review of descriptive fields (that is, those fields describing a fuel treatment).

Second, all identified potential records of fuel breaks were then manually assessed in the associated spatial data layers for each database using a GIS. This process was also used to display and search for long, narrow, linear features about 1 km or longer that, based on other available attributes or descriptions, were likely to be fuel breaks. While this process was somewhat subjective, nearly all additional linear fuel breaks identified using this process were apparent based on combinations of their physical features, treatment names, and treatment descriptions. For example, a treatment labeled "prescribed fire" that was long, narrow, and along a roadway would be included in the linear fuel break dataset.

Third, incorrectly identified records were removed from the initial list of potential fuel breaks (obtained from both the VTRT and LTDL), based on additional key word searches and information identified during a manual scanning of the attribute fields that suggested the primary treatment (for example, monitoring, erosion control, or fire rehabilitation) was not fuel related.

Fourth, the two resulting linear fuel break datasets derived from the VTRT and LTDL (via the process descried above) were merged into a single master linear fuel break database. The name, treatment type, treatment year, and all other relevant fields (for example, treatment descriptions) were brought into common fields created for the merge. To identify and remove duplicate entries between the two original databases, a customized python script was developed that identified features that intersected spatially and occurred in the same year and binned them into a single group for analysis. These features were examined, and if determined to be true duplicates, only one version of the record was kept. A similar process was used to identify multiple treatment entries for a given fuel break over time; such that fuel break boundaries were merged (dissolved) into one spatial record that retained the original information on the number, types, and dates of fuel breaks treatments over time. Finally, using a second visual inspection of the dataset, we removed all records that were not linear in nature (<1 km long).

Calculating the Linear Distance and Area of Linear Fuel Breaks

To calculate the total area by BLM district office treated as linear fuel breaks, we dissolved all fuel breaks into a single multipart feature and used ArcGIS Calculated Geometry to calculate the area in hectares. This value represents the estimated area of land that has been treated, not the number of actual treatment area, as some treatments overlap or represent maintenance of existing treatments. Thus, this value likely underestimates the true total land area and the actual area treated by district, due to both missing records and the repeated treatments within a given area being combined in this analysis. To calculate the linear distance treated of linear fuel breaks, the same multipart feature was used. However, because some fuel breaks consisted of treatments occurring along both sides of a road or highway (and even the median, if one existed), we used ET GeoWizards Aggregate Polygons tool (ET Spatial Techniques, 2016; http://www.ian-ko.com) in GIS with a 100 m buffer to aggregate separate polygons into a single polygon unit. The GeoWizards Calculate Centerline tool was then used to create a centerline for all remaining polygons. The total distance (in kilometers) of these centerlines was then calculated using ArcGIS Calculate Geometry to derive the total length of each line by BLM district office. This value represents the estimated length of land within positively identified linear fuel breaks and not the total number of treatment kilometers, as some treatments overlap or were maintained via two or more treatments over time. Moreover, many linear kilometers are likely not accounted for due to missing records (especially older treatments) in the two databases assessed (VTRT and LTDL).

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Tacoma Publishing Service Center

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Shinneman and others—**A Conservation Paradox in the Great Basin—Altering Sagebrush Landscapes with Fuel Breaks to Reduce Habitat Loss from Wildfire**—Open-File Report 2018-1034

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20181034