4. WILDLAND FIRE AND VEGETATION MANAGEMENT

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Introduction

Wildland fire has always been an important ecosystem process across the sagebrush biome. Recently, the scale of sagebrush ecosystem loss and fragmentation has increased due to a combination of uncharacteristic wildland fire, invasive annual grasses, juniper *(Juniperus* spp.) and piñon *(Pinus* spp.) expansion, and anthropogenic land use and development. A strategic approach to wildland fire and vegetation management is now required that focuses available resources in the places that will maximize conservation return on investment. Wildland fire management integrated with vegetation management (fuel reduction and ecosystem restoration) has the potential to increase that return on investment by enhancing the resilience of native sagebrush ecosystems to stress and disturbance and resistance to invasive annual grasses. Similarly, vegetation management along with postfire restoration helps maintain functionally diverse plant communities with the capacity to persist and stabilize ecosystem processes under altered disturbance regimes. When placed in the context of large landscapes, these actions collectively are part of a strategy to maintain the necessary ecosystem processes and connectivity that allow ecosystems and species to adapt to increasing pressure from anthropogenic land use and development and fluctuations in climate.

Managing for Wildland Fire-Resilient Ecosystems

An understanding of the links among ecosystem resilience to disturbance and resistance to invasive annual grasses, priority areas and habitats for management, and the predominant threats is useful for effectively targeting wildland fire and vegetation management actions. Definitions of wildland fire and related terms are in Appendix 1. In the context of the Science Framework, wildland fire has varying negative and positive effects on sagebrush communities, depending on a site's relative resilience to disturbance and resistance to invasive annual grasses (see Chambers et al. 2017 [hereafter, Part 1], sections 5.1 and 6). Geospatial analyses can be used to assess the relative resilience and resistance of areas that support species or resources at risk. They also can be used to assess the probability of wildland fire occurring within these areas and the interactions of fire with resilience and resistance in sagebrush habitats (see tables 1.3, 1.4; Part 1, sections 8 and 9).

Top: Aerial drop of fire retardant onto a wildfire (photo: USDOI Bureau of Land Management). Middle left: Fire crew on fire line (photo: USDOI Bureau of Land Management). Middle right: Planting sagebrush and other native plants after a fire on land managed by BLM (photo: Tetona Dunlap, Courtesy of TIMES-NEWS, magicvalley.com). Middle center: Removing juniper by cutting the trees with chainsaws (photo: Jeremy Roberts, Conservation media). Bottom: Mowed fuel break along road (photo: USDOI Bureau of Land Management).

Identifying Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) habitats at risk from wildland fire involves overlaying key data layers to both visualize and quantify: (1) the likely response of the area to either fire or management treatments (i.e., an area's resilience and resistance to invasive annual grasses), (2) the probability that an area has suitable GRSG breeding habitat and supports GRSG populations, and (3) the exposure to dominant threats. Using geospatial analysis to quantify areas within different resilience and resistance to invasive annual grasses and habitat categories, along with different burn probabilities, by ecoregion, Management Zone (fig. 1.1), or Priority Areas of Conservation within Management Zones for GRSG, provides additional information for prioritization.

A wildland fire risk assessment was conducted using GIS data layers to understand how resilience to disturbance and resistance to invasive annual grasses may inform wildland fire management related to preparedness, suppression, fuel management, and postfire restoration within GRSG habitat across the sagebrush biome (Part 1, Appendix 10). Three GIS datasets were used: burn probability (Short et al. 2016); GRSG breeding habitat probabilities (Doherty et al. 2016); and resilience and resistance as indicated by soil temperature and moisture regimes (Maestas et al. 2016b). The wildland fire risk assessment spatially identifies areas where ecosystem resilience and resistance interact and where sagebrush and GRSG habitats are at highest risk from fire across the sagebrush biome and current GRSG range (fig. 4.1). The wildland fire risk assessment is useful to: (1) evaluate the level of fire risk to vegetation types and species, (2) target areas for fire management, and (3) determine the most appropriate types of fire management actions based on an ecosystem's resilience to fire and resistance to invasive annual grasses. Incorporating spatial information on invasive annual grass occurrence, juniper and piñon expansion, and threatened and endangered species in the risk assessment can further inform the type of management actions and the allocation of budgets at broad (biome) and mid- (ecoregion or Management Zone) scales, as well as local (project or site) scales. Note that in the eastern part of the sagebrush biome, invasive annual grass/fire cycles are an emerging problem (Baker 2011; Floyd et al. 2004, 2006; Mealor et al. 2012, 2013) that modeled burn probabilities, based on historical burn areas, do not illustrate well.

Broad- to Mid-Scale Considerations

Wildland Fire Preparedness, Suppression, and Prevention

Optimizing wildland fire preparedness and suppression response is highly complex and considers fire danger, availability of suppression resources, access to and remoteness of the fire, and many other ecological, social, political, and economic variables. Federal land management agencies and their partners are starting to incorporate sagebrush conservation into wildland fire management decisions across the sagebrush biome. Fire operations and integrated vegetation management programs, coupled with fire simulation modeling, contribute to a strategic, landscape approach based on the likelihood of wildland fire occurrence and potential fire behavior (Finney et al. 2010; Oregon Department of Forestry 2013). Numerous factors influence the placement of fire management resources, including safety, climate, weather, human values, infrastructure, and natural resource considerations. In the sagebrush biome, the Integrated Rangeland Fire Management Strategy (IRFMS) (USDOI 2015) directs fire managers to assess preparedness and suppression responses based on the location of GRSG habitats and populations, resilience and resistance information, and other factors.

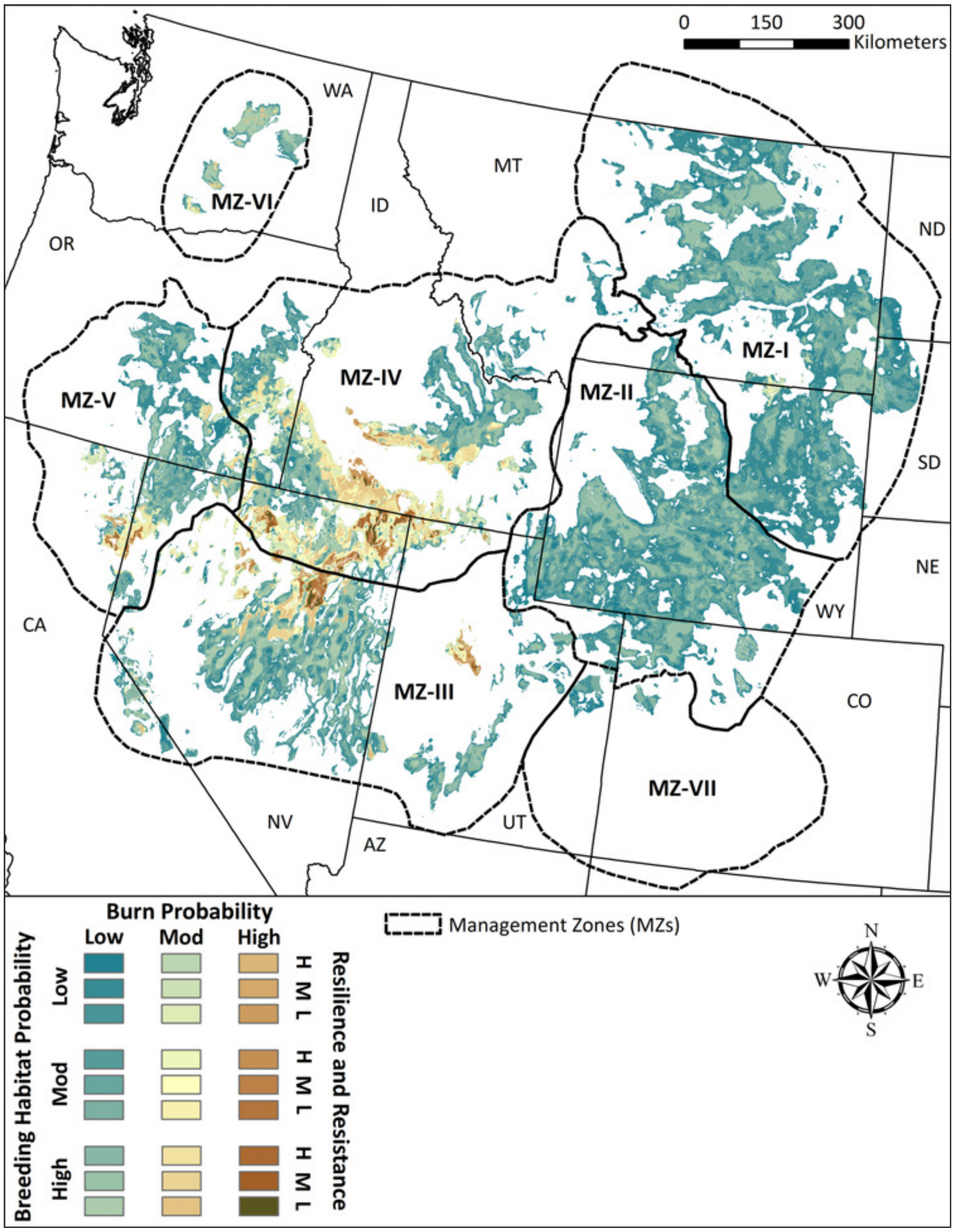

Figure 4.1—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016) depicting 27 different combinations of Greater sage-grouse breeding habitat probability (Doherty et al. 2016), resilience and resistance (Maestas et al. 2016b), and large fire probability (Short et al. 2016).

Table 4.1—Considerations for prioritizing wildfire operations response to wildfires burning in GRSG habitat. These consideration are consistent with tables 1.3 and 1.4.

- In general, areas that support medium to high GRSG breeding habitat probabilities (or other important resources) and have moderate to high wildfire risk are higher priorities for preparedness and suppression efforts, especially in low resilience and resistance categories (figs. 4.1, 4.2).
- Areas with moderate and, especially, high resilience and resistance often have the potential to recover through successional processes without management intervention (table 1.3: cells 1B, 1C, 2B, 2C; fig. 4.3). Wildfire suppression priority typically increases from low to moderate as resilience and resistance decreases from high to moderate.
- Areas adjacent to high to moderate priority habitats may be places to focus wildfire operations activities to protect priority habitats from burning during wildfire events, especially areas with low resilience and resistance that have converted to annual grasses and are prone to frequent wildfires (table 1.3: cells 1A, 2A, 3A; fig. 4.4).
- Areas with low resilience and resistance often lack the potential to recover without significant intervention. Wildfire suppression priority typically increases from moderate to high as GRSG breeding habitat probabilities and population abundances increase from moderate to high (table 1.3: cells 3B, 2C; fig. 4.2). Cheatgrass land cover layers can help identify these areas.
- Newly rehabilitated areas and areas that provide sagebrush habitat connectivity are conservation priorities and considered fire suppression priorities. Sagebrush land cover layers can help identify these areas.
- Managing wildfires in sagebrush habitats in high resilience and resistance juniper and piñon expansion areas can be part of a vegetation management strategy where: (1) weather and fuel conditions allow for managing the wildfire within acceptable limits to values at risk, (2) high priority GRSG breeding habitats and the associated populations are not at risk from loss, and (3) sufficient perennial native grasses and forbs exist to promote recovery.

The Science Framework and the GRSG wildland fire risk assessment provide a spatial framework and management considerations for prioritizing fire suppression efforts for GRSG habitats and populations (table 4.1; fig. 4.1). Geospatial datasets and the mapping process are detailed in Part 1, sections 8 and 9. This information, combined with many other risk factors, such as the wildland-urban interface, is used in the decisionmaking processes for preparing and responding to wildland fires across the Nation. Differences in environmental characteristics, resource values, predominant threats, and management strategies are included to further refine prioritizations across the sagebrush biome. For rapid response in GRSG habitat, combining results of the wildland fire risk assessment (table 4.1; figs. 4.1, 4.2, 4.3, 4.4) with National Interagency Fire Center (NIFC) Predictive Services 7-day potential fire forecasts informs where to pre-position fire crews, equipment, and aircraft in areas predicted to experience fire ignitions and large fire growth.

The mapping products described earlier are used to identify suppression priorities for GRSG and their habitats and to respond to incidents and assign resources at broad- and mid-scales. Fire managers can distribute the wildland fire risk assessment and other geospatial data layers to dispatch offices, incident commanders, fire crew bosses, and other fire responders. Recently, cooperators contributing to suppressing fire in sagebrush habitats include rural, city, and State agencies as well as Rangeland Fire Protection Associations. Sharing these mapping resources may help coordinate and improve initial attack effectiveness during periods of increased fire activity.

In fire preparedness and suppression efforts, the road network is a key element for quick wildland fire response. It also functions as a fuel break network by disrupting fuel continuity across large scales (Agee et al. 2000; Narayanaraj and Wimberly 2013; Syphard et al. 2011). Travel and recreation planning processes identify a minimum road network needed to maintain access for all aspects of land management. The geospatial data layers from the Science Framework, Part 1 are useful for identifying priorities for road maintenance and updates to standards in travel and recreation management planning efforts. Prioritizing roads in travel planning for fire management access and maintenance that are near GRSG habitat areas, at high risk of fire, and characterized by low resilience and resistance to invasive annual grasses will contribute to an effective response to fire (fig. 4.1).

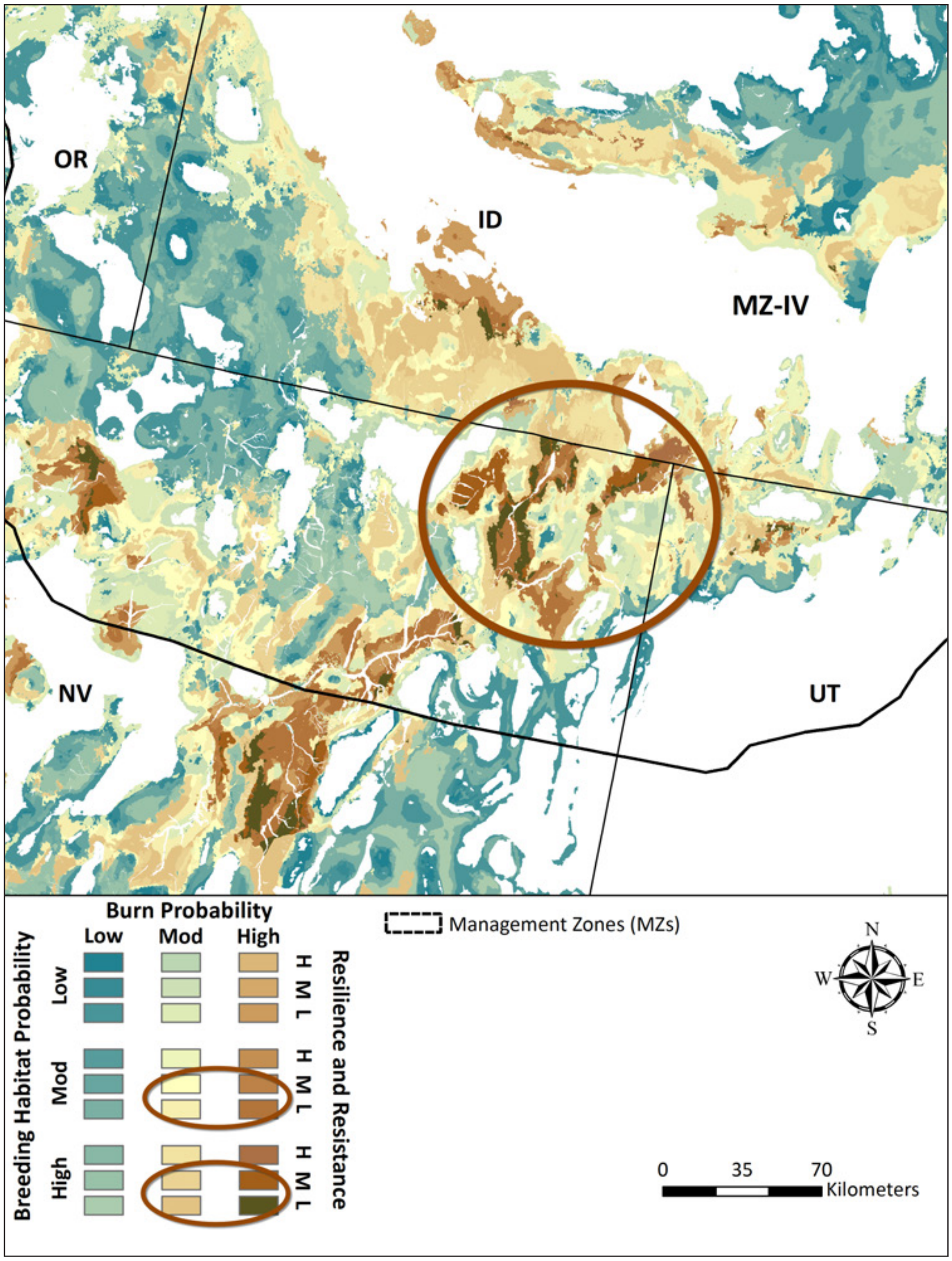

Figure 4.2—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of high to moderate burn probability, high to moderate GRSG habitat probabilities, and low to moderate resilience and resistance. High priorities for management are placing fuel reduction treatments or fuel breaks strategically around GRSG habitats, implementing fire prevention strategies, conducting postfire rehabilitation, and monitoring for spread of nonnative annual grasses. See table 1.3: cells 2B, 2C, 3B, 3C; and table 1.4.

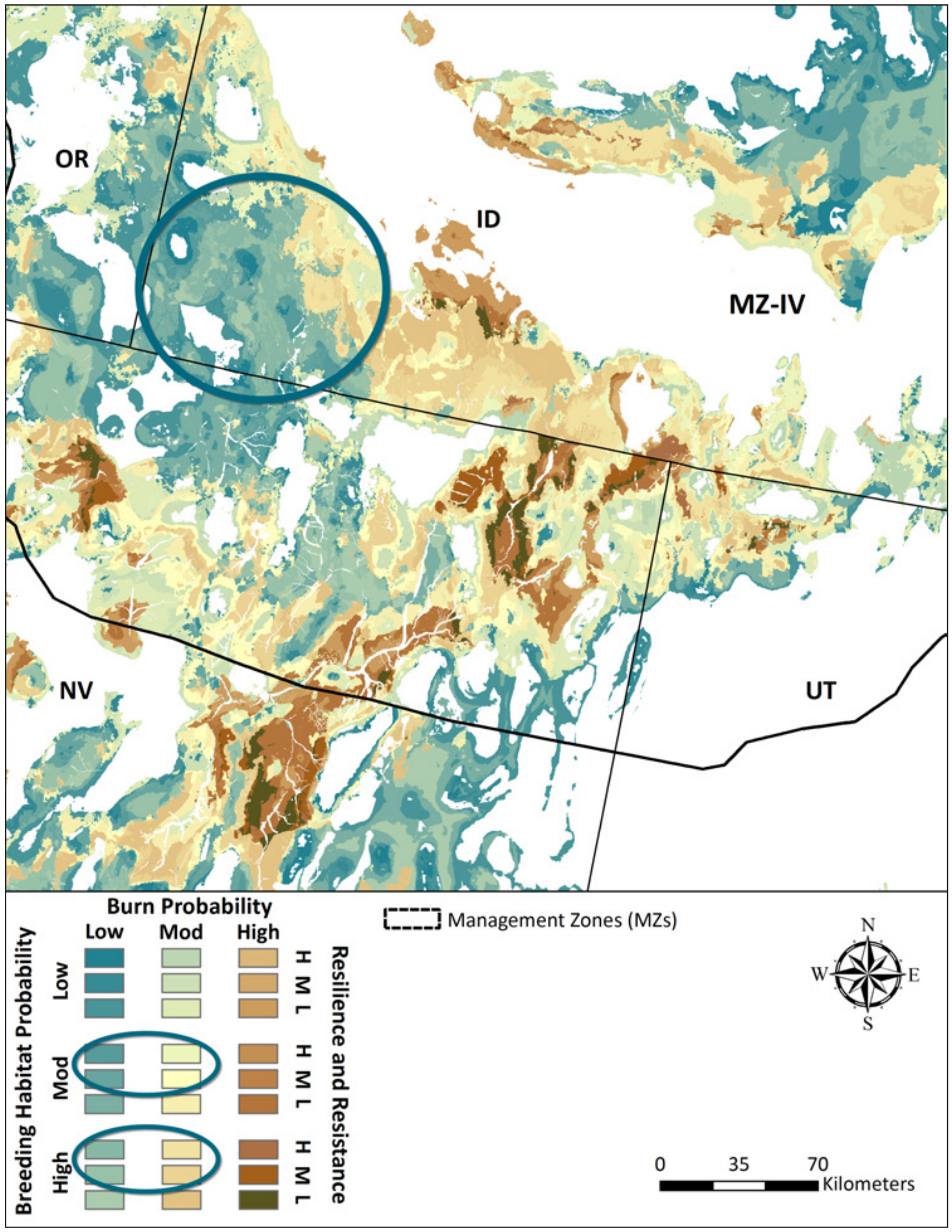

Figure 4.3—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of low to moderate burn probability, high to moderate GRSG habitat probabilities, and high to moderate resilience and resistance. High priorities for management are removing juniper and piñon in expansion areas, allowing natural recovery after fire without intervention, and monitoring for new invasions of nonnative annual grasses and changes in fire frequencies. See table 1.3: cells 1B, 1C, 2B, 2C; and table 1.4.

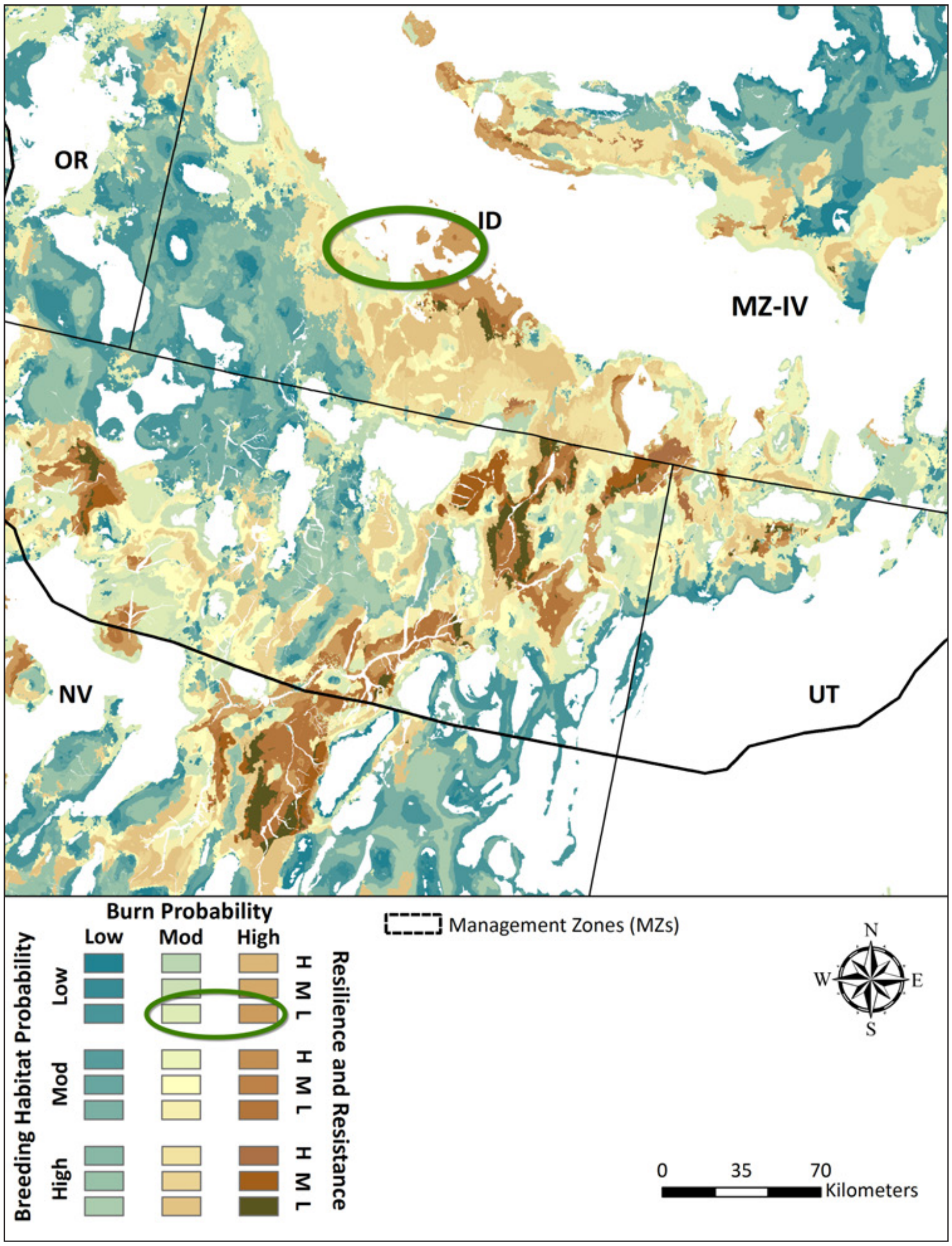

Figure 4.4—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of high to moderate burn probability, high to moderate GRSG habitat probabilities, and low to moderate resilience and resistance. High priorities for management are fuel reduction and fuel breaks, fire prevention strategies, and monitoring for changing conditions. See table 1.3: cells 2A, 3A; and table 1.4.

Wildland Fire Prevention—Human ignitions account for thousands of wildland fires each year across the western United States and well over half of all wildland fires annually (NIFC 2017). Many of these fires occur near wildland-urban interface areas and require a substantial fire suppression response. These fires can take firefighting resources away from fires occurring in sagebrush habitat and other high-value resource areas, especially when multiple fire starts occur during high-wind or lightning events. Areas at most risk from human-caused fires are sagebrush ecosystems with low resilience to fire and resistance to invasive annual grasses located near the wildland-urban interface. These human-caused fires tend to ignite easily and spread quickly, and they are difficult to control, especially in areas where continuous fuel from invasive annual grasses are present. Once fires start, options to protect and rehabilitate these sagebrush ecosystems are limited. Increases in invasive annual grasses post-fire are typical, which result in more human-caused fire ignitions and increase fire suppression costs over time. This annual grass/fire cycle could be disrupted with an effective fire prevention program that reduces human-caused fires in sagebrush ecosystems. Targeted fire prevention efforts that include **education, engineering,** and **enforcement** actions are proven to be successful in preventing human-caused ignitions.

The first step in fire prevention is using **education** to create awareness of new and common human fire causes, and inform citizens of the wildland fire risk and consequences to priority sagebrush areas that many native plant and wildlife species, and human communities, depend on. Analysis of the causes for human-ignited fires helps identify the main factors in human ignitions such as who started the fires, what caused the fires, and where and when the fires typically started for a specified area. This information combined with GIS spatial overlays of wildland fire risk based on resilience and resistance and frequency of human-starts (e.g., fig. 4.1) will help to spatially identify the design of educational campaigns, specifically, the locations and audiences that most benefit from protecting sagebrush habitats. Partnerships developed with interest groups, industries, and communities are important to foster an informed public that understands fire risk. To be effective over the long term, education efforts must move from awareness-building to providing specific information on fire safety measures that prevent ignitions by humans, such as proper fire safety procedures for agricultural or debris burning and not parking on dry grass on hot dry windy days.

Engineering actions taken to prevent wildland fires include working with power companies to ensure poles and transmission lines are constructed and maintained properly, especially in areas where repeated failures occur and ignite fires. Engineering also includes designing and maintaining recreation sites to ensure they are void of flammable vegetation that can ignite from human activities. These fire prevention measures are critical and can have an immediate and direct impact in decreasing the number of human-caused fires. Overlaying GIS datasets on locations of transmission corridors and recreation sites with the wildland fire risk for GRSG habitats depicted in figure 4.1, can determine places to prioritize these types of actions that can both decrease human ignitions and reduce fire risk to high quality sagebrush habitats at mid-scales.

Enforcement of fire safety laws and regulations is a must for an effective fire prevention program. Rigorous wildland fire investigations and cost recovery programs should determine fire origin and cause and pursue cost recovery or criminal penalties when appropriate. Fire investigations can help managers learn the cause of human-ignited wildland fires and design and implement fire prevention strategies. An aggressive cost recovery program can be an effective deterrent to human-caused fires, especially for repeat offenders. When covered by the media, cost recovery helps make the public aware of the consequences of starting a wildland fire.

Vegetation Management and Postfire Recovery

The IRFMS establishes key objectives for vegetation management and postfire rehabilitation. Meeting objectives for vegetation management includes improving the prioritization and siting of fuel reduction and management opportunities and ecosystem restoration projects. Considerations for postfire rehabilitation objectives include promoting long-term restoration efforts and natural recovery, updating prioritization criteria, and incorporating science to promote resilience to fire and resistance to invasive annual grasses. Integral to these objectives are considerations of sagebrush habitat in general, GRSG habitat, ecosystem resilience and resistance, and persistent ecosystem threats, such as fire, the current distribution and abundance of invasive annual grasses, and juniper and piñon expansion.

The Science Framework provides a spatial framework and management considerations for prioritizing vegetation management efforts for GRSG habitats and populations similar to those provided for fire suppression efforts (fig. 4.1, table 4.2). Geospatial datasets and the mapping process for prioritization are detailed in Part 1, sections 8 and 9. For mid-scale assessments conducted at the regional level, information on other resource values and the predominant threats are incorporated and the best available data are used. Depending on data availability, other data layers to consider are land cover of invasive annual grasses and juniper and piñon, habitats of other sagebrush dependent species and their movement or migration corridors, and other values at risk such as endangered plant species.

Vegetation Management—Strategic placement of vegetation management projects across large landscapes is an important step to mitigate the collective effects of wildland fires over broad spatial and temporal extents and help conserve sagebrush ecosystem patterns and processes (table 4.2). Assessments for prioritizing fuel reduction and restoration activities should consider potential fire behavior and spread, habitat fragmentation thresholds (Crist et al. 2015; Knick et al. 2013; Manier et al. 2014; Shinneman et al. 2018), minimum habitat patch sizes to support sagebrush dependent species, and corridors and movement pathways between seasonal and dispersal habitats. This information can help target fuel reduction and restoration actions to maintain or increase connected sagebrush areas while increasing capacity to protect areas at high risk from fire.

From a wildland fire behavior perspective, the siting of vegetation management projects should take into account the likelihood of fire spread around large sagebrush-dominated patches to reduce the potential for unwanted fire behavior or effects. In arid sagebrush and woodland ecosystems, increased continuity of invasive annual grass cover, such as cheatgrass (*Bromus tectorum*), can inhibit the natural recovery of native vegetation after fire. Once cheatgrass distribution moves from patchy to continuous, the invasive/fire cycle can lead to more frequent and larger fires, favoring cheatgrass dominance across broad areas. Where GRSG population densities are high and sagebrush ecosystems are intact but at risk of invasive annual grasses, strategically placed fuel reduction treatments may help maintain landscape and habitat resilience to fire (Gray and Dickson 2016). For example, relatively intact sagebrush patches may be located next to large patches of annual invasive grasses with a high likelihood of igniting and facilitating the spread of fire into the larger landscape. Sites already dominated by annual grasses that are low value GRSG habitat should be priorities for pre-positioning fire resources and proactive fuel management practices such as fuel breaks and green strips to avoid future spread into higher-value habitat in the surrounding landscape. More information on fuel break design is offered in *Local Scale Considerations*.

Table 4.2—Considerations for prioritizing vegetation management activities in areas that differ in resilience and resistance and GRSG breeding habitat probabilities. These consideration are consistent with tables 1.3 and 1.4.

- In general, areas that support medium to high GRSG breeding habitat probabilities or other important resources and have moderate to high fire risk (figs. 4.1, 4.2) are higher priorities for vegetation management.
- Areas with moderate and, especially, high resilience and resistance to invasive annual grasses often respond favorably to vegetation management projects (table 1.3: cells 1B, 1C, 2B, 2C; fig. 4.3). The risk of invasive annual grasses increases as resilience and resistance decrease.
  - Focusing tree removal in Phase I to Phase II juniper and piñon expansion areas in or adjacent to areas with high GRSG habitat breeding probabilities and populations (especially near leks) will help maintain resilience and resistance and provide necessary connectivity between sagebrush habitats. Treatment areas should contain sufficient native perennial forbs and grasses to promote recovery.
  - Prescribed fires may also be considered for reducing juniper and piñon expansion in areas with high resilience and resistance to invasive annual grasses. Important management considerations include: (1) timing the fire when weather and fuel conditions allow for managing the fire with acceptable implications to values at risk, (2) selecting areas where high priority GRSG populations and corresponding habitats would not be negatively impacted, and (3) ensuring that sufficient native grasses and forbs exist for recovery.
- Areas with low resilience and resistance to invasive annual grasses typically are more challenging to restore and take a longer time to respond to vegetation management treatments (table 1.3: cells 3B, 3C; fig. 4.2). The risk of invasive annual grasses increases as resilience and resistance decrease.
  - High quality GRSG breeding habitats with moderate to high fire risk and low resilience and resistance may be prioritized for wildfire protection activities but should not be prioritized for vegetation management activities that could degrade habitat quality and connectivity.
  - Areas of low breeding habitat quality in and adjacent to areas with high GRSG breeding habitat probabilities, moderate to high fire risk, and lower resilience and resistance may have higher priorities for fuel breaks (Maestas et al. 2016a).
  - Sagebrush reduction (prescribed fire, mechanical removal, chemical treatment) requires caution and is generally not recommended (table 1.4; also see Beck et al. 2012; Chambers et al. 2014; Davies et al. 2012).
  - Prescribed fire is also used occasionally in conjunction with other treatments to reduce invasive perennials and annual grasses as part of a sagebrush ecosystem restoration strategy. Similar management considerations as stated above should be evaluated when deciding to use this tool in these areas.
- In general, areas that support moderate to high GRSG breeding habitat probabilities or other important resources and have low to moderate resilience and resistance are priorities for postfire rehabilitation (fig. 4.2). In many cases, areas of high or moderate resilience and resistance that are relatively cool and moist recover without management intervention and are lower priorities for postfire rehabilitation (fig. 4.3).

When considering juniper and piñon removal treatments, the broader context of longer-term trends in wildland fire activity, past conifer removals, bark beetles, and climate is helpful in evaluating the need for management treatments (Allen et al. 2015; Arendt and Baker 2013; Board et al. 2018; Romme et al. 2009). Expansion of juniper and piñon woodlands into sagebrush ecosystems has occurred due to favorable climate periods for tree establishment, increases in carbon dioxide, fire suppression, and livestock grazing (Miller et al. 2011, 2013; Romme et al. 2009). This expansion, however, is not uniform across the sagebrush biome; some areas show substantial expansion and other regions show minimal to no expansion and infilling (Manier et al. 2005; Romme et al. 2009) and even declines (Arendt and Baker 2013). While rates of juniper and piñon expansion have slowed in recent decades due to less favorable climatic conditions, fewer suitable sites for tree establishment, and an increase in wildland fire and bark beetle activity in some regions (Breshears et al. 2005; Miller et al. 2008; Romme et al. 2009), infilling of trees appears to continue in expansion areas, most noticeably in the Great Basin (Miller et al. 2008). In general, early- to mid-phase (i.e., phases I and II; see Appendix 1 for definitions) juniper and piñon that have expanded into occupied GRSG breeding habitat with high to moderate resilience to fire and resistance to invasive annual grasses can be considered for removal treatments (table 1.3: cells 1B, 1C, 2A, 2B). Treatments should be conducted in areas with sufficient native perennial grasses and forbs to promote recovery and low risk of increases in invasive annual grasses (see table 1.4). Prescribed fire can be used selectively in consultation with wildlife and habitat managers. Posttreatment grazing deferral is essential to allow recovery of native grasses and forbs and reduce the risk of invasive plants.

Postfire recovery—Large wildland fires occur across environmental gradients and thus the areas burned often differ in their relative resilience and resistance to invasive annual grasses. An understanding of the areas' environmental conditions, dominant vegetation types pre-fire, and disturbance history provides the necessary information to evaluate differences in resilience and resistance, and identify areas where management actions have a higher likelihood of success for restoring ecosystem processes. In addition, this type of approach ensures that the limited rehabilitation funds are placed in the appropriate areas.

In areas with lower resilience and resistance, sagebrush restoration after a wildland fire can take several decades and presents a serious challenge for managers seeking to maintain stable populations of sagebrush dependent wildlife. Strategic placement of postfire recovery efforts to expand sagebrush patch refugia (unburned islands within a burned area) and reconnect these sagebrush patches to intact areas of sagebrush outside of burned areas will help restore large and contiguous sagebrush patches needed by GRSG and other sagebrush dependent species (Pyke 2011; Pyke et al. 2015a,b; Williams et al. 2011). Establishing patches of diverse native forbs, along with bunchgrasses and shrubs, within burned areas can increase the distribution and diversity of forbs, which serve as a foundational building block for resilient sagebrush systems. Seeding sagebrush around existing sagebrush patches can help increase connectivity for many sagebrush dependent species. This type of strategic restoration mimics natural succession where fire-tolerant plants generally resprout and fire-intolerant plants like sagebrush establish from the available seedbank or from seeds that disperse into the disturbed area from nearby unburned patches (Baker 2006; Meyer 1994; Meyer and Monsen 1990; Monsen et al. 2004; Pyke 2011; Rottler et al. 2015). This seeding strategy also addresses funding shortfalls that may not allow for seeding a diverse mixture of forbs, bunchgrasses, and sagebrush across an entire burned area.

Adaptive Management and Monitoring in Wildland Fire Management

Monitoring provides critical information on the effectiveness of management actions, including fuel management and postfire restoration treatments (see section 2). Monitoring data at broad and mid-scales should be used to evaluate changes in (1) vegetation, fuel, and fire characteristics; and (2) ecosystem response to management actions implemented to address ecosystem threats such as invasive annual grasses and juniper and piñon expansion (text box 4.1). Fire-related monitoring indicators are being identified and developed for agency monitoring programs in order to measure the effectiveness of wildland fire and vegetation management in decreasing the current trend of uncharacteristic fire in sagebrush ecosystems (e.g., the Bureau of Land Management's [BLM's] Assessment Inventory and Monitoring [AIM] and the Forest Service's Forest Inventory and Analysis [FIA] programs). Incorporating monitoring results into future assessments will provide information on where fuel reduction and restoration efforts have been successful and where changes in management strategies are needed (e.g., Knutson et al. 2014). This information should be used in an adaptive management context to determine shifts in fire management priorities and reallocate resources.

Climate Adaptation and Wildland Fire Management

Given climate variability and longer fire seasons across the western United States, resilience and resistance concepts offer a proactive approach for decreasing current trends of more frequent and large, uncharacteristic fires and for maintaining resilient ecosystems (see section 3). Wildland fire risk

Text Box 4.1—Monitoring to Inform Wildland Fire and Vegetation Managements

Monitoring is an important component of effective wildland fire and vegetation management programs and has two primary purposes. First, monitoring provides information on changes in vegetation, fuels, and fire characteristics over time that can be used to adapt fire management. Monitoring survey plots (e.g., the Bureau of Land Management's Assessment Inventory and Monitoring [AIM], the Natural Resources Conservation Service's National Resources Inventory [NRI], and the Forest Service's Forest Inventory and Analysis [FIA] program) and remote sensing data can provide information on the extent and relative abundance of woody and herbaceous plants and any transitions between dominance of woody plants and herbaceous species (especially highly flammable invasive annual grasses) that occur over time. This information is useful for pre-positioning fire-fighting resources and developing fuel treatments that address different types of fuel or build-up of fuel.

Second, monitoring provides information on the effectiveness of management treatments. Success is typically achieved by meeting predetermined treatment objectives that are measured against baseline or reference conditions or another desired condition or benchmark. Effectiveness monitoring may be conducted at the project scale following postfire rehabilitation to restore GRSG habitat. Monitoring indicators, such as establishment or cover of grasses, forbs, and shrubs, increases in invasive annual grasses, and the appropriate benchmarks, can be used to evaluate whether the effort has increased the cover of either the seeded species or invasive annual grasses above a response threshold. Results of this effectiveness monitoring are used to evaluate both the effects of site conditions on treatment success and the need for follow-up management.

assessments help identify where climate, weather patterns, and land uses contribute to increases in large, severe fires and conversion to new alternative states (Abatzaglou and Kolden 2013; Littell et al. 2009; Miller et al. 2008; Westerling et al. 2006). Identifying areas where sagebrush is projected to persist through time under differing climate scenarios can help identify sagebrush habitats in need of prioritization for protection, or management actions that maintain or improve their current habitat quality.

Local Scale Considerations

Wildland Fire Preparedness, Suppression, and Prevention

The key to effective local wildland fire management is strategic placement of fuel reduction and restoration projects in relation to fire risk and fire suppression resources for the upcoming fire season. The combination of these efforts is integral to improving the chances of reducing fire size and effects during suppression efforts. Local fire suppression priorities are developed by resource and fire managers before the fire season. Primary considerations are burn probabilities, ecosystem resilience to fire and resistance to invasive annual grasses, locations of completed vegetation and fuel reduction projects, and key habitats. For maximum effectiveness, this information should be integrated into preplanned dispatch procedures used to allocate fire suppression resources during the fire season across jurisdictional units. By using this information, local fire managers can determine where ecological benefits may or may not be achieved when managing wildland fire and where to prioritize suppression resources to protect sagebrush habitats at risk. For example, suppressing fires adjacent to or within recently restored ecosystems may promote recovery and increase capacity to absorb future changes in conditions. Additionally, wet weather years followed by dry or normal years can result in significant changes in fuel loads over time. During these climate cycles, information and maps on the changes in wildland fire risk can help inform decisions about where fire suppression strategies can best mitigate the effects of fire on key habitats.

In wildland fire suppression, tactics used when managing a fire can have major consequences for the resultant burned area, including larger final fire extents. Practices such as burning out unburned patches of sagebrush and placement of indirect fireline reduce the opportunity to maintain sagebrush seeding sources that are already established (Murphy et al. 2013). Management practices recommended to help preserve large patches of sagebrush habitat during fire incidents include: (1) extinguishing fire edges and hotspots within the burn perimeter, especially around unburned islands; (2) applying suppression strategies and tactics that retain large interior islands of unburned sagebrush within the burn perimeter; (3) considering direct rather than indirect line when locating firelines, as safety and fire behavior allow; and (4) when safety is not an issue, directing suppression efforts to the front of a fire.

Based on wildland fire weather forecasts, suppression resources are commonly staged or "pre-positioned" in anticipation of fire occurrence at certain fire weather thresholds. "Severity" funding is provided to units having high wildland fire danger based on local forecasts and conditions to obtain additional resources for initial attack. Fire operation units can acquire more aviation resources, engines, crews, and other assets to protect key GRSG habitats when known weather events or high fire danger conditions are anticipated. Data and maps contained in the Part 1 of the Science Framework and the wildland fire risk assessment (fig. 4.1) can be used to prioritize and allocate severity funding to jurisdictions that have large areas of sagebrush and GRSG habitat at risk of loss from fire.

Wildland Fire Prevention—Human-caused ignitions can have devastating effects on sagebrush landscapes, especially those with low resilience to wildland fire. Preventive actions are generally more effective when tailored and delivered at the local level such as field offices or communities surrounding BLM districts and national forests. Spatial analyses that factor in wildland fire risk along with identified causes and locations of wildland fire ignitions from local communities can be used to design fire prevention strategies. These strategies can specifically target the local causes for human-caused ignitions at sites close to or within the wildland-urban interface. Data from the Department of the Interior, Wildland Fire Management Information (WFMI) system from 1997 through 2016 identify the most common human causes (e.g., target shooting) of BLM fires that burn sagebrush habitat. While each area has a unique set of wildland fire causes, two common examples of human-caused fires, along with ways to reduce ignitions, are:

- Powerlines—Though some powerline failures will always occur, others are preventable with proper ground clearance around power poles and transmission lines and improved maintenance of powerlines to prevent failures. Working with Federal realty specialists to ensure fire prevention measures are included in Land Use Authorizations, such as rights-of-way, can also be an effective way to reduce ignitions. This is especially important in sagebrush ecosystems characterized as having low fire resilience or high priority GRSG habitats. Wildland fire prevention partnerships with power companies and other utilities can help reduce the number of failures and wildland fire starts by entering into joint inspection programs on transmission lines with a history of starting wildland fires or adopting wildland fire prevention measures during construction, maintenance, and repair activities.
- Vehicles—Roadside ignitions are common in areas with hot dry fine fuels near highways and major roads. Working with State transportation departments

to reduce flammable vegetation along highway corridors has been shown to reduce the number of ignitions occurring when vehicles pull off into fine, dry grass on the side of the road and when improperly maintained trailers break down or drag trailer parts or chains that ignite fires.

Many social science studies conducted over the past several years have focused on the public's perception of wildland fire risk and what motivates the public to take action, especially at the community level. A common finding is that, while general awareness campaigns are effective to help the public understand risk from wildland fire, awareness does not necessarily lead to action. Awareness campaigns are more effective when agencies use face-to-face meetings and two-way conversations with the publics they serve to build relationships and trust. Time as well as commitment from management, fire and resource staff, and partners is needed to communicate fire prevention strategies and messages.

Partnerships, agreements, and sound fire investigation and prevention programs at the local level are critical to reduce human-caused wildland fires each year. For example, public and private organizations such as power and railroad companies who use, or operate on, public lands have a vested interest in preventing fires and should be approached as partners to limit fire ignitions. Fire prevention measures can be incorporated into land use authorizations, and relationships can be forged to address recurring fire ignitions associated with a given land use. Though it may take years to cultivate such relationships, it is a critical step in moving toward real action, such as burying a transmission line that has caused wildland fires or removing flammable vegetation along a railroad right-of-way.

While not all human-caused wildland fires can be prevented, many can and are being prevented through an informed citizenry that understands fire risk and is taking precautions with activities that may start a fire.

Vegetation Management and Postfire Recovery

Vegetation management (fuel reduction and restoration treatments) and postfire rehabilitation activities influence the structure and composition of vegetation communities at the project scale and are intended to maintain or increase ecosystem resilience to disturbance and resistance to invasive annual grasses. The primary objective of fuel reduction treatments is removing or modifying vegetation in order to reduce fuel loads and decrease fire size and severity. Objectives of both vegetation management and postfire treatments are to maintain or increase native perennial grasses and forbs and thus recovery potential, lower the longer-term risk of increases in nonnative invasive plants, and increase soil stability and reduce erosion.

Vegetation Management—For sagebrush ecosystems exhibiting juniper and piñon expansion and infill, Miller et al. (2014) provide a framework for selecting treatment areas and methods based on resilience and resistance concepts. Specific criteria for determining suitable sites and treatments are based on: (1) ecological site characteristics, (2) the phase of juniper and piñon expansion, (3) temperature and moisture regimes, and (4) the relative abundance, type, and fire tolerance of the native perennial grasses and forbs. Other factors to be considered in treatment design include: (1) sagebrush ecosystem response to past tree removals, (2) past and current management actions, (3) variation in long-term weather patterns (e.g., warmer temperatures and less precipitation; see section 3), (4) presence and relative abundances of invasive annual grasses, and (5) tradeoffs for sharply declining populations of juniper and piñon dependent species (e.g., pinyon jay [*Gymnorhinus cyanocephalus*]). Tree removal in phases I and II to reclaim sagebrush habitat results in the removal of a biologically valuable part of the juniper and piñon woodland and sagebrush interface for other species habitats (e.g., pinyon jay; mule deer [*Odocoileus hemionus*]) (Gillihan 2005; Sauer et al. 2014). Surveying these sites for all declining wildlife populations before selecting sites for treatment, designing tree removals that mimic stand structure after natural disturbance such as fire (e.g., maintaining mature juniper and piñon and creating convoluted edges and small openings in mature woodland stands), avoiding sharp edges between sagebrush and juniper and piñon stands, and monitoring can help mitigate the effects of treatments on juniper and piñon associated and dependent species (Gillihan 2005).

For sagebrush ecosystems with significant cheatgrass cover, fuel reduction treatments are aimed at reducing the continuity of cheatgrass cover. The objective is to reduce fuel connectivity and slow or stop fire spread between cheatgrass patches and into intact native vegetation. Current methods for reducing cheatgrass fuel are detailed in section 5.

Roads play a significant role in influencing wildland fire ignition and control at the local scale. Wildland fire boundaries tend to occur near roads because roads provide access for fire suppression. Additionally, roads act as fuel breaks because the road footprint is vegetation free, providing a no-burn zone that reduces the spread of fire (Narayanaraj and Wimberly 2011, 2013; Price and Bradstock 2010; Syphard et al. 2011). In sagebrush ecosystems, fuel reductions have used roadsides to create linear fuel breaks that disrupt fuel continuity by reducing fuel accumulation (Maestas et al. 2016a; Shinneman et al. 2018). Removal of vegetation can vary (e.g., 50 feet to 0.25 mile [15–400 meters]) based on landscape conditions, fire spotting potential, and expected flame length. Fuel breaks are intended to reduce fire intensity, rates of fires spread, and flame length. Fire managers believe that they enhance firefighter access, improve response times, and provide safe and strategic anchor points for wildland firefighting activities (e.g., back burning) (Moriarti et al. 2015). Linear fuel breaks also may help to slow or stop human-caused fires ignited along roads, thereby reducing the risk of fire spread along roadsides into adjacent lands (Naravanaraj and Wimberly 2012, 2013).

While anecdotal evidence suggests that properly designed fuel breaks help with fire operations, the ecological and economic consequences of linear fuel breaks are relatively unknown (Shinneman et al. 2018). Because linear fuel breaks are located along roads, they may serve as conduits for invasive plant species, increase fragmentation of wildlife habitat, disrupt wildlife movement pathways, and increase predation on sagebrush obligates (Coates et al. 2014; Shinneman et al. 2018). As a result, the area influenced by roads and fuel breaks (e.g., edge effects) is likely to be markedly larger than the area covered by roads and fuel breaks themselves (Forman 2003; Forman and Alexander 1998; Naravanaraj and Wimberly 2013). For example, nonnative plants that invade along roads frequently create a source of combustible fuel (Arienti et al. 2009; D'Antonio and Vitousek 1992; Parendes and Jones 2000; Trombulak and Frissell 2000). Removal of native vegetation along roads can increase establishment and spread of invasive plants from the fuel break into the interior of large sagebrush patches. Subsequently, fuel breaks, if not monitored and maintained, may contribute to a greater incidence of human-caused fires near roads (Arienti et al. 2009; Syphard et al. 2007, 2008; Yang et al. 2007, 2008a,b).

In designing linear fuel breaks, Gray and Dickson (2016) and Shinneman et al. (2018) suggest using fire simulation modeling to help identify strategic places for placing fuel breaks by projecting their effectiveness in altering fire behavior and assessing utility and safety for firefighting activities. Combining these results with species habitat maps can also help to identify where fuel break placement should be avoided to maintain intact habitat and habitat connectivity. Considering the width of fuel breaks (including the width of the road) is important in assessing potential fragmentation effects on wildlife. For example, herbicide treatments of less than 30 meters (100 feet) wide help avoid negative effects on sagebrush dependent passerine birds (Best 1972). Once strategic places for fuel breaks have been identified, Shinneman et al. (2018) proposed that fuel break design along roadsides could include alternating strips of altered and undisturbed sagebrush rather than continuous altered strips along the entire length of a road. This type of design could be based on current knowledge of fire probability, habitat disturbance, fragmentation, and edge-effects to help maintain the overall integrity of sagebrush habitat in that area.

Assessments of soil characteristics and precipitation are helpful in determining which species are best suited to plant in fuel breaks (Maestas et al. 2016a). Species such as forage kochia (*Bassia prostrata* ssp.) and crested wheatgrass (*Agropyron cristatum*) or a mix of nonnative grasses are widely used to seed fire-resistant green strips and prevent soil erosion in fuel breaks. However, seeding introduced species has drawbacks (see section 6). For example, forage kochia is documented to spread outside of seeded areas (Gray and Muir 2013) and compete with slickspot peppergrass (*Lepidium papilliferum*), which is listed under the Endangered Species Act (Pellant 2004). At the same time, introduced species may establish quickly, outcompete invasive annual grasses, and persist without the need for repeated seedings dependent on environmental conditions.

Native perennial grasses and forbs are emerging as another viable alternative and have potential to be used more widely because: (1) native grasses and forbs with low stature, such as Sandberg bluegrass (*Poa secunda*), can compete well with invasive annual grasses and reduce fine fuels, fuel heights, fuel loadings, and fuel continuity; (2) many native grasses and forbs are drought tolerant and local seed sources may establish better on dry sites than forage kochia and crested wheatgrass; (3) many native grasses and forbs are tolerant of disturbance; and (4) the potential for spread into adjacent areas is not problematic (Gray and Muir 2013). Opportunities exist to test native plants that have the characteristics desired for fuel break plantings such as low stature, rapid establishment, competitive with invasive plants, remain green during the dry season, and fire tolerance. Other techniques for creating fuel breaks include modifying existing roadbeds with mowing, herbicide applications, intensive grazing, conifer removal, or prescribed fire to reduce vegetation (Moriarti et al. 2015). For fuel breaks to meet the intended purpose, the cost of monitoring and annual maintenance of fuel breaks should be analyzed, planned for, and incorporated into annual budgets upfront so that fuel breaks are maintained for safe fire operations and have minimal impacts (e.g., spread of invasive plants) to the sagebrush habitats they are designed to protect. Continual monitoring of fuel breaks is needed to determine the most appropriate strategy (timing, methods, additional seedings) for maintaining fuel breaks and assessing their potential for use in fire suppression activities every season.

Postfire Recovery—Miller et al. (2015) and Pyke et al. (2015a,b) provide frameworks for evaluating resilience to disturbance and resistance to invasive annual grasses of postfire sites in the Great Basin. They make recommendations for postfire recovery methods based on ecological site characteristics that can be modified for the eastern portion of the sagebrush biome (see Part 1, Appendix 5). The decision to seed postfire is based on rapid assessments of the ecological sites within the project area. Information on temperature and moisture regimes, preburn vegetation (including sagebrush species), perennial grasses and forbs, invasive annual grasses, and fire severity is used to rate the relative resilience and resistance of the ecological site(s). Specific criteria for determining the need to seed and appropriate seeding methods are provided based on temperature and moisture regimes and the relative abundance and type of native perennial grasses and forbs and invasive annual grasses.

In general, sites with higher resilience and resistance to invasive annual grasses (table 1.3: cells 1A, 1B, 1C) are more likely to recover without seeding than lower resilience and resistance sites (table 1.3: cells 3A, 3B, 3C) (Miller et al. 2015). If native perennial grasses and forbs are sufficient to promote recovery after fire, seeding is not needed. If native perennial grasses and forbs were depleted or absent before the fire or invasive annual grasses were abundant, seeding is likely to be needed, along with commensurate posttreatment management strategies such as grazing deferment or changes in season of use, to protect the restoration investment. Areas with severely depleted native species and abundant invasive annual grasses may require integrated management approaches that include herbicide application prior to seeding.

An understanding of resilience and resistance to invasive annual grasses as indicated by precipitation and temperature regimes can inform seeding decisions in vegetation management and postfire rehabilitation. Key considerations in determining seed mixes are selecting genetically appropriate native seed, compatibility of species in a seed mix, planting season, and appropriate seeding rates, techniques, and practices (see section 6). Nonnative species or aggressive native cultivars are often seeded in postfire recovery efforts because many germinate and establish quickly, are less expensive than native species, provide livestock forage, and compete with nonnative invasive species (Brooks and Pyke 2001; Davison and Smith 2005; Monaco et al. 2003; Pellant 1994; Pyke and McArthur 2002; Richards et al. 1998).

In the last two decades native seeds have become more readily available, the tradeoffs between seeding native and nonnative species are better understood, and resource managers are using more native species in fuel management and postfire recovery applications (see section 6). For sites with moderate to high resilience and resistance to invasive annual grasses where seeding is needed or sites with low resilience and resistance with low invasive plant densities pre-fire, native cultivars should be the preferred option given management concerns and the long-term challenges of seeding introduced species. For burned areas with low resilience and resistance to invasive annual grasses that had a low density of native species and high density of invasive plants pre-fire, native or introduced species—or a combination of both—may help minimize risk of a state shift to nonnative annual grass dominance depending on site characteristics and seeded species. In areas with low to moderate resistance to invasive annual grasses, nonnative invasive plant management is also an important consideration in postfire restoration efforts. Information for integrating nonnative invasive plant management into postfire restoration is in section 5.

Monitoring Vegetation Treatments

Monitoring to evaluate site recovery after fuel treatments and postfire rehabilitation provides the necessary information to determine whether management objectives were met and whether treated sagebrush ecosystems have recovered a composition, structure, and function that is sustainable over time (see section 2). Monitoring results can also identify areas where further restoration or adaptations to management strategies are needed to help lower wildland fire risk (text box 4.1).

Conclusions

Western sagebrush ecosystems continue to be threatened by larger and more frequent wildland fires that often result in the loss of large swaths of sagebrush and facilitate invasion by nonnative annual grasses. Longer fire seasons combined with warmer temperatures, failure to alter grazing regimes in response to climatic variability, and declines in ecological conditions are exacerbating the spread of invasive annual grasses to climatically suitable areas across the sagebrush biome. This ongoing spread of invasive plants is likely to increase fire frequency and extent in areas that currently do not experience a lot of fire. Natural recovery times and current management practices cannot keep up with the expanding invasive annual grass/fire cycle and some areas may have crossed thresholds of no return. In response, sagebrush obligate species that serve as indicators of ecosystem conditions, along with many other sagebrush obligates, are declining throughout the sagebrush biome (Coates et al. 2016).

This accelerated invasive annual grass/fire cycle needs to receive greater focus in sagebrush ecosystem conservation efforts. To help sustain ecosystems as well as transition and adapt to a changing climate, this section offers multi-scaled management approaches for wildland fire prevention, suppression, vegetation management, and postfire recovery that are prioritized based on resilience and resistance concepts. The integration of these approaches with those offered in the sections on climate adaptation (section 3), grazing (section 7), and seeding strategies (section 6) can help determine where investments are most likely to be successful in addressing uncharacteristic fire cycles and restoring sagebrush habitats. Consistency in these management approaches, to the extent possible, is key and can be achieved through collaboration and partnerships across jurisdictional boundaries, agencies, and disciplines. Changes in budgeting and policy structures are needed to increase flexibility, provide for quicker responses to disturbances, and allow longer implementation times to support restoration and climate adaptation opportunities. To help these ecosystems adapt to landscape changes in the future, we need increased efforts and focus on: (1) outreach to the public with prevention strategies targeting the causes of human-ignited fires and spread of invasive plants; (2) strategic fuel reduction and invasive plant treatments to help address climate adaptation, uncharacteristic fire cycles, and spread of invasive plants; (3) seeding strategies that mimic natural recovery, increase connectivity, and allow for natural transitions and climate adaptation; and (4) best management practices in fire suppression efforts to retain sagebrush.

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