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Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions

Part 2. Management Applications

Forest Service

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Abstract

The Science Framework is intended to link the Department of the Interior's Integrated Rangeland Fire Management Strategy with long-term strategic conservation and restoration actions in the sagebrush biome. The focus is on sagebrush (*Artemisia* spp.) ecosystems and sagebrush dependent species with an emphasis on Greater sage-grouse (*Centrocercus urophasianus*). Part 1 of the Science Framework, published in 2017, provides the scientific information and decision-support tools for prioritizing areas for management and determining effective management strategies across the sagebrush biome. Part 2, this document, provides the management considerations for applying the information and tools in Part 1. Part 2 is intended to facilitate implementation of resource management priorities and use of management strategies that increase ecosystem resilience to disturbance and resistance to nonnative invasive annual grasses. The target audience of Part 2 is field managers, resource specialists, and regional and national-level managers. The topics addressed in this volume include adaptive management and monitoring, climate adaptation, wildfire and vegetation management, nonnative invasive plant management, application of National Seed Strategy concepts, livestock grazing management, wild horse and burro considerations, and integration and tradeoffs. Geospatial data, maps, and models for the Science Framework are provided through the U.S. Geological Survey's ScienceBase database and Bureau of Land Management's Landscape Approach Data Portal. The Science Framework is intended to be adaptive and will be updated as additional data become available on other values and species at risk. It is anticipated that the Science Framework will be widely used to: (1) inform emerging strategies to conserve sagebrush ecosystems, sagebrush dependent species, and human uses of the sagebrush system; and (2) assist managers in prioritizing and planning on-the-ground restoration and mitigation actions across the sagebrush biome.

Keywords: sagebrush habitat, Greater sage-grouse, resilience, resistance, conservation, restoration, monitoring, adaptive management, climate adaptation, wildfire, nonnative invasive plants, National Seed Strategy, livestock grazing, wild horses and burros

Front cover photo. Sagebrush ecosystem in the Toiyabe Range, Nevada (photo: Jeanne Chambers, USDA Forest Service). Inset: Greater sage-grouse chick (photo: USDOI Fish and Wildlife Service).

Rear cover photo. Tail feathers of a Greater sage-grouse (photo: USDOI Fish and Wildlife Service).

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Contents

1. OVERVIEW OF THE SCIENCE FRAMEWORK

Jeanne C. Chambers, Karen L. Prentice, and Michele R. Crist

Introduction

The Science Framework is part of an unprecedented conservation effort underway across 11 States in the western United States to address threats to sagebrush (*Artemisia* spp.) ecosystems and the species that depend on them. Sagebrush ecosystems provide a large diversity of habitats and support more than 350 species of vertebrates (Suring et al. 2005). These ecosystems currently make up only about 59 percent of their historical area, and the primary patterns, processes, and components of many sagebrush ecosystems have been significantly altered since Euro-American settlement in the mid-1800s (Knick et al. 2011; Miller et al. 2011). The primary threats to sagebrush ecosystems are well recognized and include large-scale wildfire, invasion of exotic annual grasses, conifer expansion, energy development, conversion to cropland, and urban and exurban development (Coates et al. 2016; Davies et al. 2011; Knick et al. 2011; USDOI FWS 2013). The continued loss and fragmentation of sagebrush habitats has placed many species at risk, including Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG), which has been considered for listing under the Endangered Species Act several times (USDOI FWS 2010, 2015) and whose status will be reevaluated in 2020 (USDOI FWS 2015).

The Science Framework was developed to provide a transparent, ecologically defensible approach for making policy and management decisions to reduce threats to sagebrush ecosystems and GRSG across multiple scales. It is directly linked to U.S. Department of the Interior directives and ongoing multi-partner conservation efforts (table 1.1).

The Science Framework represents a paradigm shift for agencies and managers in sagebrush ecosystems. Recent research has provided the basis for characterizing sagebrush ecosystems according to their ecological resilience to disturbance and resistance to invasive annual grasses (Chambers et al. 2014a,b, 2017b; Maestas et al. 2016). This has enabled development of approaches that couple information on resilience and resistance with knowledge of GRSG habitat and threats to sagebrush ecosystems in order to prioritize conservation actions based not only on species habitat requirements but also on the likely response of that habitat to disturbances and management actions (Chambers et al. 2014c, 2016, 2017a; Ricca et al. 2018). New geospatial data and analytical approaches provide the capacity to prioritize management actions to conserve and restore sagebrush ecosystems at much larger scales than in the past. Managing multiple resources across scales and surface land management jurisdictions in an integrated and collaborative manner is becoming common practice for agencies managing sagebrush ecosystems.

Top left: Mule deer walking through sagebrush (photo: USDOI National Park Service). Top right: Badger near its burrow (photo: USDOI Fish and Wildlife Service). Middle left: Burrowing owls near their burrow (photo: USDOI Fish and Wildlife Service). Middle right: Common sagebrush lizard on a rock (photo: commons.wikimedia.org). Bottom left: Pygmy rabbit hiding underneath sagebrush in snow (photo: USDOI Fish and Wildlife Service). Bottom middle: Sagebrush sparrow on a sagebrush plant (photo: S. Richards). Bottom right: Male Hera buckmoth on a sagebrush plant (photo: USDA Forest Service).

Table 1.1—Key directives, science information, and conservation and restoration strategies for the sagebrush biome.

Title	Description	Cooperators
An Integrated Rangeland Fire Management Strategy: Final Report to the Secretary of the Interior (IRFMS)	Longer-term actions to implement policies and strategies for preventing and suppressing rangeland fire and restoring rangeland landscapes affected by fire in the Western United States. Section 7b(iv) called for development of a Conservation and Restoration Strategy for sagebrush ecosystems that considered emerging science and included a baseline assessment, conceptual models, and other components necessary to provide an overarching strategy for "on the ground" restoration actions and provide a foundation for adaptive management and budget prioritization.	U.S. Department of the Interior (DOI) (USDOI 2015)
Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions Part 1. Science Basis and Applications	Scientific information and decision-support tools to: (1) facilitate prioritization of areas for conservation and restoration management actions; (2) inform budget prioritization of management actions; and (3) inform management strategies across scales and ownerships. Developed per IRFMS, Section 7b (iv). Builds on prior interagency work that developed a strategic, multi-scale approach to manage threats to sagebrush ecosystems and sage-grouse using resilience and resistance concepts (Chambers et al. 2014a, 2016).	State and Federal agencies (Chambers et al. 2017a)
Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions Part 2. Management Applications	Guidance for applying the scientific information and decision-support tools in Part 1 of the Science Framework in order to: (1) implement resource management priorities at large, landscape scales; and (2) use management strategies that increase ecosystem resilience to disturbance and resistance to nonnative invasive plant species across scales. Developed per IRFMS, Section 7b (iv).	State and Federal agencies (Crist et al. this volume)
Sagebrush Science Initiative	A collaborative effort to identify and fill the highest priority gaps in scientific knowledge needed to effectively conserve sagebrush dependent species and the sagebrush habitats they depend on.	Fish and Wildlife Service, Western Association of Fish and Wildlife Agencies (WAFWA), Bureau of Land Management (WAFWA lead; in progress)
Sagebrush Conservation Strategy Developed to meet the requirements of IRFMS, Section 7b (iv) in collaboration with the Sagebrush Science Initiative	A comprehensive, collaborative strategy to conserve sagebrush, sagebrush dependent species, and human uses of sagebrush ecosystems that builds on the resilience and resistance concepts, threat assessments, and habitat prioritization methods described in the Science Framework. This broad strategy will provide for voluntary conservation measures for managing and conserving sagebrush ecosystems, and is intended to provide an inclusive "all-hands, all-lands" approach.	State and Federal agencies, nongovernmental organizations, universities (WAFWA lead; in progress)
Secretarial Order 3362: Improving Habitat Quality in Western Big-Game Winter Range and Migration Corridors	Guidance to conserve and restore priority winter range and migration corridors for elk, mule deer, and pronghorn, as identified by State and tribal wildlife agency partners. DOI agencies will work with State, tribal, and other Federal partners such as USDA Forest Service to restore habitats, minimize disturbance, and use other site-specific management to conserve these areas. Much of the habitat for these three species is within the sagebrush biome.	DOI agencies, State agencies, WAFWA, USDA Forest Service (USDOI 2018)

The Science Framework uses a multi-scale approach to inform management decisions and actions. It applies the best available information on resilience and resistance to invasive annual grasses, GRSG habitat, and threats to sagebrush ecosystems to: (1) inform strategic management and conservation investments at broad scales (ecoregion or GRSG Management Zone to sagebrush biome), and (2) determine appropriate management strategies at local (field office or district) scales. An integrated monitoring and adaptive management approach is recommended to reduce the uncertainty in the effectiveness of management actions over time by improving both management objectives and strategies (Allen et al. 2011; Thompson et al. 2013). Syntheses of the best available science and considerations of the tradeoffs involved in making decisions facilitate development of appropriate management objectives and strategies in planning processes as well as alternatives for National Environmental Policy Act (NEPA) analyses.

Part 1 of the "Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions" focuses on the **science basis and applications** for protecting, conserving, and restoring sagebrush ecosystems and GRSG habitat (Chambers et al. 2017a; hereafter, Part 1). Scientific information and decision-support tools are provided to: (1) assist in prioritizing areas for conservation and restoration management actions, (2) inform budget prioritization of management actions, and (3) inform management strategies across scales and ownerships.

Part 2 focuses on **management considerations and tradeoffs** for Part 1 and emphasizes adaptive management. The information in this volume can be used to apply the scientific information and decision-support tools in Part 1 in order to: (1) implement resource management priorities at large, landscape scales; and (2) use management strategies that increase ecosystem resilience to disturbance and resistance to nonnative invasive plant species across spatial scales. The concepts and approaches that form the basis for Parts 1 and 2 of the Science Framework are briefly reviewed in this section. The applications of these concepts and approaches are described in sections 2 through 8 and focus on key resource management topics, including adaptive management and monitoring, climate adaptation, wildfire and vegetation management, nonnative invasive plant management, application of National Seed Strategy concepts, livestock grazing management, and wild horse and burro considerations. Section 9 discusses integration of the management strategies for the different topics, and the associated tradeoffs involved in managing for diverse resources across large landscapes.

The Science Framework was developed to be used by resource specialists and practitioners at field and regional management levels, while providing a broader context for regional and national-level managers. Although the focus is largely on the sagebrush biome and GRSG, the information and tools provided allow managers to address other resource values and at-risk species as the necessary geospatial data are developed.

Concepts and Approaches Used in the Science Framework

The Science Framework provides the information and tools to address the primary threats to sagebrush ecosystems at geographical scales relevant to management. The threats addressed in the Science Framework were identified in the Sage-Grouse Conservation Objectives Team Final Report (USDOI FWS 2013) and reflect the threats to sagebrush ecosystems in general. These threats are consistent with those included in the Greater Sage-Grouse Monitoring Framework developed by the Interagency Greater Sage-Grouse Disturbance and Monitoring Subteam (IGSDMS 2014) and the State Wildlife Action Plans, which were prepared for the purpose of maintaining the health and diversity of wildlife within the State and reducing the need for future listings under the Endangered Species Act. In addition to these previously identified threats, climate adaptation is addressed in the Science Framework and climate adaptation strategies are provided.

The Science Framework includes three scales that inform different aspects of planning and implementation: (1) the sagebrush biome scale, where consistent data for the range of sagebrush and GRSG can inform budget prioritization; (2) the mid-scale (ecoregions and Management Zones), where assessments are typically conducted to inform budget prioritization and develop priority planning areas; and (3) the local scale, where local data and expertise are used to select project sites and determine appropriate management strategies and treatments within priority planning areas (table 1.2). At the mid-scale, a crosswalk is provided between U.S. Environmental Protection Agency ecoregions (USEPA 2016) and sage-grouse Management Zones (Stiver et al. 2006) (fig. 1.1). This approach aligns with the Sage-grouse Habitat Assessment Framework (Johnson 1980; Stiver et al. 2015).

Table 1.2—Scales and areas included in the strategic approach for managing threats to sagebrush ecosystems, sage-grouse, and other sagebrush obligate species as well as the data, tools, models, and processes considered at each scale or area.

Area	Geographic scale	Map extent	Data, tools, models	Process
Sagebrush biome and multiple Management Zones (MZs)	Broad	West-wide	Habitat Soils Population data and models Priority resource data Fire and other threat data Climate change projections	Budget prioritization for rangewide consistency
Sage-grouse MZs and ecoregions	Mid	State or national forest	Above, plus: Assessments and planning documents Regional data and models Regional tools	Assessments at ecoregion or MZ scale for prioritization of management actions
Local planning areas	Local	District, field office, or project area	Above, plus: Local data and information	Selection of treatment types within prioritized project areas

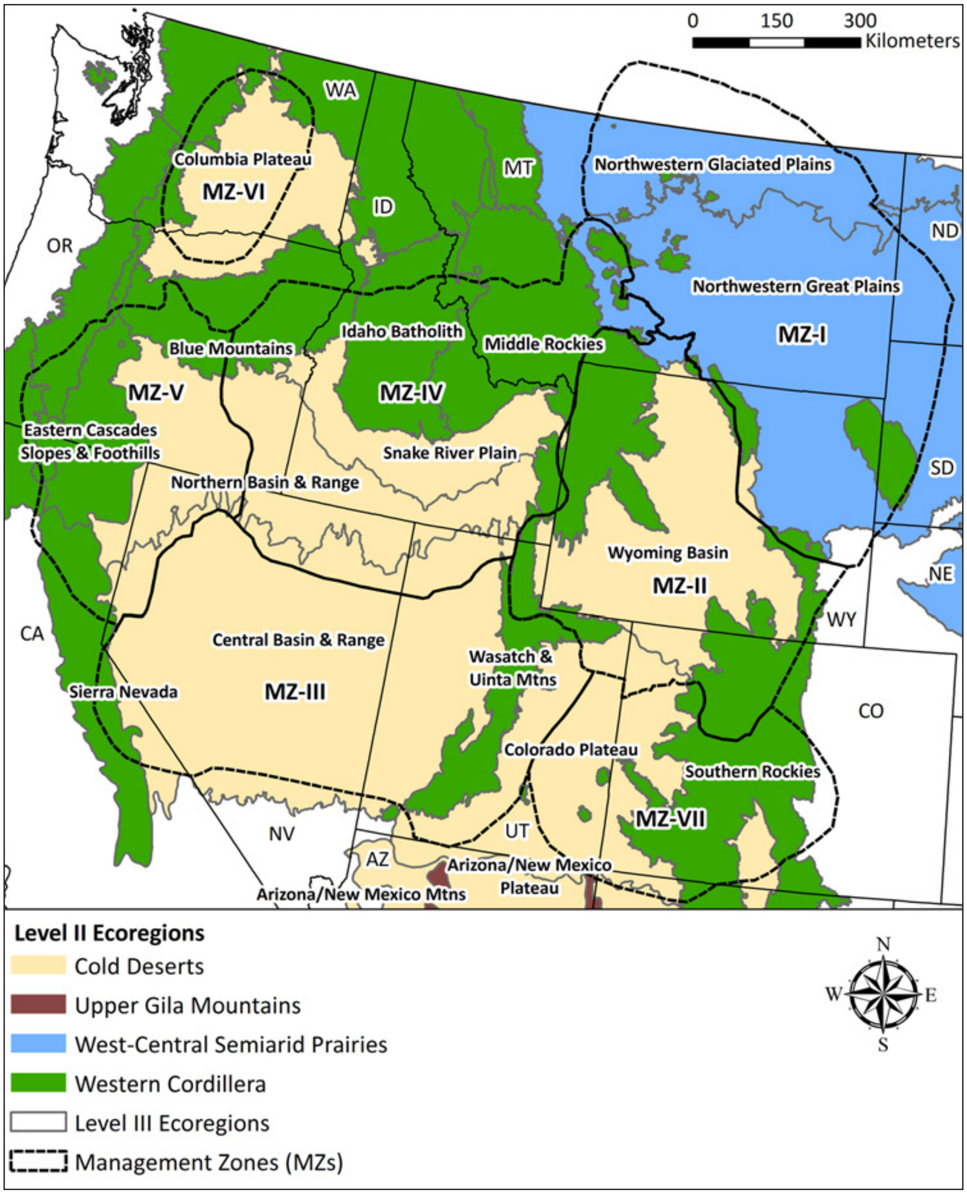

Figure 1.1—A crosswalk between level II and level III ecoregions (USEPA 2016) and sage-grouse Management Zones (MZs; Stiver et al. 2006) (Chambers et al. 2017a, fig. 1).

The Science Framework uses an approach that is based on current understanding of ecosystem resilience to disturbance and resistance to nonnative invasive plants in sagebrush ecosystems. Resilient ecosystems have the capacity to **reorganize and regain** their basic characteristics when altered by stressors such as invasive plants and disturbances such as improper livestock grazing and altered fire regimes (Angler and Allen 2016; Holling 1973). Species resilience refers to the ability of a species to recover from stressors and disturbances (USDOI FWS 2013), and is closely linked to ecosystem resilience. Resistant ecosystems have the capacity to ***retain*** their fundamental structure, processes, and functioning when exposed to stresses, disturbances, or invasive species (Angeler and Allen 2016; Folke et al. 2004). Resistance to invasion by nonnative plants is increasingly important in sagebrush ecosystems; it is a function of the abiotic and biotic attributes and ecological processes of an ecosystem that limits the population growth of an invading species (D'Antonio and Thomsen 2004). A detailed explanation of the factors that influence resilience and resistance in sagebrush ecosystems is found in Chambers et al. (2014a). Definitions of the terms used in this document are in Appendix 1.

Management focused on ecosystem resilience and resistance can help sustain local communities by ensuring that ecosystem services, such as water for human consumption and agricultural use, forage for livestock, and recreational opportunities, are maintained or improved over time. The resilience of socioeconomic systems, threats to those systems, and current capacities to implement management actions to address those threats are a separate aspect of developing an approach for conservation and restoration of the sagebrush biome and are addressed elsewhere.

The approach used in the Science Framework is intended to help prioritize areas for management and determine the most appropriate management strategies. The Science Framework is based on: (1) the likely response of an area to disturbance or stress due to threats, management actions, or a combination thereof (i.e., resilience to disturbance and resistance to invasion by nonnative plants); (2) the capacity of an area to support target species or resources; and (3) the predominant threats. It uses a mid-scale approach and has six steps.

- Identify focal species or resources and key habitat indicators for the assessment area, and then delineate their distribution or area using the best information available. For GRSG, this currently includes the modeled breeding habitat probabilities and the population index (Doherty et al. 2016). Information and tools are provided to allow managers to address other resource values and at-risk species as geospatial data for those values and species become available.
- Develop an understanding of ecosystem resilience to disturbance and resistance to nonnative invasive plants for the assessment area. At landscape scales, resilience and resistance to invasive annual grasses, which are a primary cause of altered fire regimes and habitat degradation in sagebrush ecosystems, are closely linked to soil temperature and moisture regimes (Chambers et al. 2014a,b; 2017b). Thus, soil temperature and moisture regimes are used to quantify and map resilience and resistance to invasive annual grasses (Maestas et al. 2016). More detailed information on soil characteristics and ecological site descriptions help managers to step-down generalized vegetation dynamics, including resilience and resistance concepts, to local scales.
- Integrate ecosystem resilience to disturbance and resistance to invasive annual grasses with species or resource habitat requirements and develop a decision matrix that can be used to spatially link ecosystem resilience and resistance, habitat requirements, and management strategies (table 1.3).
- Assess the key threats in the assessment area using geospatial data and maps.
- Prioritize areas for management in the assessment area using geospatial data and maps of species or resource habitat requirements, such as the breeding habitat probabilities for GRSG, resilience to disturbance and resistance to invasive annual grasses, and the key threats (fig. 1.2).
- Determine the most appropriate management strategies for areas prioritized for targeted conservation and restoration management actions based on habitat characteristics, relative resilience to disturbance and resistance to invasive annual grasses, and the predominant threats. The management strategies are developed in collaboration with stakeholders and are reconciled with socioeconomic and budgetary considerations. Other priority resources are considered such as special status plant species.

Table 1.3—Sage-grouse habitat, resilience and resistance matrix based on resilience and resistance concepts from Chambers et al. (2014a,b) and GRSG breeding habitat probabilities from Doherty et al. (2016). Rows show the ecosystem's relative resilience to disturbance and resistance to invasive annual grasses (1 = high resilience and resistance, 2 = moderate resilience and resistance, 3 = low resilience and resistance). Resilience and resistance categories were derived from soil temperature and moisture regimes (Chambers et al. 2017a [Part1], Appendix 2; Maestas et al. 2016) and relate to the sagebrush ecological types in Part 1, table 6. Columns show the landscape-scale GRSG breeding habitat probability based on Part 1, table 7 (A = 0.25 to <0.5 probability; B = 0.5 to <0.75 probability; C = ≥0.75 probability). Use of the matrix is explained in Part 1, section 7.4. Potential management strategies for persistent ecosystem threats, anthropogenic threats, and climate change are in table 1.4.

<table>
<tr><th rowspan="2">Ecosystem Resilience to Disturbance and Resistance to Invasion</th><th colspan="3">Landscape-Scale Sage-Grouse Breeding Habitat Probability</th></tr>
<tr><th>Low
(0.25 to <0.5 probability)

Landscape context is likely to be limiting habitat suitability. If limiting factors are within management control, significant restoration may be needed. These landscapes may still be important for other seasonal habitat needs or connectivity.</th><th>Moderate
(0.5 to <0.75 probability)

Landscape context may be affecting habitat suitability and could be aided by restoration. These landscapes may be at higher risk of becoming unsuitable with additional disturbances that degrade habitat.</th><th>High
(≥0.75 probability)

Landscape context is highly suitable to support breeding habitat. Management strategies to maintain and enhance these landscapes have a high likelihood of benefiting sage-grouse.</th></tr>
<tr><td rowspan="2">High</td><td>1A</td><td>1B</td><td>1C</td></tr>
<tr><td colspan="3">Potential for favorable perennial herbaceous species recovery after disturbance without seeding is typically high.

Risk of invasive annual grasses becoming dominant is relatively low. EDRR can be used to address problematic invasive plants.

Tree removal can increase habitat availability and connectivity in expansion areas.

Seeding/transplanting success is typically high.</td></tr>
<tr><td rowspan="2">Moderate</td><td>2A</td><td>2B</td><td>2C</td></tr>
<tr><td colspan="3">Potential for favorable perennial herbaceous species recovery after disturbance without seeding is usually moderately high, especially on cooler and moister sites.

Risk of invasive annual grasses becoming dominant is moderate, especially on warmer sites. EDRR can be used to address problematic invasive plants in many areas.

Tree removal can increase habitat availability and connectivity in expansion areas.

Seeding/transplanting success depends on site characteristics, and more than one intervention may be required, especially on warmer and drier sites.

Recovery following inappropriate livestock use depends on site characteristics and management.</td></tr>
<tr><td rowspan="2">Low</td><td>3A</td><td>3B</td><td>3C</td></tr>
<tr><td colspan="3">Potential for favorable perennial herbaceous species recovery after disturbance without seeding is usually low.

Risk of invasive annual grasses becoming dominant is high. EDRR can be used to address problematic invasive plants in relatively intact areas.

Seeding/transplanting success depends on site characteristics, extent of annual invasive plants, and post-treatment precipitation, but is often low. More than one intervention likely will be required.

Recovery following inappropriate livestock use is unlikely without active restoration.</td></tr>
</table>

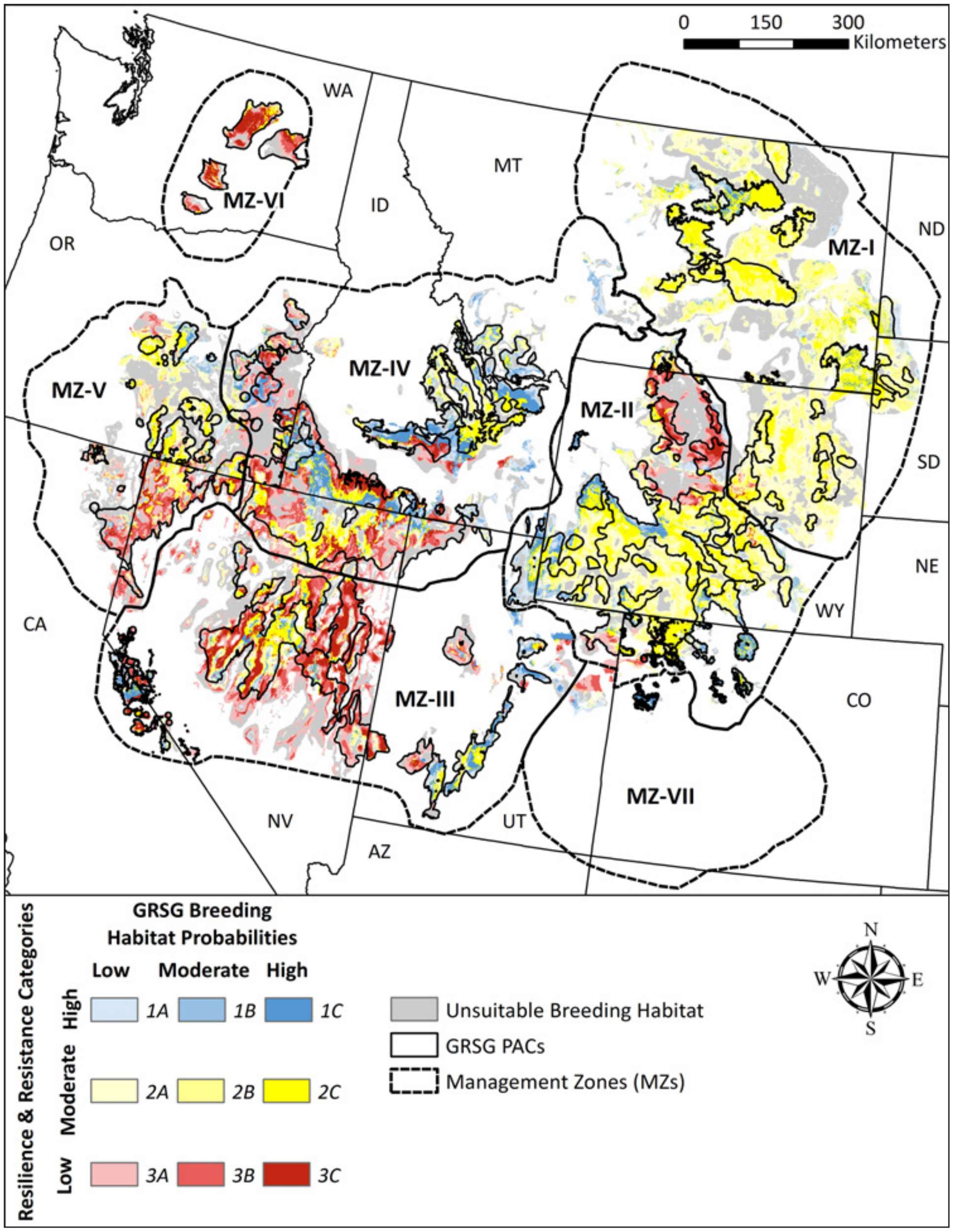

Figure 1.2—Greater sage-grouse (GRSG) breeding habitat probabilities based on 2010–2014 lek data (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes (Chambers et al. 2017a). This map provides a spatial depiction of the sage-grouse habitat, resilience and resistance matrix (Chambers et al. 2017a, fig. 38).

These six steps help identify priority areas for management and overarching management strategies for the assessment area. Key aspects of the approach are the sage-grouse habitat resilience and resistance matrix (table 1.3) and linked management strategies for addressing threats to sagebrush ecosystems (table 1.4). To step down ecoregion or Management Zone priorities to the local scale, managers and stakeholders are engaged to: (1) refine priorities and management strategies based on higher resolution geospatial products, additional species information, and local knowledge, including traditional ecological knowledge; (2) select specific project areas; and (3) identify opportunities to leverage partner resources.

Table 1.4—Management strategies for persistent ecosystem threats, climate change, and land use and development threats. Recommendations are provided for prioritizing and targeting strategies based on cells in the sage-grouse habitat, resilience and resistance matrix (table 1.3). Threats and strategies are cross-cutting and affect multiple program areas. While many of the strategies fall under the broad umbrella of vegetation management, a coordinated and integrated approach is likely to be used in addressing threats. For example, it is expected that many agency program areas, such as nonnative invasive plant management, fuel management, range management, and wildlife, will contribute to strategies that use vegetation manipulation to address persistent ecosystem and anthropogenic threats.

Threat—Nonnative Plant Invasive Species

Management strategies

- Apply integrated vegetation management practices to manage nonnative invasive plant species, using an interdisciplinary and coordinated approach in designing and implementing projects and treatments.
  - Prioritize areas where management resources are likely to be available to ensure successful management in the long term.
- Use resilience and resistance categories and knowledge of invasive plant distributions to select appropriate management approaches.
  - Protect high quality (relatively weed-free) sagebrush communities with moderate to high sage-grouse habitat probabilities (cells 1B, 1C, 2B, 2C, 3B, 3C):
    - Focus on preventing introduction and establishment of invasive plant species, especially in low resistance areas with high susceptibility to annual grass invasion (in and adjacent to cells 3B, 3C);
    - Avoid seeding introduced forage species (e.g., crested wheatgrass, smooth brome) in postfire rehabilitation or restoration in moderate to high resilience and resistance areas because these species can dominate sagebrush communities; and
    - Practice Early Detection and Rapid Response (EDRR) approaches for emerging invasive species of concern (in and adjacent to cells 1B, 1C, 2B, 2C, 3B, 3C).
  - Where weed populations already exist, seek opportunities to maximize treatment effectiveness by prioritizing restoration within relatively intact sagebrush communities (cells 1B, 1C, 2B, 2C, 3B, 3C). Restoration is likely to be easier at locations in cooler and moister ecological types with higher resilience and resistance.
    - Prioritize sites with sufficient native perennial herbaceous species to respond to release from invasive plant competition;
    - Manage grazing to reduce invasive species and promote native perennial grasses. In the West-Central Semiarid Prairies and other cool and moist areas, manage grazing to reduce crested wheatgrass, Kentucky bluegrass, smooth brome, and other introduced forage species and to promote native cool season perennial grasses (see grazing strategies).
  - Restrict spread of large weed infestations located in lower breeding habitat probability areas (cells 1A, 2A, 3A) to prevent compromising adjacent higher quality habitats (cells 1B, 1C, 2B, 2C, 3B, 3C).

Threat—Conifer Expansion

Management strategies

- Addressing localized conifer expansion requires an interdisciplinary approach and necessarily involves multiple program areas.
  - Apply integrated vegetation management practices to treat conifer expansion, using an interdisciplinary approach in designing projects and treatments.
  - Focus tree removal on early to mid-phase (e.g., Phases I, II) conifer expansion into sagebrush ecological sites to maintain shrub/herbaceous cover.
  - Use prescribed burning cautiously and selectively in moderate to high resilience/resistance (cells 1A, 1B, 2A, 2B) to control conifer expansion.
  - Prioritize for treatment:
    - Areas with habitat characteristics that can support sage-grouse with moderate to high resilience and resistance (cells 1B, 1C, 2B, 2C), especially near leks. (Note: Cells 3B and 3C are generally too warm and dry to support conifers.)
    - Areas where conifer removal will provide connectivity between sagebrush habitats.
    - Areas where sufficient native perennial grasses and forbs exist to promote recovery and limit increases in invasive plant species.

Threat—Wildfire

Management strategies

The wildfire threat is generally addressed through fire operations, fuel management (mechanical treatments, prescribed burning, chemical and seeding treatments), and postfire rehabilitation.

Fire Operations: Protection of areas supporting sagebrush is important for maintaining sagebrush habitat. The types and locations of GRSG habitats have been incorporated into decision support, dispatch, and initial attack procedures, and represent key considerations for fire managers.

(Continued)

Table 1.4—(Continued).

If resources become limiting, consider the following prioritization:

- Fire suppression—typically shifts from low to moderate priority when resilience and resistance categories shift from high to moderate, but varies with large fire risk and landscape condition (cells 1B, 1C, 2B, 2C). In low resilience and resistance areas, the priority shifts from moderate to high as sage-grouse habitat probability increases (cells 3B, 3C). Scenarios requiring high priority may include:
  - Areas of sagebrush that bridge large, contiguous expanses of sagebrush and that are important for providing habitat connectivity;
  - Areas where sagebrush communities have been successfully reestablished through seedings or other rehabilitation investments; and
  - All areas during critical fire weather conditions, where fire growth may move into valued sagebrush communities. These conditions may be identified by a number of products including, but not limited to: Predictive Services National 7-Day Significant Fire Potential products; National Weather Service Fire Weather Watches and Red Flag Warnings; and fire behavior analyses and local fire environment observations.

Fuel Management: Fuel management is a subset of vegetation management. Fuel management activities include treatments that mitigate wildfire risk, modify fire behavior, improve resilience to disturbance and resistance to invasive annual grasses, and protect and restore habitat. Mechanical treatments are typically applied to reduce fuel loading, modify fire behavior, augment fire suppression efforts, or alter species composition consistent with land use plan objectives. Roadside fuel breaks are applied most commonly in MZ III, IV, and V. Prescribed burning is one form of fuel management that may be used to improve habitat conditions or create fuel conditions that limit future fire spread in areas with moderate to high resilience and resistance, but should be considered only after consultation with local biologists and land managers. Chemical and seeding treatments are conducted to reduce invasive plants and change species composition to native, more fire resistant species, or a combination thereof, where native perennial grasses and forbs are depleted. When setting priorities for fuel management, consider the following.

<u>Mechanical Treatments—Conifer Removal</u>

- Conifer removal conducted to decrease woody fuels and reduce the loss of large, contiguous sagebrush stands are high priority in areas with high GRSG breeding habitat probabilities and moderate to high resilience and resistance (cells 1B, 1C, 2B, 2C), and shift to low in areas with low breeding habitat probabilities (cells 1A, 2A). In these areas, the focus is primarily on conifer expansion areas with sufficient native perennial understory species for recovery.
- Management activities may include:
  - Tree removal in early to mid-phase (Phases I, II) postsettlement conifer stands to maintain shrub/herbaceous cover and reduce fuel loads;
  - Tree removal in later phase (Phase III) postsettlement conifer stands to reduce risks of large or high severity fires; and
  - Herbicide, seeding associated with mechanical treatments, or both, to reduce invasive species and restore native perennial herbaceous species where native perennial species are depleted.

<u>Mechanical Treatments—Fuel Breaks</u>

Fuel breaks are strategically placed treatments where vegetation is modified in order to change fire behavior, making fire control efforts safer or more effective. Common types of fuel breaks include road maintenance/roadside disking (brown strips), mowed fuel breaks, and vegetative fuel breaks (green strips).

- In areas of low resilience and resistance, fuel breaks may increase in priority as sage-grouse habitat probability increases (cells 3B, 3C). Repeated treatments may be necessary to maintain functional fuel breaks.
- Key management considerations for the design and placement of fuel breaks:
  - Implement where fire managers believe they will benefit suppression efforts;
  - Design at large landscape scales, providing multiple options for fire managers;
  - Design collaboratively with interdisciplinary specialists, private landowners, fire response partners, and other agencies;
  - Include plans for long-term monitoring and maintenance;
  - Design to minimize habitat impacts, including nonnative invasive species introduction and spread, while maximizing potential fire management benefits.
- Key ecological considerations for the design and placement of fuel breaks:
  - Design fuel breaks in an interdisciplinary setting which addresses the need, cumulative effects, alternative treatments, and possible undesired results;
  - Consider ecosystem resilience and resistance and place fuel breaks to minimize catastrophic ecological state changes;
  - Include conservation buffers around sagebrush leks, habitat fragmentation thresholds, and minimum habitat patch sizes;
  - Include the influence on habitat connectivity between seasonal sage-grouse habitats;
  - Follow technical guidance related to recommended design features (see Maestas et al. 2016a).

(Continued)

Table 1.4—(Continued).

Prescribed Fire

Prescribed fire to address the threat of wildfire includes burning to reduce woody biomass resulting from treatments, to control conifer expansion, to reduce hazardous fuels, and to create fuel breaks which augment fire suppression efforts. When setting priorities for prescribed fire, consider the following:

- Consider alternatives to prescribed burning where other treatment alternatives may meet management objectives.
- In low resilience and resistance areas, consider prescribed fire only after consultation with local biologists and land managers and when:
  - Site information, such as state-and-transition models, affirm that the postburn trajectory will lead to functioning sagebrush communities. Most low resilience and resistance areas that receive <12 in/yr (30 cm/yr) of precipitation do not respond favorably to burning (see Miller et al. 2014).
  - Burning is part of multi-stage restoration projects where burning is required to remove biomass following chemical treatments for site preparation or for improved chemical applications.
  - Monitoring data validates that the preburn composition will lead to successful, native plant dominance post-burn
- Use prescribed fire cautiously and selectively in moderate to high resilience and resistance areas, after consulting with local biologists and land managers and assessing site recovery potential and other management options based on the following:
  - Preburn community composition;
  - Probability of invasive species establishment or spread;
  - Historical fire regime, and patch size/pattern to be created by burning;
  - Wildfire risk and desired fuel loading to protect intact sagebrush; and
  - Alternative treatments that may meet objectives.

Chemical Treatment of Nonnative Invasive Plant Species and Seeding

Chemical treatments and seedings are used to decrease invasive species composition and increase native species dominance in areas where native perennial grasses and forbs are insufficient for site recovery. Chemical and seeding treatments may be selectively applied in conjunction with prescribed fire or mechanical treatments. Typically, these treatments are in response to clear evidence of a nonnative invasive species threat. Areas of higher priority for chemical and seeding treatments:

- Lower resistance and resilience cells (2A, 2B, 3A, 3B) lacking the ability for natural recovery;
- Recently disturbed areas where recovery will not occur without chemical or seeding treatments;
- Areas where investments have been made and objectives cannot be attained without chemical or seeding treatments.

Postfire Rehabilitation: General considerations for prioritization of postfire rehabilitation efforts are:

- Priority generally increases as resilience and resistance decrease and habitat probability for sage-grouse increases. High priorities include areas of low to moderate resilience and resistance that (1) lack sufficient native perennial grasses and forbs to recover on their own and (2) have nearby areas still supporting sage-grouse habitat (cells 2B, 2C, 3B, 3C). Areas of low habitat probability for sage-grouse (cells 2A, 3A) are generally lower priority but may become higher priority in areas that support other resource values or that increase connectivity for GRSG populations.
- Areas of higher priority across all cells include:
  - Areas where prefire perennial herbaceous cover, density, and species composition is inadequate for recovery (see Miller et al. 2015);
  - Areas where seeding or transplanting sagebrush is needed to maintain habitat connectivity for sage-grouse;
  - Areas threatened by nonnative invasive plants; and
  - Steep slopes and soils with erosion potential.

Threat—Sagebrush Reduction

Management strategies

- Avoid intentional sagebrush removal (either prescribed fire or mechanical removal) across all areas in the West-Central Semiarid Prairies due to relatively limited sagebrush availability and extended periods of recovery in the region. Many areas are characterized by moderate to moderately low resilience and resistance, and many sagebrush species lack the capacity to resprout.
- Use caution when attempting to increase herbaceous perennials by reducing sagebrush dominance through mechanical or chemical treatments in general.
  - Lower resistance and resilience areas are prone to annual grass increases and potential dominance if invasive annual grasses exist in the area before treatment.
  - Pretreatment densities of 2 to 3 native perennial bunch grasses per square meter are often necessary for successful increases in perennial herbaceous plants and for suppression of invasive annual grasses after treatment in lower resistance and resilience areas (Miller et al. 2014, 2015).

(Continued)

Table 1.4—(Continued).

Threat—Climate Change

Management strategies

- Continue to use best management practices where effects of climate change and its interactions with stressors are expected to be relatively small and knowledge and management capacity are high.
- Consider proactive management actions to help ecosystems transition to new climatic regimes where climate change and stressor interactions are expected to be severe.
- Practice drought adaptation measures such as reduced grazing during droughts, conservation actions to facilitate species persistence, and seeding and transplanting techniques more likely to work during drought. Consider developing formal drought management plans for livestock grazing.
- Anticipate and respond to species declines such as may occur on the southern or warmer edges of their geographic range.
- Favor genotypes for seeding and out-planting that are better adapted to future conditions because of pest resistance, broad tolerances, or other characteristics.
- Increase diversity of plant materials for restoration activities to provide those species or genotypes likely to succeed.
- Protect future-adapted regeneration from inappropriate livestock grazing.
- Monitor transition zones between climatic regimes (the edges) to provide advanced warning of range shifts. Plant community shifts that affect management decisions often occur between Major Land Resource Areas or level III ecoregions.

Threat—Cropland Conversion

Management strategies

- Secure Conservation Easements to maintain existing sagebrush grasslands and sage-grouse habitat and prevent conversion to tillage agriculture. Prioritize all areas supporting moderate to high sage-grouse habitat probability (cells 1B, 1C, 2B, 2C, 3B, 3C) in locations where tillage risk is elevated (see Sage Grouse Initiative, Cultivation Risk layer).
- Secure term leases (e.g., 30 years) to maintain existing sagebrush grasslands and sage-grouse habitat and prevent conversion to tillage agriculture as a secondary strategy to Conservation Easements. Prioritize all areas supporting moderate to high sage-grouse habitat probability (cells 1B, 1C, 2B, 2C, 3B, 3C) especially in locations where tillage risk is elevated (see SGI Cultivation Risk layer).
- Offer alternatives to farming on expired USDA Conservation Reserve Program (CRP) lands through Federal and State programs. Prioritize lands in and around intact habitats (cells 1B, 1C, 2B, 2C, 3B, 3C).
- Encourage enrollment in the USDA CRP or similar programs to return tilled lands to perennial plant communities supporting mixtures of grasses, forbs, and sagebrush where there are benefits to sage-grouse. Prioritize lands in and around intact habitats (cells 1B, 1C, 2B, 2C, 3B, 3C).

Threat—Energy Development

Management strategies

- Avoid development, if feasible, in areas with high breeding habitat probability for sage-grouse and high sagebrush cover (cells 1C, 2C, 3C) and steer development in non-habitat areas (1A, 2A, 3A).
- Minimize habitat fragmentation in areas with moderate and high breeding habitat probabilities for sage-grouse (cells 1B, 2B, 3B, 1C, 2C, 3C).
- For disturbances that remove vegetation and cause soil disturbance, minimize and mitigate impacts (topsoil banking, certified weed-free [including annual bromes] seed mixes, appropriate seeding technologies, and monitoring). Plan for multiple restoration interventions in areas with low resilience and resistance (cells 3B, 3C).
- Minimize or co-locate energy transport corridors (e.g., roads, pipelines, transmission lines) and limit vehicle access, where feasible.
- Maintain resilience and resistance of existing patches of sagebrush habitat by aggressively managing weeds that may require the following management practices (especially important in low resilience and resistant areas—cells 3A, 3B, 3C):
  - Implement a weed management plan that addresses management actions specific to a project area;
  - Use certified weed-free (including annual bromes) gravel and fill material;
  - Assess and treat weed populations, if necessary, prior to surface disturbing activities;
  - Remove mud, dirt, and plant parts from construction equipment;
  - Address weed risk and spread factors in travel management plans;
  - Ensure timely establishment of desired native plant species on reclamation sites;
  - Use locally adapted native seed, whenever possible;
  - Intensively monitor reclamation sites to ensure seeding success, determine presence of weeds, and implement corrective actions as necessary;
  - Use mulch, soil amendments, or other practices to expedite reclamation success when necessary; and
  - Ensure weeds are controlled on stockpiled topsoil.

(Continued)

Table 1.4—(Continued).

Threat—Urban and Exurban Development ***Management Strategies*** • Secure conservation easements to maintain existing sagebrush stands and sage-grouse habitat. Prioritize areas with high habitat probability for sage-grouse and high sagebrush cover (cells 1C, 2C, 3C). • Encourage the protection of existing sage-grouse habitat through appropriate land use planning and Federal land sale policies. Steer development toward non-habitat (cells 1A, 2A, 3A) where habitat is unlikely to become suitable through management.
Threat—Livestock Grazing ***Management strategies*** • Manage livestock grazing to maintain a balance of native perennial grasses (warm or cool season species, or a combination, as described in Ecological Site Descriptions for that area), forbs, and biological soil crusts to allow natural regeneration and to maintain resilience and resistance to invasive plants. Ensure strategies prevent degradation and loss of native cool-season grasses in particular. Areas with low to moderate resilience and resistance may be particularly vulnerable (cells 2A, 2B, 2C, 3A, 3B, 3C). • Implement grazing strategies that incorporate periodic deferment from use during the critical growth period, especially for cool season grasses, to ensure maintenance of a mixture of native perennial grasses. This strategy is important across all sites, but particularly essential on areas with low to moderate resilience and resistance supporting sage-grouse habitat (cells 2B, 2C, 3B, 3C). • Ensure grazing strategies are designed to promote native plant communities and decrease nonnative invasive plants. In ephemeral drainages and higher precipitation areas in the West-Central Semiarid Prairies that receive more summer moisture and have populations of nonnative invasive plant species, too much rest may inadvertently favor species such as field brome, Kentucky bluegrass, and smooth brome. Adjustments in timing, duration, and intensity of grazing may be needed to reduce these species.

To support use of the Science Framework, geospatial data, maps, and models are provided through the Bureau of Land Management's (BLM's) Landscape Approach Data Portal (https://landscape.blm.gov/geoportal/catalog/main/home.page) and U.S. Geological Survey's (USGS's) ScienceBase database (https://www.sciencebase.gov/catalog/). USGS is developing a visualization tool that supports use of this information and that when completed will be accessible through the Landscape Approach Data Portal and ScienceBase database.

Updates to the Science Framework

The Science Framework, both Part 1, **science basis and applications,** and Part 2, **management considerations,** is intended to be adaptive and will be updated to highlight potential management considerations as new science and information on focal species and habitats become available. The mechanism for providing updates is being developed and is likely to include Fact Sheets and webinars developed with partner research and management agencies and organizations. Updates will be linked to periodic updates of the Western Association of Fish and Wildlife Agencies' (WAFWA's) Sagebrush Science Initiative and Sagebrush Conservation Strategy (table 1.1). Updates will be numbered to show the relationship to Part 1, Part 2, and the broader Sagebrush Conservation Strategy and will be housed on the BLM's Landscape Approach Data Portal, the Great Basin Fire Science Exchange website (http://greatbasinfirescience.org/), and USGS's ScienceBase database.

Updates to the Science Framework are expected to address the sagebrush biome, mid-, and local scales and may include new information, science, and analyses that were not included in this version. Updates to the Science Framework could be informed by State Heritage databases and the results of new research conducted as part of implementation of the Actionable Science Plan (IRFMSASPT 2016) and other ongoing research efforts. The State Wildlife Action Plans provide a resource for more detailed information for the Science Framework at the State level, while the Science Framework provides a resource for Wildlife Action Plan revisions by the individual States. Science synthesized to support the WAFWA Sagebrush Conservation Strategy or during development of NEPA analyses to support management decisions could also be considered for inclusion.

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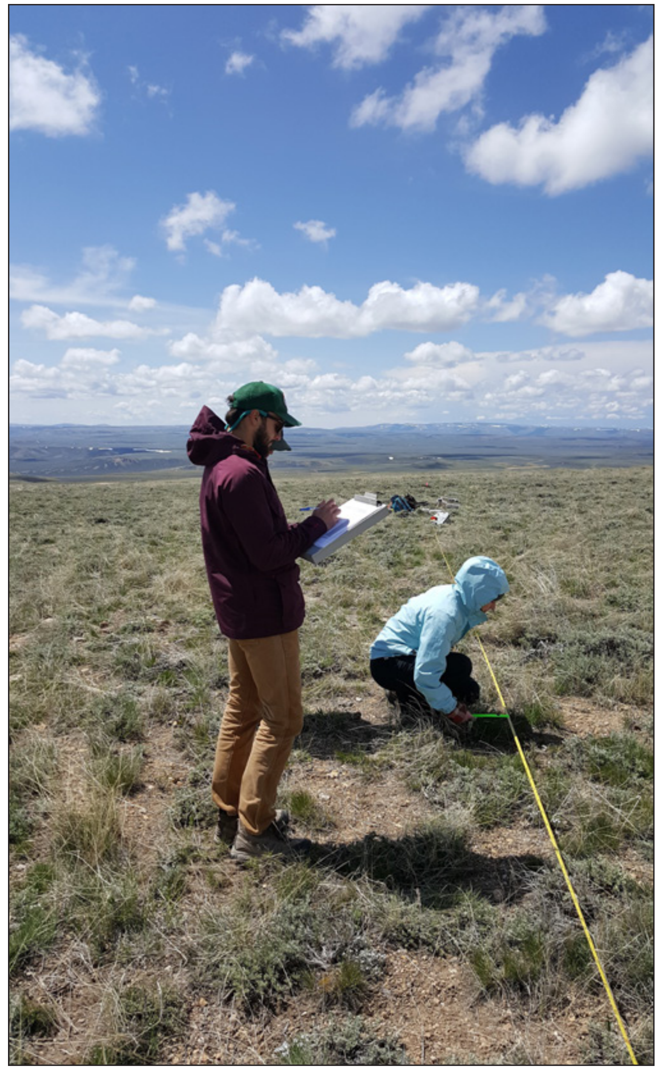

2. ADAPTIVE MANAGEMENT AND MONITORING

Lief A. Wiechman, David A. Pyke, Michele R. Crist, Seth M. Munson, Matthew L. Brooks, Jeanne C. Chambers, Mary M. Rowland, Emily J. Kachergis, and Zoe Davidson

Introduction

Monitoring programs designed to track ecosystem changes in response to both stressors and disturbances use repeated observations of ecosystem attributes. Such programs can increase our understanding of how interactions among resilience to disturbance, resistance to invasive species, and "change agents" including management actions influence resource conditions (or status) and trends and outcomes of conservation and restoration actions. This type of monitoring information provides the basis for adaptive management. The overarching goal of an integrated monitoring and adaptive management program is to reduce the uncertainty in the effectiveness of management actions over time by improving management objectives and strategies to increase the effectiveness of those actions.

An integrated monitoring and adaptive management program includes a series of steps that are repeated over time and are designed to facilitate "learning by doing" (fig. 2.1). A structured decisionmaking process may be useful for developing meaningful objectives, and can aid land managers and stakeholders in examining the context, options, and probable outcomes of decisions through an explicit and repeatable process (Allen et al. 2011; Marcot et al. 2012; Thompson et al. 2013). The first step, **assessment**, involves defining the problem, identifying objectives, and determining evaluation criteria. In the second step, **design**, the alternatives are defined, the consequences and key uncertainties are identified, and tradeoffs are evaluated. Next, the preferred alternative is identified, and the decision is made to **implement** the preferred alternative and management action(s).

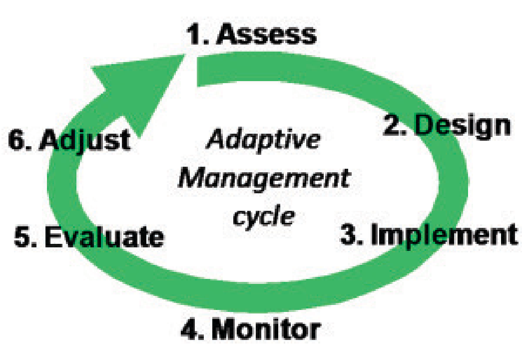

Figure 2.1—The primary components of the adaptive management cycle.

Top left: Assessment, Inventory, and Management (AIM) meeting (photo: Emily Karchergis, USDOI Bureau of Land Management). Middle left: Mark Szcztpinski using telemetry to track the movements of Greater sage-grouse (photo: Kenton Rowe. Montana Fish, Wildlife and Parks). Bottom left: Digging a soil pit and describing the soils (photo: Emily Karchergis, USDOI Bureau of Land Management). Right: Monitoring vegetation (photo: Emily Karchergis, USDOI Bureau of Land Management).

Text Box 2.1—Components of Monitoring Objectives

An example monitoring objective is:

- Maintain sagebrush cover greater than 15 percent and less than 25 percent across 70 percent of the sage-grouse nesting and early brood-rearing habitats in the assessment area.

Monitoring objectives should identify:

- The indicator(s) that will be monitored;
  - In this example, the indicator would be ***sagebrush cover***.
- Quantitative benchmark(s) for each indicator;
  - In this example, a range of values from ***15 to 25 percent*** sagebrush cover across ***70 percent of the sage-grouse brood-rearing habitat*** in the assessment area would be used.
- A timeframe for evaluating the indicator(s);
  - In this example, the timeframe is likely to be determined by the ***life of the management plan or strategy.*** However, projects and treatments may have a finite timeframe.
- The geographic scale(s) (likely local to mid-scale) over which the monitoring results will be reported (e.g., treatment area, land use planning area).
  - In this example, the scale would be ***sage-grouse nesting and brood-rearing habitat*** in the assessment area.

For more detailed information, refer to part B of table 2.1

Monitoring is the fourth step and is key to adaptive management. The information from a long-term monitoring program is used to **evaluate** ecological status and trends and whether or not management objectives are being met. That information is then used to **adjust**, as necessary, the management action(s) to meet management objectives. A well-designed and rigorous monitoring program has many components (table 2.1) Together these components are used to estimate the proportion of an area that is or is not meeting certain objectives or standards, and provide an unbiased estimate of environmental conditions and changes for ecosystems, species, and populations. Describing the likely data analysis techniques can help ensure that the sampling design will produce meaningful results.

Elzinga et al. (1998) describe how to establish a monitoring program for plant populations and Hayward and Suring (2013) describe this process for wildlife habitat monitoring. These sources provide the necessary information for developing monitoring programs for other types of resources. Definitions related to developing a monitoring program are in Appendix 1.

Monitoring is most effective for adaptive management when the objectives are clearly defined and are consistent with the broader management objectives for the resource. Text box 2.1 provides an example of a monitoring objective. To determine whether the objectives are being met, specific indicators are identified that can be measured and can account for changes in the resource within a realistic timeframe and budget given the site potential and spatial scale of the area being managed (table 2.1).

Benchmarks are indicator values, or ranges of values that establish desired conditions and are meaningful for management. Benchmarks are used to compare observed indicator values to desired conditions. For example, achieving a benchmark value of plant density may tell the practitioner that a seeding project was successful; failure to achieve it may prompt a reevaluation of seeding methods.

Benchmarks for a given indicator may vary for sites with different biophysical characteristics and ecological potential (e.g., ecological site types). Thus, it may be necessary to group benchmarks for areas with different characteristics within a project area and to include the proportion of the landscape that is required to meet a given benchmark. Without appropriate benchmarks, such values lack context and cannot be used to assess condition or the attainment of management objectives.

Table 2.1—Components of a monitoring program based on Elzinga et al. (1998) and Goldstein et al. (2013).

A. Complete Background Tasks

1. Compile and review existing information on the ecosystems, species, and populations. Ecological models of the relationships among ecosystem or habitat characteristics, species abundance, and management effects can help in developing monitoring objectives and improve interpretation and application of the data.
2. Review existing planning documents describing management objectives, including benchmarks or desired conditions, and planned management actions.
3. Prioritize the ecosystems, species, and populations to be monitored based on existing assessments. These priorities may require periodic reassessment due to changes in threats, management, conflicts, and the interests of outside parties.
4. Assess the resources available for monitoring, including management support, priorities, and people and equipment available.
5. Determine the scale of interest for the monitoring effort, such as the sagebrush biome, the range of a species, certain ecological types, or local scales (e.g., populations in certain management units).
6. Determine the type and intensity of monitoring based on the management objectives.
7. Ensure adequate review of the proposed monitoring program by higher level management and by individuals working in relevant disciplines. For larger programs or highly controversial ecosystems, species, and populations, a team may need to be assembled.

B. Develop Monitoring Objectives

1. Develop monitoring objectives that are consistent with the management objectives.
2. Select indicators that can be used to identify the status and trends of a resource or the effectiveness of a management action.
3. Identify the indicators that are most sensitive and appropriate for measuring status and trends or change toward the management goals or benchmarks.
4. Specify the amount and direction of change that is desired or that can be tolerated for each indicator. This science-based value may include a percentage change, or a target or threshold value.
5. Specify a biologically meaningful timeframe for monitoring, considering the indicators selected, to measure ecosystem and species responses following a management action.
6. Specify the management responses needed if monitoring indicates that the management objectives have or have not been met.

C. Design the Monitoring Methodology

1. Develop the sampling objectives.
2. Determine and map the area to be monitored.
3. Define the sampling unit for each indicator that will be measured.
4. Determine the method of sampling unit placement within the monitoring area. An unbiased estimate of resource status and trends can be gained by incorporating randomization into sampling designs.
5. Determine biologically meaningful monitoring durations, intervals, and frequencies.
6. Design the data sheets for the indicator to be measured.
7. Describe the likely data analyses for the different indicators.
8. Identify the necessary resources required to implement the monitoring plan.
9. Write a monitoring plan that has sufficient details for the monitoring to be repeated over time.

F. Implement Monitoring

1. Collect the data at specified intervals using trained personnel.
2. Analyze the data that are collected after each measurement cycle.
3. Describe what if any monitoring triggers have been passed, or what if any benchmarks have been met during the monitoring cycle.
4. Evaluate monitoring methods, costs, sample sizes, and relevance after each measurement cycle. Conducting a trial run or pilot study can expose problems and allow adjustments in the methodology to increase monitoring effectiveness.

G. Manage, Store, and Report Data

1. Ensure that the data for each measurement cycle are complete, entered into standardized databases, verified, and backed up.
2. Analyze all data collected over the reporting period.
3. Review the results for potential issues with either the data collection protocols or the amount and direction of change occurring in the indicator variables.
4. Compile the data and analyses into reports. For data collected over longer time periods, reports should be developed at regular intervals.

H. Apply Results of Monitoring in an Adaptive Management Context

1. Use monitoring results to adjust priority areas for programs of work and resource allocation.
2. Use monitoring results to inform revisions of Land Use Plans and Amendments.
3. Use monitoring results to assess the effectiveness of management strategies and treatment methods and to guide revisions in these as needed.

Monitoring benchmarks can be established based on the management objectives and current ecological site potential of the area (text box 2.2). For example, the Bureau of Land Management (BLM) has set a number of benchmarks for sagebrush cover and other vegetation characteristics in order to maintain habitat for Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) (e.g., Stiver et al. 2015). Ecological site descriptions and state-and-transition models provide information on the current ecological states and the likely effects of stressors, disturbances, and management actions and can be used to help determine appropriate management objectives (see text box 7.2) and set meaningful benchmarks.

Environmental **thresholds** (conditions sufficient to modify ecosystem structure and function beyond the limits of ecological resilience that result in transition to alternative states [Briske et al. 2008]) are necessary to provide a clear path for management options or alternatives under adaptive management. Knowledge, or estimates, of environmental **thresholds** is important for establishing monitoring triggers. **Triggers** are levels of environmental conditions that can provide an early warning of possible thresholds and of management changes that may be necessary to maintain the desired environmental conditions (Briske et al. 2008; Goldstein et al. 2013).

Monitoring of the indicators must be repeated over sufficient, predetermined time intervals to detect changes and trends in resource status at the spatial scale of management interest. After each measurement cycle is complete, the data are entered into standardized databases, verified, and backed up. **Analyzing** the monitoring data to assess whether the management objective has been achieved or any thresholds have been crossed is the fifth step in an adaptive management program.

The final step is either continuing or changing management at the scale necessary to achieve the desired response or condition. Natural resource decisions are often complex and made with uncertainty, yet managers and biologists are expected to effectively justify and communicate their decisions. In the context of Part 1 of the Science Framework (Chambers et al. 2017; hereafter, Part 1), monitoring results can be used to adjust priority areas for programs of work and budget allocation, to inform efforts such as Federal land use plans (LUPs) and State Wildlife Action Plan revisions, to assess the effectiveness of management strategies and treatment methods, and to guide improvements.

Text Box 2.2—Information to Consider for Establishing Benchmarks

Sources of information and data that can be used to develop benchmarks in an interdisciplinary team environment to build consensus include:

- Policy (e.g., sage-grouse habitat standards, State water quality standards)
- Ecological site descriptions or state-and-transition models
- Comparable monitoring efforts (e.g., baseline Assessment, Inventory, and Monitoring [AIM] data)
- Scientific literature (e.g., sage-grouse habitat assessments)
- Predicted natural conditions (e.g., ecological models)
- Best professional judgment (e.g., considering local knowledge and best available science together)
- Paired reference sites

Overview of the Types of Monitoring

Monitoring can be divided into two categories. The first category describes the ecological status and trends of management areas, and the second category evaluates how well management objectives are being met in project areas. For the purposes of this document, we define "treatments" as site-specific management actions that directly influence one or more of the four ecosystem attributes that are defined in the next paragraph (e.g., biotic integrity can be influenced by juniper and piñon removals, fuel treatments, or GRSG population size). "Projects" can encompass multiple treatments and may relate to broader-scale landscape objectives. "Management action" is a general term that includes active treatments, but may also include actions such as changing management of livestock grazing or recreational uses.

Regardless of the category of monitoring, four ecosystem attributes are important to monitor for determining ecosystem status of an individual management unit (local scale), an ecoregion or Management Zone (mid-scale), or the sagebrush biome (broad scale). Because these attributes are difficult to measure directly, they must be tracked through multiple indicators (Herrick et al. 2010, 2017).

Soil Stability and Health. Soil is the basic foundation of terrestrial ecosystems. Thus, the attributes of soil stability and soil health (quality) are critical elements for sustaining plant, animal, fungal, and microbial functions.

Hydrologic Function. Hydrologic function of terrestrial systems is closely linked to soil stability and quality. All land types (upland, wetland, and riparian ecosystems) are important for maintaining the capture, storage, and release of water.

Water Flow and Quality. Lentic (still water) and lotic (moving water) ecosystems have unique functions as basic resources for biotic integrity, but their capacity to function properly (e.g., recharge and discharge of water to or from the soil) may be linked to other attributes such as soil stability (e.g., sedimentation) or hydrologic function.

Biotic Integrity. Biotic integrity of the plant, animal, fungal, and microbial components of the ecosystem, whether on land or in water, is closely linked to resilience to disturbance and resistance to invasion. This may often include composition, structure, and function of the community or ecosystem.

Monitoring Ecological Status and Trends (Condition and Change)

Status and trends monitoring aims to understand the current condition of natural resources (status) as well as changes in resource condition over time (trends). This type of monitoring informs adaptive management decisionmaking by revealing whether any triggers or benchmarks in soil stability and health, hydrologic function, water flow and quality, and biotic integrity have been reached and whether subsequent management actions are necessary. Status and trends monitoring in sagebrush ecosystems can address questions about the quality and quantity of habitat, the spatial distribution of observed changes, and when possible, **why** resource conditions are changing over time (see *Validation Monitoring*). Such monitoring is often a subset of a larger program or inventory aimed at a broad set of resources within a particular land ownership or jurisdiction. Ideally, by using standardized protocols across land ownership or jurisdictional boundaries, data can be aggregated to understand changes at multiple scales (Rowland and Vojta 2013). Monitoring may be intensified in areas where more information is needed such as in high-priority GRSG habitat and areas with low resilience and resistance (table 1.3: cells 3B, 3C). Causal associations between resource conditions and drivers of change, such as land management decisions or climate change, can be determined by evaluating information from status and trends monitoring along with spatial information about those drivers and reference or control sites.

An unbiased estimate of resource status and trends can be gained by incorporating randomization into sampling designs across an area of interest and keeping track of other potential influences on monitoring results, such as different detection levels, observers, and environmental conditions, which can be accounted for in the analysis. Finally, this type of monitoring can provide information at multiple scales of interest.

Several monitoring programs have been developed to address status and trends of resources, including the BLM's Assessment, Inventory, and Monitoring (AIM) and the Natural Resources Conservation Service's National Resources Inventory (NRI), both of which use common indicators and protocols; the Forest Service's Forest Inventory and Analysis (FIA) program; and the national Landscape Monitoring Framework, which is part of BLM's AIM strategy. Although AIM and NRI use different measurement techniques from FIA, the sample designs allow for analyses that cross administrative boundaries, provided that appropriate analytical methods are implemented (Patterson et al. 2014). Regional and finer scale monitoring efforts are also implemented through BLM AIM, the National Park Service Inventory and Monitoring Program, National Inventory and Monitoring Initiative (I&M) managed by the National Wildlife Refuge System, and other efforts. These types of monitoring efforts are the recommended means of understanding status and trends of GRSG habitat (e.g., Stiver et al. 2015; USDOI 2014).

Monitoring to Evaluate Management Objectives

To evaluate whether management objectives are being met, measurements can be conducted at local, mid-, and broad scales. The types of monitoring typically used to monitor management objectives, **implementation**, **effectiveness**, and **validation**, are described next.

Implementation Monitoring

Implementation monitoring determines whether planned management decisions, actions, and treatments have been implemented, and whether standards outlined within planning documents were followed or modified. The BLM and Forest Service report on the actions implemented that are described in their LUPs and that relate to decisions aimed at conserving, improving, or restoring sagebrush habitats (USDOI 2014). Initially, this type of monitoring is conducted by planning units. However, given some consistencies in management objectives across planning unit boundaries, this level of monitoring can often be scaled up to the mid-scale.

Effectiveness Monitoring

Effectiveness monitoring assesses the condition of a management action's outcome. Success is typically achieved by meeting predetermined treatment objectives that can be measured against baseline or reference conditions determined by status and trends monitoring, or another desired condition or benchmark as stipulated in the treatment objectives (table 2.1). As an example, effectiveness monitoring may be conducted at the project scale when expanding juniper and piñon or nonnative invasive plants are removed to restore GRSG habitat. Monitoring indicators, such as landscape cover of trees, and the appropriate benchmarks can be used to evaluate whether the effort has reduced tree cover below the response threshold (e.g., less than X% cover across Y% of the monitoring area, which varies regionally) (Baruch-Mordo et al. 2013). Pretreatment levels (baseline) of nonnative invasive plants can be compared to posttreatment levels of perennial native grasses and forbs (e.g., Chambers et al. 2014). If radio-marked GRSG are being monitored in the area of the treatment, the subsequent space or habitat use can be monitored and used to evaluate the efficacy of the treatment. The effectiveness of multiple projects or treatments within the mid-scale can help determine the effectiveness of the management objectives contained within a LUP or other guiding management document. Appropriate landscape-level indicators tied to project objectives provide the opportunity to assess the effectiveness of efforts in achieving conservation goals at the broad scale. This type of monitoring also lends itself to evaluating the effectiveness of and potential benefit achieved from mitigation efforts.

Validation Monitoring

Validation monitoring uses an experimental approach to determine whether the observed outcome is due to the management action. This requires treating some areas and leaving some areas untreated to serve as "controls" for the treated areas, as is done in research and management projects like the Sagebrush Treatment Evaluation Project (http://www.sagestep.org/). The untreated areas are compared to the treated areas to determine whether they differ in meeting the stated objectives. For example, after a wildfire in a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) ecosystem with low to moderate resilience and resistance, restoration efforts might focus on seeding Wyoming big sagebrush and native perennial bunchgrasses in a randomly selected sample of potential treatment sites. After X years of monitoring ("X" is equal to the time stated in the objectives statement), cover of native perennial bunchgrasses and stem density of sagebrush are measured to determine whether they are trending toward the desired management objective. If the treated sites have higher cover of native perennial bunchgrasses and stem density of sagebrush than the untreated sites, then the management treatment was successful. If the cover and stem density are similar between treated sites and untreated (or control) sites, then the outcome may be attributed to natural successional processes. Due to its relatively high costs and complexity, validation monitoring is most likely to occur at the local scale rather than at mid- or broad scales.

A combination of these monitoring approaches can ensure that management objectives are achieved at multiple spatial scales and that the observed outcome is due to the treatment. These different types of monitoring provide important feedbacks for adaptive management and thus provide further support for incorporating monitoring strategies into the planning or development phase of any project or treatment, including budget planning. Archiving data collected through implementation, effectiveness, and validation monitoring in tools, such as the Land Treatment Digital Library for the BLM (Pilliod and Welty 2013) and the Conservation Efforts Database (USDOI FWS 2014), and analyzing the status and trends can allow managers to learn from past treatments and decide on appropriate management actions in the future.

Standardization of Indicators and Protocols

Adoption of a standardized set of indicators and protocols for collecting indicator data will allow a wide range of users (i.e., managers, landowners, interested public, and researchers) to compare data collected in different areas and for different objectives. The NRCS and BLM currently use common protocols for national and regional monitoring of many rangeland vegetation and soil indicators (Herrick et al. 2010, 2017; Toevs et al. 2011). The Forest Service recently released protocols for standardized wildlife habitat monitoring (Rowland and Vojta 2013), which rely primarily on existing, commonly used sampling methods and datasets. The Integrated Rangeland Fire Management Strategy (IRFMS) (USDOI 2015) provides guidance for working out some of the differences among protocols and indicators to reduce conflicts.

Measuring standardized indicators with consistent protocols allows ground-based data to be scaled-up from local to mid-scales through ground-truthing and validation with remotely sensed data. Provided that data are collected using a randomized sampling design with known methods of stratification, level of effort, and other parameters, data collected from each location or landscape can be weighted in a statistically sound manner and combined with similar data in other areas to obtain cross-site or cross-landscape comparisons with spatial relevance and known levels of error (Patterson et al. 2014).

Rule sets for making data collection decisions are necessary to ensure precise measurement among different field crews (Rowland and Vojta 2013). Herrick et al. (2005) illustrate how rule sets are stipulated. BLM's AIM and NRCS's NRI both use rule sets to standardize measurement decisions. No one rule set is perfect, but rule sets provide a means for collecting consistent data among different observers.

Linking Resilience and Resistance Concepts and Monitoring

Monitoring landscape heterogeneity over time can provide a clearer understanding of how sagebrush dominated landscapes are changing in response to natural ecosystem processes, anthropogenic disturbances, and management actions. Relative resilience to disturbance and resistance to invasive annual grasses influence the responses of sagebrush ecosystems to threats such as wildfire, land uses, and development. Information on resilience and resistance can provide an additional data layer in monitoring programs that can be used to help understand the changes in ecosystem status and trends and the effectiveness of management treatments at broad, mid-, and local scales. The relationships among resilience and resistance, as indicated by soil temperature and moisture regimes, the predominant sagebrush ecological types, and the responses of those ecological types to both disturbance and management, can be used to inform monitoring designs, to help develop benchmarks and triggers for changes in management, and to determine appropriate changes in management strategies and treatments (Part 1, section 6).

By stratifying monitoring across resilience and resistance categories, the range of potential responses to management actions can be captured. Even if a monitoring program is already in place, including resilience and resistance as a factor in the analyses may still provide useful information and context on the effects of resilience and resistance given adequate sample sizes in the different categories.

Generalized state-and-transition models developed for the dominant ecological types in both the western and eastern parts of the sagebrush biome and GRSG range, provide information on the alternative states for these types, the effects of ecosystem threats and management actions on these states, and the potential restoration pathways (Part 1, Appendices 5 and 6). Examples of how to apply resilience and resistance concepts are provided for areas with different ecological types and threats (Part 1, section 9.2).

Using the Science Framework Approach to Inform Monitoring

The Science Framework, Part 1 gives an approach for prioritizing areas for management and determining effective management strategies based on: (1) the predominant threats, (2) the likely response of an area to disturbance or stress due to threats or management actions (i.e., resilience to disturbance and resistance to invasive annual grasses), and (3) the capacity of an area to support target species or resources.

The geospatial data layers and analyses used in the approach are described in Part 1, sections 8.1 and 8.2, and can be used to help design monitoring programs and interpret monitoring results. Analyses are generally conducted at the mid-scale because of similarities in ecoregional climate, soil properties, resilience to disturbance, and resistance to invasive annual grasses. Key data layers include resilience and resistance as indicated by soil temperature and moisture regimes, GRSG breeding habitat probabilities, habitats of other sagebrush dependent species, and the primary threats for the ecoregions or Management Zones. At the mid- to local scale higher resolution geospatial data that are specific to the assessment area (i.e., the best available data) are used in the analyses. Interpretations of these analyses for monitoring programs, based on the Science Framework approach for GRSG (tables 1.3, 1.4), follow a similar approach and can be used for other species at risk as well as priority resources.

Monitoring areas of high GRSG breeding habitat probability (table 1.3: cells 1C, 2C, 3C) provides information on whether these areas are retaining their composition, structure, and function as GRSG habitat. Protective management is used to retain resilience and resistance in these areas. Monitoring for status and trends and using the Early Detection and Rapid Response approach (EDRR) (USDOI 2016) for nonnative invasive plants can help ensure that invasive plants do not increase and thereby degrade these high value sites. Monitoring areas of low resilience and resistance with high GRSG breeding habitat probabilities is especially important because these areas are at high risk of habitat loss from wildfire and potential for conversion to invasive annual grasses (table 1.3: cell 3C). Regardless of an area's resilience and resistance, implementation and effectiveness monitoring are used to assess treatment outcomes and determine whether follow-up management is needed.

Areas with moderate breeding habitat probabilities are a focus for habitat improvements (table 1.3: cells 1B, 2B, 3B). Treated areas within GRSG habitat are often moderate to high priority for monitoring because habitat improvements resulting from treatments could translate into increased use or improved demographic indices (e.g., population trends, survival), or both, for GRSG. Treated areas typically undergo EDRR, implementation, and effectiveness monitoring to ensure that the treatments were implemented as planned, objectives of the management action(s) are met, and an understanding of the effectiveness of the outcome is gained (Mulder et al. 1999; Noss and Cooperrider 1994).

Monitoring areas with low GRSG breeding habitat probabilities and low resistance and resilience can provide information on continued changes in composition, structure, and function, but is generally lower priority unless other at-risk species or management concerns are identified in these areas (table 1.3: cells 1C, 2C, 3C). Areas of low resilience and resistance and with low breeding habitat probabilities that are currently dominated by invasive annual grasses may be given the lowest priority for monitoring (table 1.3: cell 3A). These areas of invasive annual grasses have gaps in function and structure, which can hinder management efforts toward reference conditions. This reduces the number of adaptive management options.

Monitoring Change in Landscape Status and Trend

Landscape monitoring is an important aspect of land management that provides a way to examine the big picture—it gives information on ecosystem processes, habitat characteristics, and species distributions and movements that operate beyond the scope of management units and land ownership boundaries. This type of monitoring can also provide information on the landscape characteristics of areas with different resilience and resistance and the response of these areas to ecosystem threats and management actions. There are several types of indicators (e.g., indicators developed to map broad spatial patterns for different vegetation types) that can be used to monitor landscapes and evaluate: (1) change in environmental conditions and ecosystem structure, process, and function; (2) cumulative effects of management activities; and (3) crossing of thresholds over broad areas. These indicators can measure physical characteristics on the ground and connect them to ecological processes. They may also be used as surrogates for environmental conditions that cannot be measured directly. Typically, these types of indicators are calculated using spatial data within a specified assessment area (e.g., ecoregion, Management Zone, jurisdictional boundary). The resulting measurements from monitoring these indicators may differ based on the size of the assessment (broad, mid-, and local). Thus, it is important to measure the appropriate indicators at the appropriate resolution and scale to provide comprehensive, integrated monitoring for the scale of interest.

Landscape Indicators

There are certain indicators useful for monitoring and quantifying landscape heterogeneity and change at multiple scales. Examples of indicators that can be monitored and quantified across an assessment area to identify natural and human-caused change over time are: percent cover of the vegetation types occurring across the assessment area, the average cover of all vegetation or habitat patch size, patch size coefficient of variation, the average and range of distance to neighboring patches, vegetation or habitat patch richness, and patch edge contrast or density (Cushman et al. 2008, 2013a,b; Goldstein et al. 2013). These indicators measure various aspects of landscape structure, but when analyzed together can offer a comprehensive evaluation of change in landscape pattern, land cover class conversion, and fragmentation across the assessment area. For example, an aggregate of local-scale monitoring data and remote sensing data (e.g., National Gap Analysis [GAP], Landscape Fire and Resource Management Planning Tools [LANDFIRE], National Land Cover Database [NLCD], Geospatial Multi-Agency Coordination [GeoMAC] Wildland Fire Support Tools) can be examined to quantify sagebrush landscape pattern, heterogeneity, and change over time independently or relative to other landscape class mean patch sizes. These indicators, when evaluated within or across land cover classes, quantified over specific time intervals, provide a measure of how sagebrush patches have changed (expanded or contracted) in response to natural ecosystem processes, anthropogenic disturbances, and management actions over time.

Depending on the management question, distance to neighboring vegetation patches may increase or decrease over time. This indicator combined with other landscape indicators (e.g., change in average sagebrush patch size) will help provide information on whether the assessment area is meeting management objectives and benchmarks and avoiding triggers. For instance, an increase in the average nearest neighboring patch distance along with a decrease in the average sagebrush patch size over time typically indicates an increase in fragmentation of sagebrush across the assessment area. In contrast, a decrease in distance to neighboring sagebrush patches combined with an increase in average sagebrush patch size may indicate successful restoration and a decrease in fragmentation across the assessment area. The landscape indicators monitored should be identified carefully and should address the management objectives. The use of consistent landscape indicators across jurisdictional boundaries will improve our understanding of overall landscape change at the biome scale as well as provide the information needed by land management agencies to understand how management practices are effective in meeting management goals.

Landscape Monitoring of Habitats

Habitats are spatially structured, forming patterns at multiple scales. These patterns may influence wildlife behavior and use of space and influence population dynamics and community structure (Johnson et al. 1992). For all species, habitat must have sufficient size and proximity of resource patches to: (1) support reproduction, (2) facilitate dispersal, and (3) maintain metapopulation structure (if that is a characteristic of the species) (Cushman et al. 2013a). To monitor landscape-level changes within the sagebrush ecosystem with a focus on wildlife-specific species indicator data, landscape indicators can be used to quantify how habitat changes over time in response to management decisions and natural ecosystem processes. For example, much information is available on landscape indicators for GRSG, such as habitat intactness (Aldridge et al. 2008; Wisdom et al. 2011); breeding habitat probability (Doherty et al. 2016); landscape genetics (Cushman et al. 2013b; Row et al. 2015); habitat patch size, habitat connectivity, and networks; ecological minimums (thresholds) (Crist et al. 2015; Knick and Hanser 2011; Meinke et al. 2009); edge effects (Coates et al. 2014; Howe et al. 2014); and distance to water (Donnelly et al. 2016). Goldstein et al. (2013) provide an example monitoring plan for GRSG habitat monitoring at multiple scales, with sagebrush patch size, sagebrush canopy cover, and habitat connectivity selected as landscape-level habitat monitoring indicators. Spatial data from remote sensing efforts (e.g., NLCD, LANDFIRE, GeoMAC, GAP), along with monitoring data collected on the ground, can be used to analyze these indicators and quantify the amount of habitat area and connectivity lost or gained due to habitat conversion or natural succession (Goldstein et al. 2013).

Disturbance, Reclamation, and Restoration

Tracking and measuring the influence of persistent ecosystem and anthropogenic threats, separately and in combination at broad scales, can provide useful information on whether or not management objectives for sagebrush ecosystems are met. Overlaying information on resilience and resistance can aid in the interpretation of management outcomes. For example, the ability to achieve successful reclamation and subsequent restoration will differ for ecosystems with different resilience and resistance. Monitoring can help inform where to prioritize management and conservation actions, what to expect under certain measured conditions, and what the best indicators of overall management effectiveness are.

Classifying habitat restoration, vegetation treatments for fuel management, and other types of vegetation treatments separately from land cover classifications used in vegetation mapping (e.g., Homer et al. 2015) can allow these treatments to be monitored and evaluated over time at the landscape scale. This can provide the basis for determining whether an area has recovered, whether benchmarks (or triggers) at the landscape level (ecosystem or species-specific) have been exceeded, and whether management actions are needed. For example, triggers associated with habitat thresholds, such as mean distance to, and density of, oil and gas wells (Doherty et al. 2008; Holloran et al. 2005; Lyon and Anderson 2003; Naugle et al. 2011; Walker et al. 2007), have guided science-based land use and management decisions in recently amended BLM and Forest Service LUPs, and some State plans.

Recent work has shown variation in threshold responses to disturbance, such as canopy cover and the human disturbance index, across the different sage-grouse Management Zones, indicating that a one-size-fits-all approach to setting thresholds is seldom appropriate (Doherty et al. 2016). These authors (Doherty et al. 2016, p. 23) stated that "when potential for conflict is high and thresholds are extrapolated into novel landscapes, clearly defined adaptive management goals and monitoring systems would be prudent." This recommendation highlights the tension between using research conducted in small parts of the sagebrush biome and the extrapolation of those results to new areas to justify the claim of treatment effectiveness in other parts of the area. This emphasizes the need to have monitoring systems in place to understand whether the results are applicable in the ecological context of the system in which the treatments are occurring. Information on resilience and resistance has provided the means for developing appropriate management strategies based on the likely response of ecosystems to both disturbance and management actions. Monitoring ecosystem threats and land use and development threats at the same time will aid in determining the effectiveness of on-the-ground conservation actions, understanding the reasons for changes in the landscape, and designing more effective management strategies.

Linking Efforts to Identify GRSG Population and Habitat Thresholds

Certain population response thresholds have been defined for managing GRSG habitat within State and Federal plans and in the scientific literature (Doherty et al. 2016; Knick et al 2013; Manier et al. 2014). Disturbance data collected at the project scale can be aggregated within habitat management designations across a landscape. These data can be used to determine whether adaptive management triggers associated with thresholds (such as disturbance caps and limitations of disturbance density specified in the Federal LUPs, and some State plans) have been met or exceeded that prompt actions or decisions by the appropriate agencies responsible for land management. By building on the GRSG Monitoring Framework (IGSDMS 2014) and the Sage-Grouse Habitat Assessment Framework (Stiver et al. 2015), adaptive management triggers tied to population levels or GRSG habitat, or both, have been developed for each LUP. For GRSG, individual and population responses to road densities, oil and gas densities, and other factors (Knick and Hanser 2011; Knick et al. 2013; Manier et al. 2014) are available and can be assessed to gain a better understanding of habitat and GRSG population conditions relative to these specified thresholds as well as offer a more of the landscape-level perspective.

Establishing a robust monitoring program or strategy that informs clearly defined management objectives is paramount to a meaningful adaptive management process. Monitoring the outcomes of management actions allows land managers and resource specialists to gain the necessary knowledge and information to locate treatments and projects in areas where they are more likely to be effective. Monitoring outcomes is essential for understanding the effectiveness of management actions in sustaining sagebrush ecosystems over time. In the aggregate, these efforts can improve resilience and resistance across the sagebrush biome and increase the return on conservation investments.

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3. CLIMATE ADAPTATION

Jeanne C. Chambers, Louisa Evers, and Linda A. Joyce

Introduction

Management actions that enable adaptation to climate change and promote resilience to disturbance are becoming increasingly important in the sagebrush biome. In recent decades temperatures have increased, growing seasons have lengthened, and in many areas the timing and amount of precipitation has changed (Chambers et al. 2017 [hereafter, Part 1], section 4; Kunkel et al. 2013a,b,c). Global climate change models are used to project future changes in temperature and precipitation based on relative concentration pathways of likely emissions of carbon dioxide ($CO_{2)}$ and other trace gases and information on the Earth's surfaces and oceans. These models project continued temperature increases and additional changes in precipitation throughout the remainder of the century, although the magnitude and rate of change differ based on the relative concentration pathway used (Part 1, section 4; Kunkel et al. 2013a,b,c).

Continued changes in climate are likely to influence the distributions of native species (Bradley 2010; Homer et al. 2015; Schlaepfer et al. 2012c; Still and Richardson 2015), invasive annual grasses (Bradley et al. 2016), fire regimes (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014), and insects and disease (Bentz et al. 2016). Snowpacks are declining in many areas (Mote and Sharp 2016), droughts are becoming more severe (Cook et al. 2015; Prein et al. 2016), and the length of the fire season and duration of extreme fire weather is increasing (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014; but see also McKenzie and Littell 2017). Reducing ecosystem vulnerability, or the degree to which a system is susceptible to the adverse effects of climate change, including climate variability and extremes (IPCC 2014), will require scientific guidance and agency direction to enable climate adaptation planning and implementation across scales.

Climate adaptation, the process of adjusting to actual or expected changes in climate, is an important consideration when developing management strategies in the face of climate change. The focus of climate adaptation is to moderate or avoid harm or to exploit beneficial opportunities (IPCC 2014). Adaptation can be **incremental**, where the objective is to maintain the integrity of a system or process at a given scale. Climate scientists anticipate that climate will continue to change throughout the 21st century due to continued accumulation of greenhouse gases in the atmosphere. As the climate warms, ecosystems may not persist in their current locations. Thus, adaptation can also be **transformational**, where actions focus on changing the fundamental attributes of a system in response to climate and its effects (IPCC 2014). Mitigation of climate change is another approach to managing climate change that is based on reducing the sources or enhancing the storage of greenhouse gases (IPCC 2014). This section focuses on incremental and transformational adaptation actions that can enhance the resilience of sagebrush systems. It also reviews the available information on the effects of management actions on carbon storage.

Top: Road to Nixon, Nevada, sunrise (photo by Nolan Preece, used with permission). Middle right: Dr. Matt Germino illustrating a weather station on the Soda Fire in SE Idaho (photo: U.S. Geological Survey). Middle left: A common garden study for assessing the importance of local adaptation in sagebrush (photo: USDA Forest Service). Bottom: Planting sagebrush seedlings after a wildfire (photo: USDA Forest Service). Bottom inset. Sagebrush transplant (photo: Stacy Moore, Institute for Applied Ecology).

Climate Adaptation and Resilience Management

Concepts

Managing natural resources within the context of climate adaptation is consistent with the approach described in Part 1 of the Science Framework, but requires the necessary flexibility to modify management actions as environmental conditions change. Widely used concepts for addressing adaptation in use by the Fish and Wildlife Service (FWS) (USDOI FWS 2010), the Forest Service (USDA FS 2011), and their partners focus on climate resistance, resilience, response, and realignment strategies (Halofsky et al. 2018a,b). Resistance strategies aim to increase the capacity of ecosystems to retain their fundamental structure, processes, and functioning despite climate-related stressors such as drought, wildfire, insects, and disease. These types of strategies may offer only short-term solutions, but often describe the intensive and localized management of rare and isolated species (Heller and Zavaleta 2009). Strategies to increase ecosystem resilience aim to minimize the severity of climate change impacts by reducing vulnerability and increasing the capacity of ecosystem elements to adapt to climate change and its effects. Response strategies seek to facilitate large-scale ecological transitions in response to changing environmental conditions and may include realignment or the use restoration practices to ensure persistence of ecosystem processes and functions in a changing climate.

These concepts of climate resistance, resilience, and response apply to many management and land ownership contexts and can be used to help determine appropriate climate adaptation strategies. Using these concepts to manage for changes in climate involves examining whether current assumptions about the effects of weather and climate on environmental responses and underlying assumptions about the expected result of management actions are still viable in a changing environment. Examples are ecological site descriptions and state-and-transition models in which the reference state often serves as the management target (fig. 3.1) (Bestelmeyer et al. 2009; Briske et al. 2005; Caudle et al. 2013). While managers can use historical data to help understand ecosystem response to environmental changes (e.g., Swetnam et al. 1999), it is important to recognize that the relationship between climate and ecosystem response will shift over time with continued warming. Consequently, managing for historical conditions may not maintain ecological sustainability (goods and services, values, biological diversity) into the future and management actions should be planned accordingly (Hobbs et al. 2009; Millar et al. 2007).

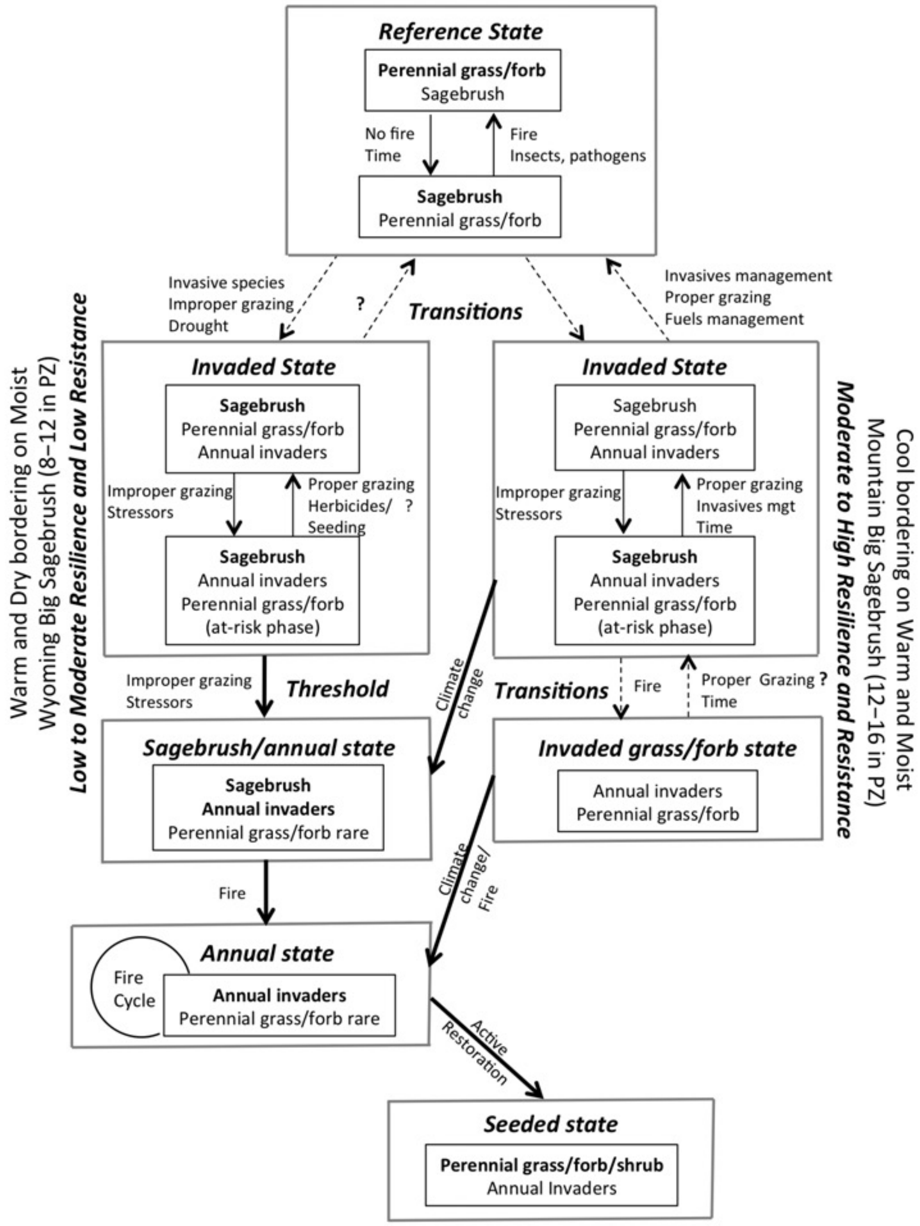

Figure 3.1—Generalized conceptual model showing the states, transitions, and thresholds for relatively warm and dry Wyoming big sagebrush ecosystems with low to moderate resilience and low resistance to cheatgrass and cool and moist mountain big sagebrush ecosystems with moderate resilience and resistance in the Cold Deserts (Chambers et al. 2017, Appendix 6). Reference state: Vegetation dynamics are similar for both types. Perennial grass/forb increases due to disturbances that decrease sagebrush, and sagebrush increases with time after disturbance. Invaded state: An invasive seed source, improper grazing, stressors such as drought, or a combination thereof, trigger a transition to an invaded state. Perennial grass/forb decreases, and both sagebrush and invaders increase with improper grazing and stressors, resulting in an at-risk phase in both types. Proper grazing, invasive species management, and fuel treatments may restore perennial grass and decrease invaders in relatively cool and moist Wyoming big sage and in mountain big sage types with adequate grass/forb, but return to the reference state is likely only for mountain big sage types. Sagebrush/annual state: In the Wyoming big sagebrush type, improper grazing and stressors trigger a threshold to sagebrush/annual dominance. Annual state: Fire, disturbances, or management treatments that remove sagebrush result in dominance of annuals. Perennial grass is rare, and repeated fire causes further degradation. Seeded state: Active restoration results in dominance of perennial grass/forb/shrub. Treatment effectiveness and return to the annual state are related to site conditions, posttreatment weather, and seeding mixture. Invaded grass/forb state: In the mountain big sagebrush type, fire results in a transition to annual invaders and perennial grass/forb. Proper grazing and time may result in return to the invaded state given adequate perennial grass/forb. Increases in climate suitability for cheatgrass and other annual invaders may shift vegetation dynamics of cooler and moister mountain big sagebrush ecosystems toward those of warmer and drier Wyoming big sagebrush ecosystems. Although not shown here, woodland expansion and infill in mountain big sagebrush sites with conifer potential can result in transition to woodland-dominated or eroded states, leading to crossing of biotic and abiotic thresholds (adapted from Chambers et al. 2014b).

Climate Adaptation Strategies

Due to uncertainty about exactly what the future will look like, planning for multiple possibilities and using adaptive management principles is essential. Adaptive management uses the best available information for helping ecosystems and the plant and animal species they support to adapt to inevitable changes in climate (Millar et al. 2007). Climate adaptation strategies for the sagebrush biome are in table 3.1. The specific approaches for sagebrush ecosystems build on the sage-grouse habitat resilience and resistance matrix (table 1.3) and the sagebrush ecosystem management strategies (table 1.4).

Climate adaptation strategies incorporate multiple scales and focus on preventing the loss of ecosystem services by maintaining and enhancing ecosystem processes, functional attributes, and feedbacks (table 3.1). For example, the extent and connectivity of intact sagebrush ecosystems provide a buffer that facilitates species adaptation and movement in response to climate change as well as to the increasing effects of human development and land use (e.g., Knick et al. 2011, 2013; Millar et al. 2007). Maintaining intact and connected sagebrush ecosystems is based on developing public land use plans (LUPs) and policies that reduce the impact of existing ecological, land use, and development stressors on these ecosystems at broad (sagebrush biome and multiple Management Zones) to mid- (Greater sage-grouse [*Centrocercus urophasianus*; hereafter, GRSG] Management Zone and ecoregion) scales. It also involves strategic placement of conservation easements to prevent conversion to tillage agriculture and anthropogenic developments and to maintain existing connectivity at mid- to local (district, field office, or project level) scales.

Many climate adaptation strategies work together to accrue multiple ecosystem benefits. Maintaining or enhancing key plant structural and functional groups is central to most climate adaptation strategies. Certain plant structural and functional groups are critical for stabilizing hydrologic and geomorphic processes, promoting desired successional processes, and lowering risk of conversion to invasive annual grasses following disturbances that remove native vegetation (Pyke 2011). Postfire rehabilitation and restoration activities can increase ecosystem capacity to absorb change by using functionally diverse species mixtures and including plant materials from across a greater geographic range that considers current climate and near-future climate (next 20 to 30 years) (table 3.1) (Butler et al. 2012; Finch et al. 2016). Favoring existing genotypes that are better adapted to future conditions because of broad tolerances to disturbances, drought adaptations, pest resistance, or other characteristics can also increase adaptive capacity (table 3.1) (Butler et al. 2012; Finch et al. 2016). Where shown to be successful, assisted migration, or the purposeful movement of individuals or propagules of a species to facilitate or mimic natural range expansion or long-distance gene flow within the current range, may facilitate community adjustments (Buchorava 2017). Implementing these strategies requires developing the necessary research and management capacity to forecast changes in ecological conditions and species distributions and to better understand ecosystem and species response to changes in climate at mid- to local scales.

Table 3.1–Climate change adaptation strategies for the sagebrush biome. General strategies are based on Millar et al. (2007, 2012) and Butler et al. (2012). Specific approaches for sagebrush ecosystems build on the sage-grouse habitat, resilience and resistance matrix (table 1.3) and management strategies for persistent ecosystem threats and land use and development threats (table 1.4). Resistance = R1; Resilience = R2; Response = R3.

Sustain fundamental ecological conditions (R1, R2, R3)

- Maintain or restore soil quality and nutrient cycling by reevaluating the timing and intensity of land use practices such as livestock grazing
- Maintain or restore hydrologic and geomorphic processes following stress and disturbance

Reduce the impact of existing ecological, land use, and development stressors (R1, R2, R3)

- Develop appropriate policies, land use plans, and project plans to protect sagebrush habitat and prevent fragmentation
- Secure conservation easements to prevent conversion to tillage agriculture, housing developments, and other land conversions, and maintain existing connectivity

Promote landscape connectivity (R2, R3)

- Reduce juniper and piñon expansion to maintain connectivity among sage-grouse and sagebrush dependent species populations and facilitate seasonal movements
- Suppress fires that occur under more severe burning conditions in targeted areas where altered fuel beds facilitate large and severe fires, increase landscape fragmentation, and impede dispersal, establishment, and persistence of native plants and animals
- Manage landscapes to create or enhance permeability and increase the ability of sagebrush dependent species to move between individual Priority Areas for Conservation or Biologically Significant Units

Maintain or create refugia (R1)

- Identify and maintain ecosystems that: (1) are on sites that may be better buffered against climate change and short-term disturbances, and (2) contain communities and species that are at risk across the greater landscape
- Prioritize and protect existing populations on unique sites
- Prioritize and protect sensitive or at-risk species or communities
- Establish artificial reserves for at-risk and displaced species

Reduce the risk of wildfires that result in abrupt transitions to novel states (R1, R2)

- Reduce fuel loads and fuel continuity to (1) decrease fire size, alter burn patterns, decrease perennial grass mortality, and maintain landscape connectivity; (2) decrease competitive suppression of native perennial grasses and forbs by woody species, including sagebrush; and thus (3) lower the longer-term risk of dominance by invasive annual grasses and other invaders
- Use mechanical treatments (e.g., cutting, mastication) to reduce woody fuels in juniper and piñon expansion areas with moderate to high resilience that have little or no presence of invasive annual grasses and sufficient perennial grasses and forbs to promote recovery
- Use prescribed fire to create fuel mosaics and promote successional processes in sagebrush and juniper and piñon expansion areas with moderate to high resilience that have little or no presence of invasive annual grasses and sufficient perennial grasses and forbs to promote recovery
- Use herbicide applications and appropriately timed livestock grazing to reduce cheatgrass fuels in sagebrush ecosystems where they have potential to increase perennial grasses and forbs
- Suppress wildfires in moderate and especially low resilience and resistance sagebrush-dominated areas to prevent conversion to invasive annual grass states and thus maintain ecosystem connectivity, ecological processes, and ecosystem services
- Suppress wildfires adjacent to or within recently restored ecosystems to promote recovery and increase capacity to absorb future change
- Use fuel breaks in carefully targeted locations along existing roads where they can aid fire suppression efforts and have minimal effects on ecosystem processes (Maestas et al. 2016)

Reduce the risk of nonnative invasive plant species introduction, establishment, and spread (R1, R2, R3)

- Limit anthropogenic activities that facilitate invasion processes including surface disturbances, altered nutrient dynamics, and invasion corridors
- Use Early Detection and Rapid Response (USDOI 2016) for emerging invasive species of concern to prevent invasion and spread
- Manage livestock grazing to promote native perennial grasses and forbs that compete effectively with invasive plants
- Actively manage invasive plant infestations using integrated management approaches such as chemical treatment of invasives and seeding of native perennials from climatically appropriate seed sources

(Continued)

Table 3.1—(Continued).

Maintain or enhance key structural and functional groups (R1, R2, R3) • Manage grazing by livestock and wild horse and burro populations to maintain soil and hydrologic functioning and capacity of native perennial herbaceous species, especially perennial grasses, to effectively compete with invasive plant species • Manage grazing by livestock and wild horse and burro populations to maintain riparian-wetland functioning, streambank and floodplain stability, and vegetation sufficient to dissipate flood energy, promote infiltration, minimize erosion, and compete with invasive plant species • Reduce conifer expansion to prevent high severity fires and maintain native perennial herbaceous species that can stabilize geomorphic and hydrologic processes and minimize invasions • Restore disturbed areas with functionally diverse mixtures of native perennial herbaceous species and shrubs with climatically appropriate seed sources and with capacity to persist and stabilize ecosystem processes under altered disturbance regimes and in a warming environment
Enhance genetic diversity (R2, R3) • Use seeds, germplasm, and other genetic material from across a greater geographic range based on current climate and near-future (next ~20–30 years) climate considerations • Favor existing genotypes that are better adapted to future conditions because of pest resistance, broad tolerances, or other characteristics • Increase diversity of nursery stock to provide those species or genotypes likely to succeed
Facilitate community adjustments through species transitions (R3) • Monitor both native and invasive species at range margins to provide advanced warning of range shifts • Investigate assisted migration options—the purposeful movement of individuals or propagules of a species to facilitate or mimic natural range expansion or long-distance gene flow within the current range—in areas with high rates of climate change
Plan for and respond to disturbance (R3) • Practice drought adaptation measures, such as altered grazing seasons or reduced grazing during droughts, and implement conservation actions to facilitate species persistence • Identify current and potential future areas where snowpack cover and duration are declining in order to manage to reduce other current stressors • Anticipate and respond to species declines such as may occur on the southern or warmer edges of their geographic range by including plant materials from neighboring climate types in seed and planting mixes • Leverage topographic features (landforms) that retain soil moisture longer for restoration activities (Bainbridge 2007) • Favor or restore native species that are expected to be better adapted to the future range of climatic and site conditions • Protect future-adapted restoration and reclamation seedings from inappropriate livestock grazing and wild horse and burro populations • Avoid seeding introduced forage species such as crested wheatgrass that outcompete native species (Davies et al. 2013; Lesica and Deluca 1996)

Management and research studies coupled with landscape monitoring can provide the basis for developing cost-effective and feasible management strategies for adapting to climate change. Carefully designed management and research studies implemented in the near future may increase our understanding of viable approaches for adaptation measures, such as appropriate grazing regimes for drought conditions, conservation actions to facilitate species persistence during climate warming, seeding and transplanting techniques during drought, and identification of species and ecotypes that can be used successfully in assisted migration. Monitoring to detect the rates and magnitudes of change occurring within the context of adaptive management can identify both populations and habitats that are declining (Carwardine et al. 2011; Field et al. 2004), as well as new or novel combinations of species that constitute a functioning ecosystem under climate change. Increased understanding of both the changes occurring and viable strategies for addressing those changes may reduce uncertainty and provide direction for adaptive management strategies (Hobbs et al. 2009).

A participatory scenario planning process may be one approach to help identify relevant adaptation strategies in the context of adaptive management (Cross et al. 2013; Star et al. 2016; USDA FS 2012; USDOI NPS 2013). Participants can use climate change projections and associated natural resource models to depict both the amount of change and the degree of uncertainty (Star et al. 2016). Decisionmakers, stakeholders, and experts can work together to identify the most relevant and uncertain drivers of system change, which often include sociopolitical and socioeconomic factors. They can then develop a shared understanding of future climate scenarios that is likely to lead to broader support for suggested adaptation strategies (Star et al. 2016). To date, scenario planning has been more commonly used in nongovernmental organizations and local government planning.

Prioritizing Management Actions and Determining Appropriate Management Strategies

Assessing ongoing and projected climate change using the best available data is integral to evaluating priority areas for management at mid-scales and determining appropriate management treatments at local scales. In the context of the Science Framework, the effects of changes in climate on species and ecosystems can be addressed similarly to other persistent ecosystem threats such as wildfire and invasive annual grasses (see Part 1, section 8; table 3.1, this volume). For GRSG and other at-risk species and resources, the process involves overlaying key data layers in a geospatial analysis to both visualize and quantify: (1) species locations and abundances, (2) the probability that an area has suitable habitat, (3) the likely response to disturbance or management treatments, and (4) the dominant threats including projected climate change.

Geospatial analyses with overlays of key data layers can: (1) help evaluate the level of risk to vegetation types and species to climate change, (2) target areas for adaptive management, and (3) determine the most appropriate types of management actions. Key data layers include projected changes in climate variables (Part 1, section 8). Land managers can use these layers to assess the rate and magnitude of change projected for the assessment area. Other important layers are projections for changes in individual plant species (e.g., Bradley et al. 2016; Homer et al. 2015; Still and Richardson 2015) and vegetation types (e.g., Rehfeldt et al. 2012; Schlaepfer et al. 2012c) under different climate change scenarios. In addition, climate change vulnerability analyses of key ecological and socioeconomic resources (water, fisheries, vegetation and disturbance, wildlife, recreation, infrastructure, cultural heritage, and ecosystem services) are available for the Intermountain Region (Halofsky et al. 2018b) and Northern Rocky Mountain Region (Halofsky et al. 2018a). Additional websites and resources for climate change are in Appendix 2.

Climate change projections can be factored into prioritizing areas for management within assessment areas (Part 1, section 8) by considering the following factors.

- Continued changes in climate (i.e., increases in temperature and shifts in precipitation timing and amount) and the associated effects are expected to be relatively small within the next decade or two. Areas can be prioritized for management that provide suitable habitat and support species populations at mid-scales, and management practices can be adapted to build resilience to changes in climate into sagebrush ecosystems at local scales (table 3.1). Monitoring can provide critical information on changes

in species and ecosystems resulting from climate changes that allows managers to take advantage of opportunities to facilitate transitions to systems that will be better adapted in the long term.
- Changes in climate and the interactions of these changes with other threats are already documented and are expected to be large (e.g., rapid warming events, uncertainty of snowpack, extreme drought) in the next few decades (table 3.1). The impacts of changes in climate on plant community composition and vegetation types will be most evident following major disturbances, such as wildfires, that occur at an ecotone between different vegetation types or on warmer, drier sites. In this case, more proactive adaptation strategies may be necessary to facilitate community adjustments and species persistence. These may include favoring or restoring native species that have been shown to be better adapted to the future range of climatic and site conditions and to have acceptable effects on biotic interactions and ecosystem process (Bucharova 2017). The use of assisted migration to address changes in climate suitability will require additional research and management guidelines to evaluate the potential positive as well as negative effects of purposeful species movements (Bucharova 2017).

Key Topics in Climate Adaptation

Across much of the sagebrush biome, climate change is resulting in a warmer and drier environment (Kunkel et al. 2013a,b,c). In turn, the warmer, drier conditions are resulting in increasing magnitude and frequency of droughts (Cook et al. 2015; Prein et al. 2016), increasing dust in the atmosphere (Livneh et al. 2015; Painter et al. 2012; Steltzer et al. 2009), and in most areas, decreasing snowpacks (Mote and Sharp 2016). Several studies indicate that the length of the fire season and duration of extreme fire weather also are increasing (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014). These changes are projected to have significant effects on ecosystem processes, species distributions, and community composition (e.g., Blumenthal et al. 2016; Schlaepfer et al. 2012c). Changing climate conditions can also influence the abundance and spread of insects and diseases and increase the stress levels of host species, making them more susceptible to the effects of insects and diseases and causing higher mortality (IPCC 2014). Developing an understanding of the changes that are occurring is essential for evaluating the effects of ongoing management actions and determining effective adaptation strategies (text box 3.1).

Drought

From a meteorological perspective drought is defined as the accumulated imbalance between the supply of water and the demand for water by plants, animals, the atmosphere, the soil column, and humans (Kunkel et al. 2013a,b). Drought can also be defined from other perspectives including hydrologic (e.g., streamflow), agricultural (e.g., ecosystem productivity), or socioeconomic (Luce et al. 2016). Determining whether a drought is occurring can take a relatively longer time for areas where the effects of drought may accumulate slowly, such as forests and sagebrush ecosystems. Ecological indicators of drought exist for rangelands and can be listed sequentially: Water shortages stress plants and animals, vegetation production is reduced, plant mortality increases, plant cover is reduced, amount of bare ground increases, soil erosion becomes more

Text Box 3.1—Monitoring Climate Change Effects

Long-term monitoring results can be used to track changes in species and ecosystems induced by the effects of climate change. At the biome to mid-scale, remote sensing can be used to detect changes in environmental conditions, such as the duration of snowpacks and seasonal soil moisture availability, and the effects on ecosystems, such as changes in plant phenology and productivity. Remote sensing can also be used to monitor changes in persistent ecosystem threats, such as plant invasions and wildfire patterns. Information on the rates and direction of change across the sagebrush biome can be used to prioritize resource allocation for management of invasive species, wildfire and vegetation, and wild horses and burros. It can also be used to determine where to target adaptation strategies to maintain landscape connectivity, ecosystem redundancy, and refugia.

Combining ground-based monitoring with remote sensing can help scale-up results to assess which species and ecosystems may be most vulnerable to climate change. Focusing monitoring efforts on climate transition zones and areas projected to exhibit rapid change (e.g., rapid warming events, loss of snowpack, extreme drought) can provide much needed information on climate change effects. Information on these changes can be used to identify effective adaptation strategies, such as maintaining or enhancing key structural and functional groups, increasing genetic diversity, facilitating community adjustments through species transitions, and planning for and responding to disturbance. Monitoring following changes in management or after treatments can be used to verify the effectiveness of management strategies designed to help ecosystems transition to the new climatic conditions.

prevalent, habitat and food resources for wildlife are reduced, wildlife mortality increases, rangeland fires may increase, some insect pests and invasive weeds may increase, forage value and livestock carrying capacity decrease, and then, economic depression in the agricultural sector sets in (Finch et al. 2016).

Drought adaptation measures with shorter-term and longer-term horizons have been identified for rangelands and forests across the western United States (see Briske et al. 2015; Finch et al. 2016; Joyce et al. 2013). Planning for a drought involves developing a drought management plan (UNL-NDMC 2012; examples available at http://drought.unl.edu/ranchplan/WriteaPlan.aspx). Management actions vary regionally and reflect the resources available to cope with drought. In general, the goal is to minimize the risk of environmental degradation and loss of ecosystem function. Planning for adaptation actions is most successful if coordinated across all land ownerships and if management plans consider the next drought as well as the current drought and its aftermath (Finch et al. 2016).

Current management actions may need to be reexamined with the onset of drought. For example, adaptation actions with respect to livestock management during the drought include: reducing stocking rate to allow plant recovery; using fencing and other developments to manage livestock distribution; using drought-resistant restoration species; using drought-adapted stock; adjusting season of use; implementing a deferred grazing system; developing, restoring, or reclaiming water sources; providing shade structures for livestock; reducing the time livestock graze a specific grazing unit; increasing the time between periods of grazing (rest); and testing new techniques for responding to drought.

With respect to restoration, climate and weather models are now available that can be used to help inform the timing of planting (Hardegree et al. 2012). Under certain conditions, it may be beneficial to delay planting and shift the focus to restoring areas with less desirable species. For example, implementing measures to control crested wheatgrass (*Agropyron cristatum*) during dry years and seeding native grass in wetter years may result in more effective restoration in the West-Central Semiarid Prairies (Bakker et al. 2003). To mitigate the longer-term impact of drought or other abiotic stressors, plant material selection should consider the adaptive capacity of different species and genetic variation within species (Richardson et al. 2012). Assisted migration can be considered for areas where high rates of climate change are expected and the likelihood of success has been evaluated (table 3.1). These decisions will be critical given the potential for increased frequency and duration of drought in the future.

Snowpack and Dust

Total snowfall has been declining precipitously in the West since the 1920s (Kunkel et al. 2009). Maximum seasonal snow depth declined from winter 1960–1961 to winter 2014–2015 across North America, and other studies showed declines in snow cover as well (Kunkel et al. 2016). A recent analysis of April snowpack data, which are used extensively for spring streamflow forecasting, indicated declines at more than 90 percent of the sites when measured from 1955 to 2016 (Mote and Sharp 2016). The average change across all sites amounted to about a 23-percent decline in snow water equivalent. These decreases were observed throughout the western United States, with the most prominent declines in Washington, Oregon, and the northern Rockies (Mote and Sharp 2016).

Decreases in snowpack may not affect overall patterns of soil water availability if precipitation that arrives during the cold season simply switches from snow to rain (Schlaepfer et al. 2012a). However, increases in soil temperature and associated decreases in soil water availability due to longer growing seasons and higher evapotranspiration may influence plant species establishment and survival and thus community composition (Palmquist et al. 2016a,b).

Drought, wildfire, and agricultural activities in the western United States contribute to dust in the atmosphere, which settles on snow-covered areas in the winter. Over the last decade, the number of dust-on-snow events increased in the Colorado Rocky Mountains (Painter et al. 2007; Toepfer et al. 2006). Dust-on-snow events reduce duration of snow cover (Painter et al. 2007), increase rate of snowmelt associated with more extreme dust deposition, and produce earlier peak stream flows of 1 to 3 weeks (Livneh et al. 2015; Painter et al. 2012; Steltzer et al. 2009). As a result of these dust-on-snow events, snow chemistry increases in pH, calcium content, and acid neutralizing capacity with more pronounced effects at upper elevations than lower elevation forested sites (Rhoades et al. 2010).

Effects of decreasing snowpack on sagebrush ecosystems will be widespread, but are likely to be most significant in areas with measurable changes in the amount and duration of snowpack. The most vulnerable areas are likely to be those that previously retained snow cover for all or most of the winter, or where winter snowpack was critical to recharge deep soil water. Adaptation strategies specific to these areas have not been developed (but see David 2013). However, identifying these areas and managing them to sustain ecological functions and reduce the impact of existing ecological, land use, and development stressors can facilitate adaptation (table 3.1). Monitoring these areas for changes in soil moisture and temperature and in species composition can provide information on (1) establishment and spread of nonnative invasive plant species and the need for intervention and (2) the need for community adjustments through species transitions.

Fire Regimes

Higher temperatures associated with climate change have been linked to increases in fire size and longer fire seasons and durations of extreme fire weather in forested ecosystems (Westerling et al. 2014). Although some have suggested that these relationships also exist for the western portion of the sagebrush biome, recent analyses of LANDFIRE data (1984–2014) for the Basin and Range, Snake River Plain, and Columbia Plateau ecoregions (fig. 1.1) fail to show significant changes in number of large fires per year, total fire area per year, or 90th percentile large fire size per year. However, these analyses do point toward increasing total fire area and 90th percentile fire size (Dennison et al. 2014). In addition, analyses of fire patterns in juniper and piñon land cover types show that the fire season started earlier and ended later in the Basin and Range ecoregions over the same 30-year study period (1984–2014) (Board et al. 2018).

Both temperature and amount and seasonality of precipitation influence fire regimes. In the Basin and Range, Snake River Plain, and Columbia Plateau ecoregions most precipitation arrives as winter snow and rain, and woody species, such as sagebrush, tend to dominate vegetation communities (Part 1, section 4). In these areas, most fires burn in July and August. Fire intensities are typically moderate to high and extreme fire weather can result in extensive fire spread (Brown 1982; Romme et al. 2009). In contrast, the Northwestern Plains and portions of the Wyoming Basin and Southern Rockies receive more summer precipitation and most fires burn earlier in the year. These areas have higher relative abundance of grasses and usually exhibit moderate fire spread (Brown 1982; Romme et al. 2009). Fire regimes are further influenced by fire season length, which varies from about 90 days per year in cooler and moister ecoregions to more than 135 days per year in warmer and drier ecoregions (Board et al. 2018). Changes in amount and seasonality of precipitation may cause shifts in relative abundances of woody species and grasses and thus live fuel moisture dynamics, which will affect fire behavior. Further increases in temperature without compensating increases in precipitation, especially during the growing season, will continue to cause greater aridity, longer fire seasons, and more extreme fire weather across much of the sagebrush biome (Dai 2013).

Changes in precipitation due to climate change may have very different effects than changes in temperature on the locations and characteristics of wildfires in sagebrush ecosystems, and these effects are likely to differ within and across ecoregions. The relationships between precipitation and fire exhibit high regional variability due to the heterogeneity of topography, climate, soils, vegetation, and land use (Littell et al. 2009; Pilliod et al. 2017). In general, warmer and drier areas characterized by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) at lower elevations have the potential for large fires to burn every summer, but are **fuel limited** and do not always have enough fuel to burn (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014). These areas often require 1 or more years with above-normal precipitation to create sufficient fuel for large wildfires (Crimmins and Comrie 2004; Littell et al. 2009; Pilliod et al. 2017; Westerling et al. 2014). At higher elevations, temperatures become cooler, precipitation usually increases, and ecosystems become increasingly **energy limited** in that they have enough fuel to support fires every summer, but may not be dry enough to burn (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014). Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and mountain shrub communities exhibit these characteristics. These areas often require warmer and drier conditions to decrease fuel moisture sufficiently for large wildfires to burn.

Invasive annual grasses are influencing both the areas burned and fire size through the invasive annual grass-fire cycle, primarily in relatively warm and dry areas, where most precipitation arrives in winter and spring (Balch et al.

2013; Pilliod et al. 2017). These grasses increase fine fuels and fuel continuity and thus fire frequency and extent (Balch et al. 2013; Brooks et al. 2004). A 1- to 3-year lag effect of precipitation on both area burned and number of fires in landscapes dominated by cheatgrass (*Bromus tectorum*) is typical (Pilliod et al. 2017). Changes in fire regimes due to invasive annual grasses are most evident in the Snake River Plain and Northern Great Basin (Balch et al. 2013; Pilliod et al. 2017), but these species are projected to expand northward and upwards in elevation with climate warming (Bradley et al. 2016) and are increasing in the eastern portion of the range (Knight et al. 2014; Lauenroth et al. 2014).

Wildfire and vegetation management plays a key role in enhancing resilience to disturbance and resistance to invasive annual grasses in the face of climate change (tables 1.3, 1.4). Primary objectives are to reduce ecosystem vulnerability, increase the capacity of ecosystems to adapt to climate change and its effects, and facilitate species and plant community transitions in response to changing environmental conditions. This entails: (1) reducing fuel loads and continuity to decrease fire severity or extent, or both; (2) lowering competitive suppression of perennial herbaceous species, which largely determine resilience to wildfire and resistance to invasion; and (3) using postfire revegetation to design vegetation communities that maintain higher live fuel moisture and have lower fuel bed continuity and packing ratios (a measure of fuel bed compactness or the fraction of fuel bed volume that is occupied by fuel).

Fuel management to reduce fuel loads and continuity focuses on areas with increased woody fuels (sagebrush or juniper [*Juniperus* spp.] and piñon [*Pinus* spp.]) or fine fuels (grasses and forbs), or both. Woody fuel loading and fine fuel loading interact with fire weather to influence the propensity for wildfires, and decreases in fuel loads can lower the likelihood of wildfires over a range of fire weather conditions (fig. 3.2). A variety of treatments exist to reduce woody fuels, including sagebrush mowing; juniper and piñon cutting, shredding, and mastication; and prescribed fire (table 1.4 and section 4). Similarly, treatments exist to reduce fine fuels, such as herbicide applications and appropriately timed livestock grazing in areas dominated by cheatgrass (Strand et al. 2014; table 1.4 and section 5, this volume). The use of fuel breaks in carefully targeted locations can aid fire suppression efforts (Maestas et al. 2016). For treatments to maintain or increase resilience to wildfire as the climate changes, it is necessary to ensure that sufficient perennial herbaceous species exist before treatment to promote ecosystem recovery and that treatments do not introduce or lower resistance to invasive plants (Chambers et al. 2014a,b). Use of traditional phenological knowledge from Native Americans regarding the appropriate timing of treatments, including use of prescribed fire, shows promise for achieving desired conditions (Armatas et al. 2016; Huffman 2013).

Managing for fuel beds with high temporal and spatial variability could increase resilience to wildfire (Abatzoglou and Kolden 2013; Kay 1995; Littell et al. 2009). This could include treatments that increase sagebrush patch size and variability in gap size (the distances between shrubs and grasses) (Kay 1995). Patch burning to increase vegetation heterogeneity is increasingly used in the U.S. Great Plains, southern Africa, and Australia (e.g., Bird et al. 2013; Brockett et al. 2001; Fuhlendorf et al. 2017; Ricketts and Sandercock 2016; Voleti et al. 2014). It may be possible to create fuel bed heterogeneity in sagebrush ecosystems by conducting patch-scale burns in early spring or late fall to remove conifers and shrubs in ecosystems with moderate to high resilience (e.g., Davies et al. 2008; Pyle and Crawford 1996; Trauernicht et al. 2015).

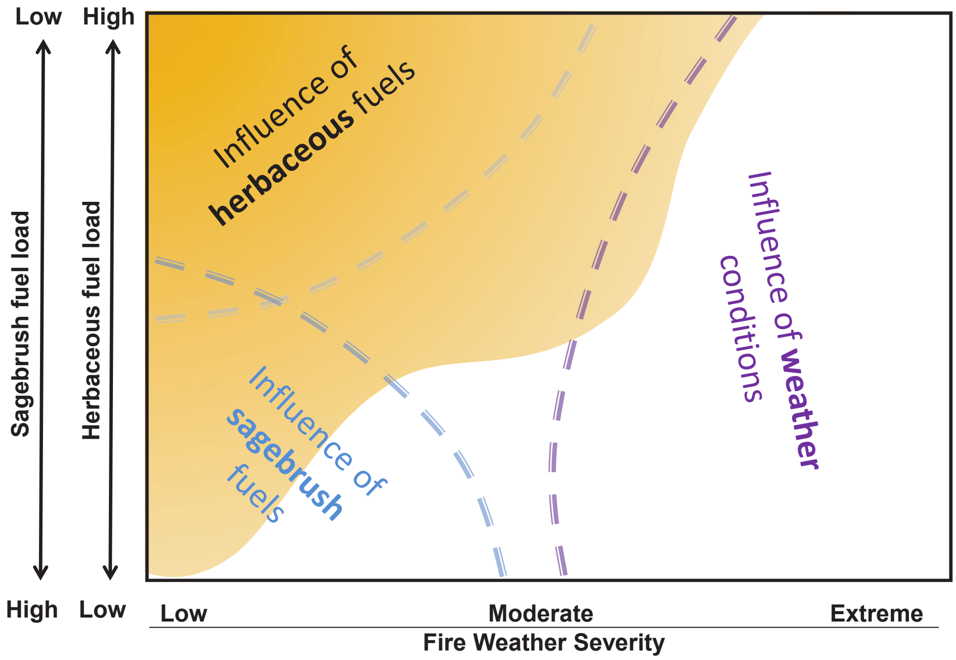

Figure 3.2—The interaction of herbaceous and sagebrush fuels with fire weather severity. In this conceptual model, fuel composition is displayed on the y-axis and fire weather condition is displayed on the x-axis. Low fire weather severity is characterized by high fuel moistures, high relative humidity, low temperature, and low wind speeds, while extreme fire weather is characterized by the opposite conditions. As woody fuel loading or fine fuel loading, or both, increases, fuel packing ratios become more optimal, fuel continuity increases, and less severe fire weather is required for large wildfires. Annual grasses fill interspaces between native fuels (shrubs and bunchgrasses) and are particularly problematic. However, progressive increases in sagebrush or juniper and piñon stand density also lower the severity of fire weather required for large wildfires. Reductions in fuel loads can decrease the likelihood of large wildfires over a range of fire weather conditions. However, extreme fire weather conditions, which are projected to increase in the future, can override the influence of fuel loads and continuity (figure modified from Strand et al. 2014).

Post-wildfire revegetation provides an opportunity to establish vegetation communities with high fuel bed heterogeneity that may be more resilient to wildfire. Resilience to wildfire could be increased by restoring or maintaining plant communities that maintain higher live fuel moisture during dry periods or drought through differences in the relative proportions of herbaceous vegetation to shrubs, varying phenologies and water use patterns, and differences in the cure rate of grasses and forbs (Kay 1995; Palmquist et al. 2016a,b; Schlaepfer et al. 2012b). Also, fuel bed continuity and packing ratio could be decreased by seeding native plant species with growth forms and structures (e.g., size of stems, distance between stems) that are not conducive to carrying fire, even when cured. Most native forbs and some rhizomatous grasses, such as western wheatgrass (*Pascopyrum smithii*), have these properties.

Monitoring the responses of sagebrush ecosystems to wildfire as the climate changes can help inform adaptive management strategies (text box 3.1). At broad scales monitoring changes in wildfire patterns in relation to habitats of species at risk and other resource values can help prioritize resource allocation for preparedness, prevention, suppression, and postfire rehabilitation. At mid- to local scales, information on changes in wildfire area burned and size for specific ecological types or ecological sites that characterize ecoregions provides the basis for adjusting preparedness, prevention, and suppression management strategies over time (section 4). Large changes in species composition and decreased resistance to invasive plants, particularly invasive annual grasses, indicate decreased resilience to wildfire and the need to modify postwildfire rehabilitation strategies.

Changes in Species Distributions and Community Composition

The changes in precipitation and temperature regimes occurring as a result of climate warming are projected to have large consequences for species distributions and, because individual species differ in their climatic requirements, for community composition (Part 1, section 5.2). The distribution of species such as big sagebrush is projected to move to the north and upward in elevation (Bradley 2010; Homer et al. 2015; Schlaepfer et al. 2012c; Still and Richardson 2015). For juniper and piñon species, habitat with suitable climate is projected to move north and upslope with principal gains in Colorado and southwest Wyoming and losses in the Southwest (Rehfeldt et al. 2006, 2012). Cheatgrass is likely to spread upward in elevation while red brome (*Bromus rubens*) moves northward or increases its abundance in the Cold Deserts and Colorado Plateau, or both (Bradley et al. 2016). Decreases in average summer precipitation or prolonged summer droughts could enable cheatgrass invasion into sagebrush ecosystems that are currently more resistant to invasion and resilient to fire disturbance (Bradley et al. 2016; Mealor et al. 2013), such as the northern mixed-grass prairie, allowing it to more successfully colonize what is currently considered a largely invasion-resistant grassland (Blumenthal et al. 2016).

Climate adaptation strategies for the sagebrush biome are designed to facilitate adaptation of species and communities to a warming climate and to reduce the risk of nonnative invasive plant species introduction, establishment, and spread. An understanding of the rates and magnitude of projected change (see Part 1, Appendix 3) can help managers to prioritize areas for different types of management actions (table 3.1). Areas that are likely to support big sagebrush ecosystems in the future may be good candidates for proactive weed and fire management. Areas that may become more suitable for big sagebrush over time may be candidates for assisted migration during restoration activities. Areas that are unlikely to support big sagebrush ecosystems in the future require careful evaluation to determine the types of ecosystems they are likely to support and whether they merit investment in conservation and restoration resources. Careful assessment of connectivity requirements for sagebrush-dependent species to survive and persist as the climate changes can help inform decisions about where to place limited conservation and restoration resources (Part 1, Appendix 9).

Successful adaptation will include monitoring along climate transition zones to detect changes in both soil temperature and moisture regimes and species composition. Consideration of scale will ensure that planning at broad scales promotes strategies such as landscape connectivity, ecosystem redundancy, and refugia, and that planning at more local scales promotes strategies such as maintaining or enhancing key structural and functional groups, increasing genetic diversity, facilitating community adjustments through species transitions, and planning for and responding to disturbance.

Insects and Disease

Major insect pests and diseases affecting plant and sagebrush dependent wildlife species are poorly identified and studied in sagebrush ecosystems. For example, Aroga moth (*Aroga websteri*), or sagebrush defoliator, is a native moth that experiences periodic outbreaks over large areas affecting sagebrush and sage-grouse habitat quality and quantity. West Nile virus (*Flavivirus* spp.) is a recently established disease in the western hemisphere with potential to greatly reduce many avian species populations such as GRSG.

Outbreaks of the native Aroga moth can damage and kill sagebrush over local to mid-scales, although the only documented outbreaks to date have been in the Cold Deserts in the western part of the sagebrush biome. Anecdotal evidence from the northern Great Basin indicates that Aroga moth outbreaks can be associated with years that have much larger than average fires (Tony Svejcar, retired Rangeland Scientist and Research Leader, Burns, OR, personal communication, 2012). Outbreaks are associated with warm conditions from mid-May through mid-June, during the first and second instar development, followed by high precipitation in June and July, during the fourth and fifth instar development (Bolshakova 2013; Bolshakova and Evans 2016). Peak larval abundance occurs around 239 degree-days (accumulated since January 1 using a base temperature of 5 °C [41 °F]), so managers can track degree-days and monitor larval populations to determine when an outbreak is possible (Bolshakova and Evans 2016). How changes in climate may alter the likelihood of such outbreaks is unclear. Outbreaks may occur at the same frequency but earlier in the year as conditions warm, or the frequency may decline due to the combination of warming temperatures and changes in precipitation timing.

Higher moth survival and abundance are also associated with northerly aspects at mid-elevation, suggesting that sagebrush canopy cover may play an as-yet poorly understood role in outbreaks (Bolshakova and Evans 2014). These sites typically experience lower daily and annual temperature fluctuation, greater snow accumulation, and slower snowmelt, thereby creating more favorable conditions for moth larvae and adults (Bolshakova and Evans 2014). More homogeneous stands of sagebrush may serve as epicenters for outbreaks (Bolshakova 2013; Bolshakova and Evans 2014), suggesting that enhancing heterogeneity of sagebrush cover may limit the size and impact of future outbreaks.

Sage-grouse mortality from West Nile virus typically occurs between mid-May and mid-September with peak mortality in July and August (Walker and Naugle 2011), which are also the warmest and driest months. Sage-grouse frequently use ponds, springs, and other standing water sources during hot weather, which are the same sites used by *Culex tarsalis*, the primary mosquito species that transmits West Nile virus to birds (Schrag et al. 2010; Walker and Naugle 2011). Increasing storm intensity that results in more runoff than infiltration, and the potential need to develop additional water sources for domestic and wild ungulates or for irrigation, could result in creating new or enhancing existing breeding sites for *C. tarsalis* mosquitoes. Where West Nile virus is present, fencing or other modifications to watering sites to limit trampling by livestock, wild horses and burros, and wild ungulates can reduce the number of potential *Culex* mosquito breeding sites (NTT 2011, p. 61). Ponds and tanks can be constructed or modified to discourage breeding mosquitoes (Doherty 2007; Walker and Naugle 2011).

Greenhouse Gas Emissions and Carbon Storage

Actions taken to maintain or enhance the resilience of sagebrush ecosystems to disturbance have implications for greenhouse gas emissions and carbon storage. Semiarid ecosystems strongly influence the trend and interannual variability in the global carbon balance, in part due to widespread woody species expansion and high interannual variability in temperature and precipitation (Ahlström et al. 2015). In wetter years, semiarid systems are typically carbon sinks, while in drier years they tend to be carbon sources because respiration exceeds photosynthesis. In more-or-less average years, semiarid systems tend to be more carbon neutral with uptake by photosynthesis roughly equal to release by respiration (Ahlström et al. 2015; Svejcar et al. 2008).

Actions intended to avoid or halt the spread of invasive annual grasses by increasing resilience to disturbance and resistance to invasion and by restoring invaded sites to sagebrush communities would enhance carbon storage and reduce potential greenhouse gas emissions at all scales. In sagebrush ecosystems most carbon is stored belowground in the roots (Rau et al. 2011a). Conversion of native sagebrush ecosystems to annual grassland converts a greenhouse gas sink into a greenhouse gas source with reductions in aboveground and especially belowground carbon storage (Bradley et al. 2006; Germino et al. 2016; Rau et al. 2011a).

Juniper and piñon expansion and infill in sagebrush ecosystems increase aboveground carbon storage many-fold due to the large increase in biomass, but the impacts belowground are not well understood (Rau et al. 2011b, 2012). Once aboveground tree cover equals 50 percent, resilience to disturbance and resistance to invasive annual grasses drop, and the site may become susceptible to invasive annual grasses after fire (Rau et al. 2012) or other stand-replacing disturbances. The tree cover at which this reduction occurs may be lower on less productive sites.

Further, juniper and piñon expansion and infill reduce total soil nitrogen, which has long-term adverse implications for carbon storage in deep soil, where the carbon pool is very stable (Rau et al. 2012). Juniper and piñon expansion and infill can lengthen fire return intervals but greatly increase the biomass consumed during fire in comparison to sagebrush dominated ecosystems. Consequently, the science is unclear as to the long-term tradeoffs in potential greenhouse gas emissions. Even though the increase in biomass from tree cover would seem more consistent with increasing carbon storage, over the longer term it may be less sustainable than maintaining or restoring sites to sagebrush ecosystems. Short-term greenhouse gas emissions and reductions in carbon storage from projects intended or designed to reduce juniper and piñon expansion and restore sage-grouse habitat are acceptable tradeoffs (CEQ 2016, p. 18). Management objectives to increase carbon storage that are consistent with maintaining habitat and key ecosystem functions will be most beneficial in the long term.

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4. WILDLAND FIRE AND VEGETATION MANAGEMENT

Michele R. Crist, Jeanne C. Chambers, and Jonathon A. Skinner

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.

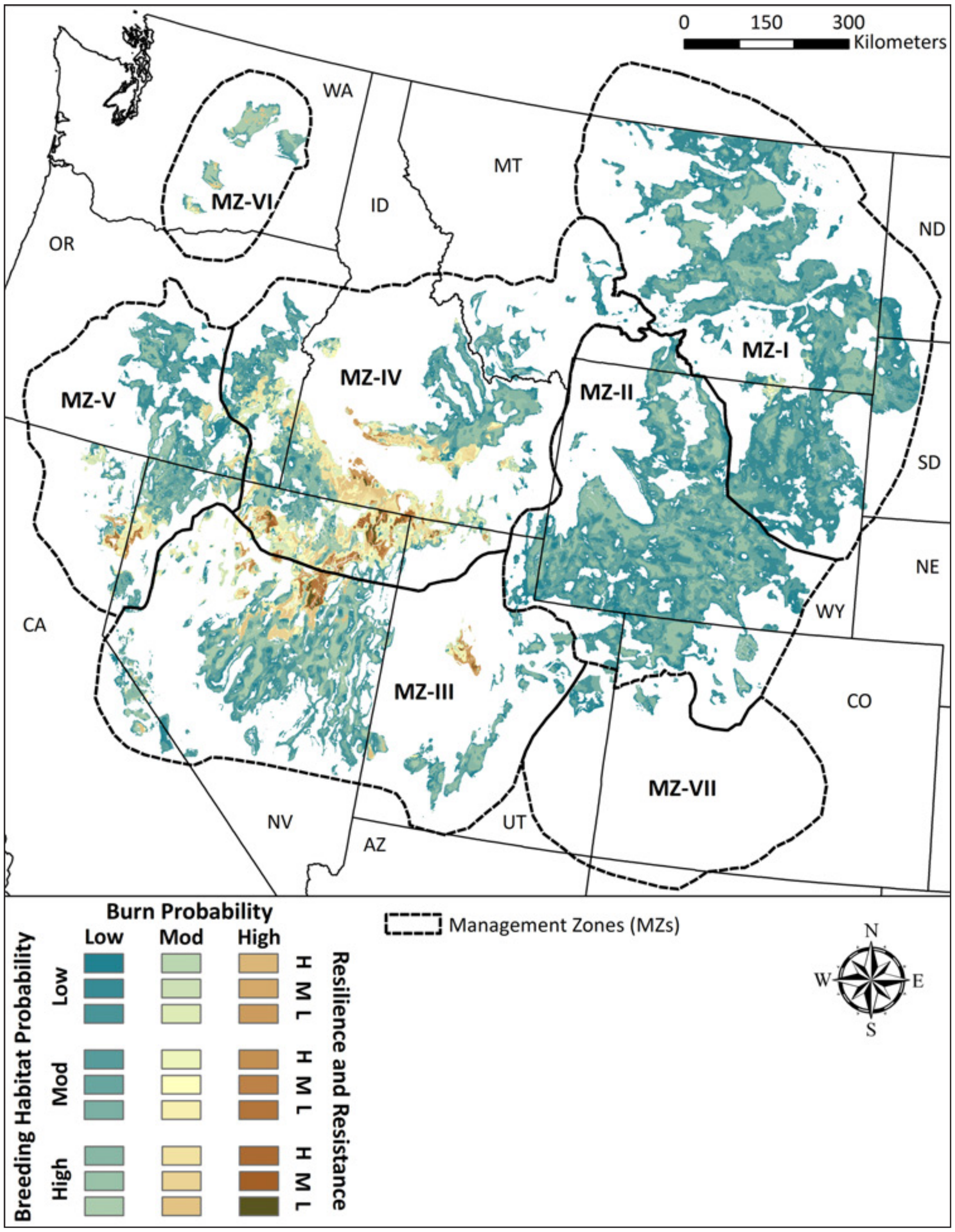

Figure 4.1—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016) depicting 27 different combinations of Greater sage-grouse breeding habitat probability (Doherty et al. 2016), resilience and resistance (Maestas et al. 2016b), and large fire probability (Short et al. 2016).

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).

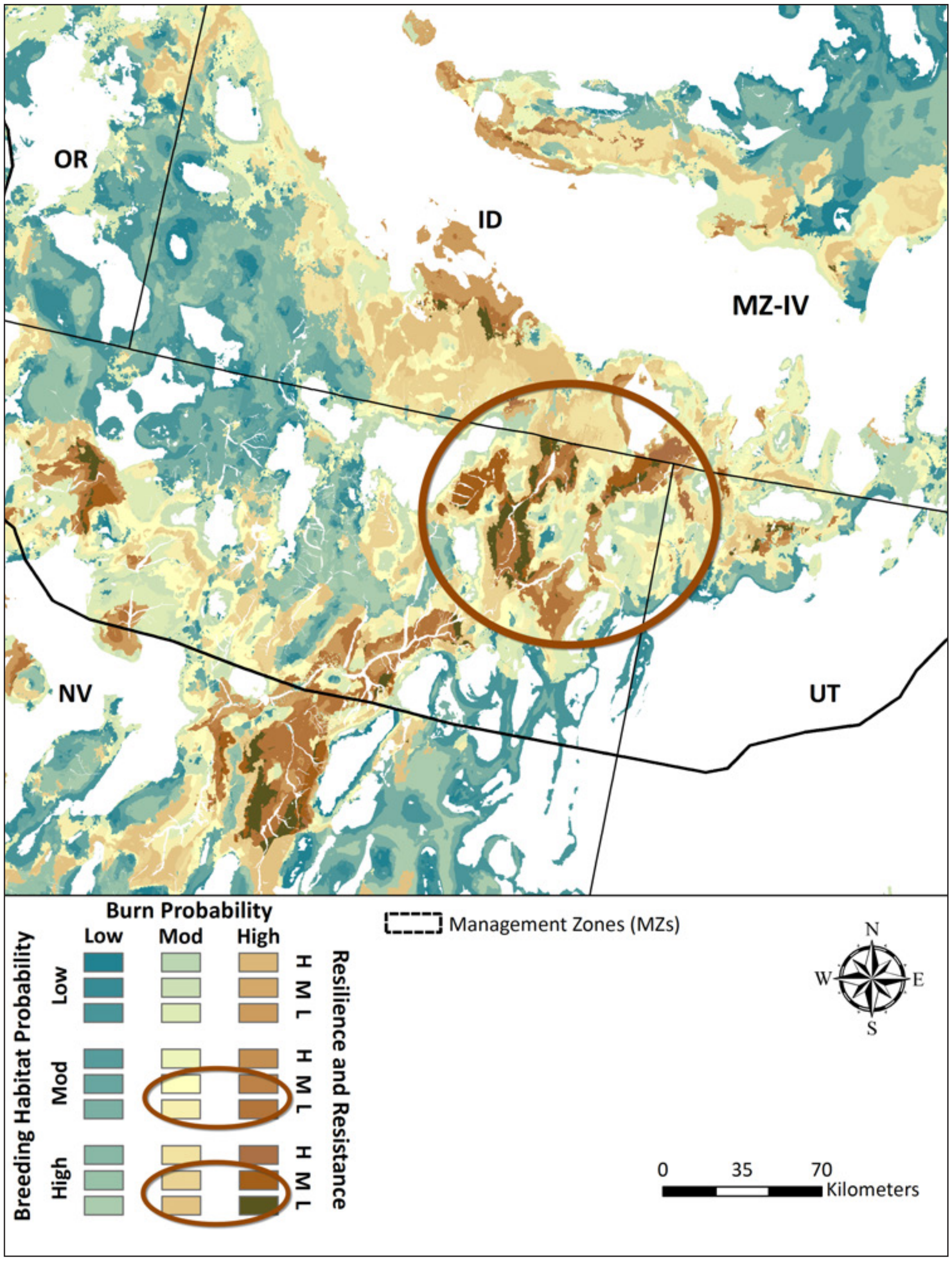

Figure 4.2—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of high to moderate burn probability, high to moderate GRSG habitat probabilities, and low to moderate resilience and resistance. High priorities for management are placing fuel reduction 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.

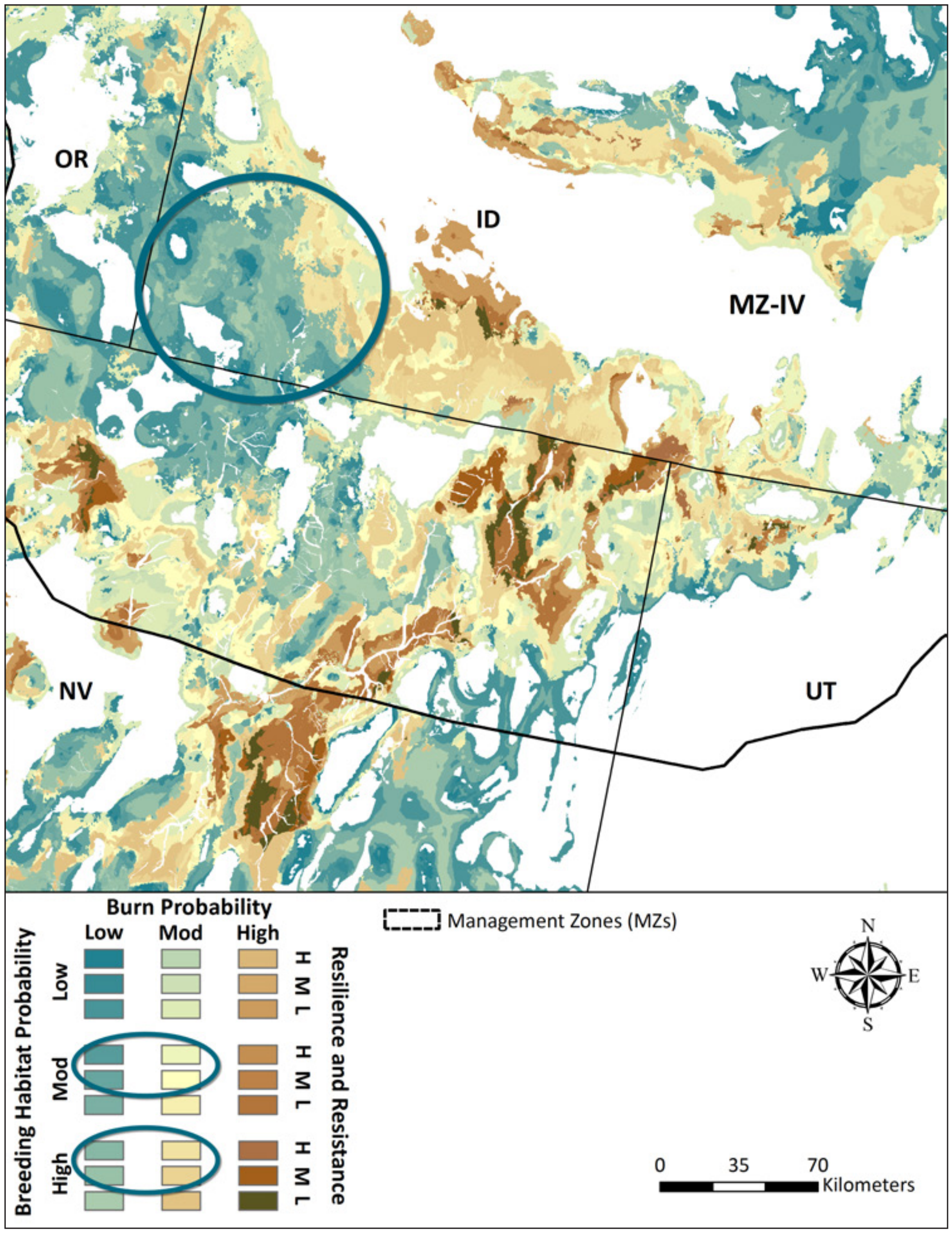

Figure 4.3—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of low to moderate burn probability, high to moderate GRSG habitat probabilities, and high to moderate resilience and resistance. High priorities for management are removing juniper and 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.

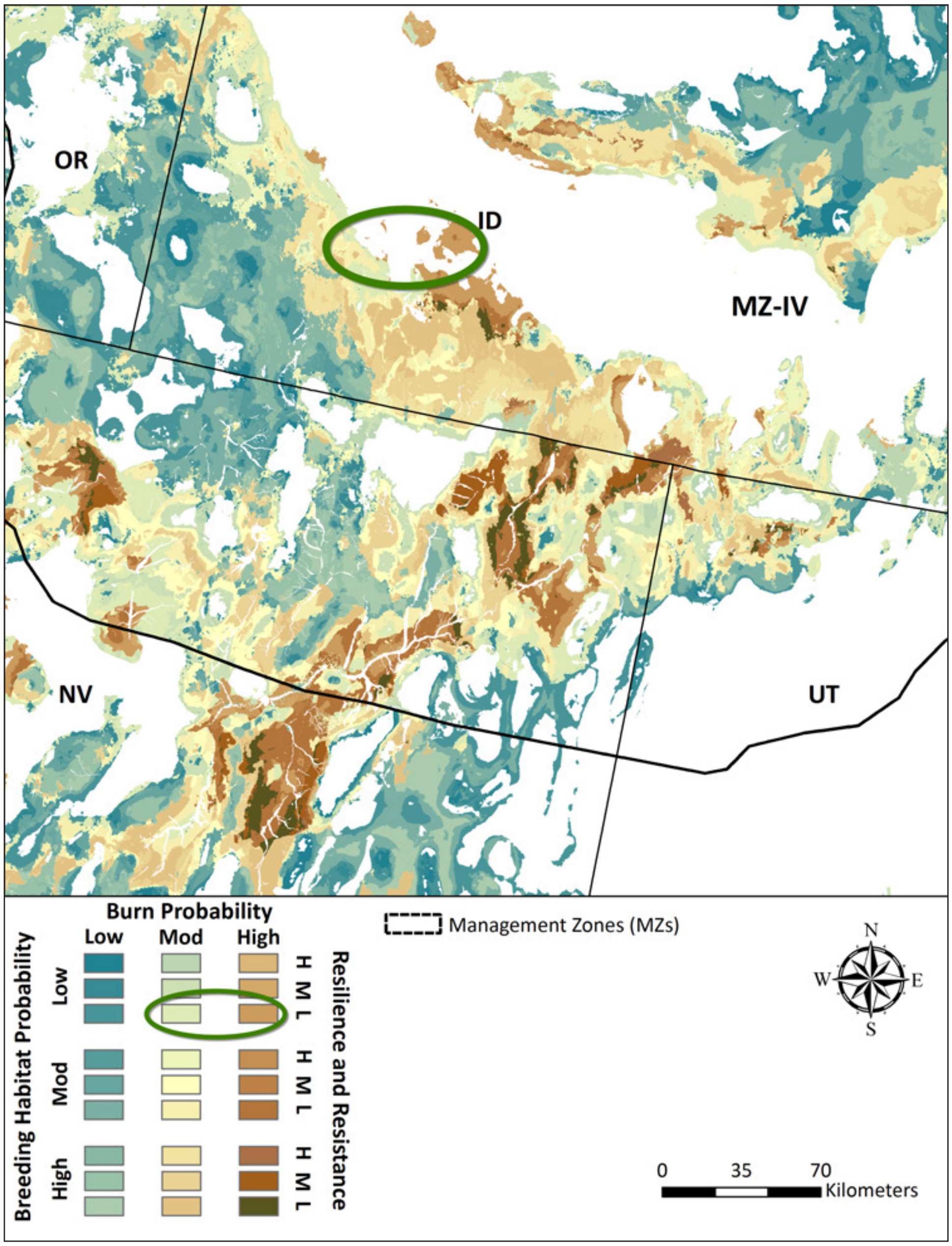

Figure 4.4—Wildland fire risk map (Chambers et al. 2017, Appendix 10; Crist et al. 2016), where circles depict areas of high to moderate burn probability, high to moderate GRSG habitat probabilities, and low to moderate resilience and resistance. High priorities for management are fuel reduction and 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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5. INVASIVE PLANT MANAGEMENT

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Introduction

One of the most significant stressors to the sagebrush biome is expansion and dominance of nonnative ecosystem-transforming species, particularly invasive annual and perennial plants. Presidential Executive Orders 13112 and 13751 define an invasive species as "a non-native organism whose introduction causes or is likely to cause economic or environmental harm, or harm to human, animal, or plant health." The use of the term "invasive species" requires two basic criteria to be met: (1) the species is alien, nonnative, or exotic to the ecosystem in question; and (2) the species has been documented as causing harm as noted in the definition. In addition, invasive annual and perennial plant species are categorized as either regulated species (nonnative species regulated under State or Federal noxious weed laws), or unregulated species (nonnative species which may pose a threat but have not been officially designated as regulated or restricted under State or Federal law). Cheatgrass (*Bromus tectorum*), for example, is not a Federally designated noxious weed, nor a State-designated noxious weed in many western States, but there are other State and local restrictions associated with this species in some areas.

Based on this definition, the labeling of a species as invasive requires closely examining both the origin and the effects of the species. Native species that may influence management objectives within a particular ecosystem would not be defined as invasive. For example, juniper (*Juniperus* spp.) and piñon pine (*Pinus* spp.) expansion into sagebrush ecosystems is a natural process resulting from a variety of factors (Miller et al. 2013; Romme et al. 2009) (see section 4). Yet unlike native juniper and piñon pine expansion, the establishment and spread of invasive plants, such as cheatgrass, Dyer's woad (*Isatis tinctoria*), and many other high-risk invasive perennial and annual plants, is not a natural ecosystem process in the sagebrush biome. There are important differences in the short- and long-term impacts to the sagebrush biome from invasive plant species compared to native species. Each invasive plant carries a different level of risk and properly describing these stressors helps managers to more effectively focus their restoration and management activities across the landscape.

Many invasive plants respond positively to ecosystem disturbance (e.g., human development, improper grazing practices, wildfires) and spread through various pathways and vectors, such as roads, trails, and vehicles (Pollnac et al. 2012; Trombulak and Frissell 2000); transmission corridors; and fuel breaks. Invasive plant species can colonize new areas rapidly, even areas that are somewhat ecologically intact. Once established, invasive plant species can continue to

Top: Spraying invasive plants with herbicides using backpack sprayers (photo: USDOI National Park Service). Middle left: Dalmation toadflax (Cal-IPC.org.; photo by Joe DiTomaso). Middle center: Spotted knapweed (photo: Alaska Plant Materials Center, State of Alaska). Middle right: Rush skeletonweed (photo: Washington State Noxious Weed Control Board). Bottom: Constantia Fire, Long Valley, California (photo: Nolan Preece, used with permission).

spread across the landscape where suitable conditions exist. Invasive plant species can become ecologically dominant, creating near-monocultures that result in reduced wildlife habitat, recreational opportunities, livestock forage, and altered fire regimes (Pyke et al. 2016). For example, even after disturbances are removed, invasive annual grasses (e.g., cheatgrass) can remain dominant. Native species may show little recovery even decades later (Keeley et al. 2003; Stromberg and Griffin 1996; Stylinski and Allen 1999) due to seed limitations of native species (Seabloom et al. 2003) and adverse interactions among invasive and native plants at the seed and seedling stages (DiVittorio et al. 2007). The complete elimination of invasive annual grasses is unlikely in these areas as the exotic annuals are highly competitive with native species for limiting resources (HilleRisLambers et al. 2010). This type of ecosystem conversion to invasive plants degrades ecosystem function by affecting geomorphic processes, hydrology, nutrient cycling, community structure, composition, productivity, and regeneration of native species (Germino et al. 2016).

The magnitude of the risk or impact that invasive plants pose to sagebrush ecosystems varies and depends on site conditions and the species' characteristics. Invasive annual grasses, most notably cheatgrass, medusahead (*Taeniatherum caput-medusae*), and red brome (*Bromus rubens*) are arguably the most widespread ecosystem disruptors across the sagebrush biome. Yet many other invasive species are also responsible for environmental impacts to sagebrush ecosystems (Ielmini et al. 2015) and new invaders (Appendix 3) continue to add to the existing management burden. For example, leafy spurge (*Euphorbia esula*) disperses into riparian and wet meadow areas important to Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) brood-rearing habitat. Tap-rooted invasive plants, such as spotted knapweed (*Centaurea maculosa*), Russian knapweed (*Acroptilon repens*), and yellow salsify (*Tragopogon dubius*), spread into upland sagebrush ecosystems, especially in areas that experience heavy livestock grazing and other disturbances (Hill et al. 2006; Prevey et al. 2010). Additionally, species such as Dalmatian toadflax (*Linaria dalmatica*) are spreading into moister areas throughout the sagebrush biome (Ielmini et al. 2015).

Land managers are tasked with controlling various species of invasive plants, but limited resources are available for invasive plant management. Invasive species ranking systems (e.g., USDOI FWS 2018) can assist land managers in ranking invasive plant species for level of threat, feasibility of control, and degree of negative impact, but this information is lacking for several species. Therefore, land managers face difficult decisions regarding how to use limited resources and whether to target high-risk pathways and vectors of invasion for efficiency; focus on specific invasive plant patches that are feasible to control, such as Early Detection and Rapid Response (EDRR) programs for targeted species; or treat the periphery of a large invasion to slow and contain the spread. The need to manage multiple invasive plant species while considering ecological impacts and social and political priorities often results in significant challenges in determining how to partition resources for invasive plant management. Achieving long-term ecosystem conservation and restoration goals for invasive plant-dominated landscapes requires a substantial increase in invasive plant management capacity and the management flexibility to better align invasive species management and native plant restoration activities. It also requires innovative approaches that capitalize on the targeted ecosystem's resilience to disturbance and resistance to invasive plant invasion.

Integrating Resilience and Resistance Concepts into Invasive Plant Species Management

An understanding of ecosystem resilience to disturbance and resistance to invasive plants can be used to help prioritize invasive plant management and determine effective management strategies. Resistance to invasive plants is of particular relevance to this section. The resistance of an ecosystem to an invasive plant is a function of (1) the suitability of the ecosystem's climate and soils for establishment and persistence of the invasive plant, and (2) the capacity of the native plant community to prevent increases in the invasive plant's population through factors such as competition, herbivory, and ability of native plants to adapt to environmental conditions (Chambers et al. 2014a). Soil temperature and moisture regimes are a primary determinant of a species' ability to establish and persist in a given ecosystem and are an important indicator of ecosystem resistance to invasive plants, such as invasive annual brome grasses (Brooks et al. 2016; Chambers et al. 2016). In areas with suitable climate and soils for invasion, increases in invasive plant populations are strongly influenced by interactions with the native perennial plant community. Disturbances or management activities that reduce abundance of native perennial grasses and biological soil crusts and increase the distances between perennial grasses often are associated with higher resource availability and increased competitive ability of invasive annual grasses (Chambers et al. 2007; Collins and Uno 1985; Reisner et al. 2013; Roundy et al. 2014; Salo 2005) and invasive forbs like spotted knapweed (Willard et al. 1988). Reductions in native perennial grasses and herbaceous species coupled with increases in invasive plants can decrease the resilience of an ecosystem or its capacity to recover following disturbances such as wildfire.

The following questions identify the basic invasive plant management information needs for informing management decisions in the context of resilience to disturbance and resistance to invasive plants:

- Where are the priority areas for management, how are they defined (e.g., GRSG habitat, mule deer [*Odocoileus hemionus*] wintering habitat, particular allotment, community at risk of wildfire), and where can resources be leveraged with partners and stakeholders for the greatest chance of success (e.g., relative resilience to disturbance and resistance to invasive plants)?
- What is the current state of invasion and how great is the risk for new invasion of priority management areas (e.g., areas of low resilience and resistance to invasive plants, significant disturbance levels, high density of vectors, other invasions in the area)?
- Which management strategies (e.g., prevention, EDRR, eradication, suppression, containment, or restoration) are feasible and within the level of return for investment desired for a particular site. For example, containment may be the only feasible strategy for a site with low resilience and resistance that is dominated by invasive annual grasses.
- Which tool(s) is most appropriate for the site condition and level of invasion (e.g., herbicide application on a new invasion for eradication, biocontrol for suppression when several hundred acres are infested, and restoration or postfire rehabilitation for low to moderate levels of infestation in areas with moderate to high resilience and resistance to invasive annual grasses)?
- Is a monitoring plan in place to determine whether the management objective was achieved and the invasion threat reduced, and whether subsequent treatments are needed?

Broad- to Mid-Scale Considerations

Using the Science Framework Approach to Inform Invasive Species Management

Many invasive plants, such as invasive annual grasses, represent persistent ecosystem threats (Chambers et al. 2017a) and are widely distributed across the sagebrush biome. The extensive nature of the invasion threat and limited resources for invasive plant management preclude addressing invasive species across the entire biome. Part 1 of the Science Framework provides an approach that uses assessments at the mid-scale to help prioritize areas for management and determine effective management strategies (Chambers et al. 2017a; hereafter, Part 1). Although the approach was developed with a focus on invasive annual grasses, it is applicable to other invasive plants where information exists on the environmental characteristics necessary for their establishment, growth and reproduction, and persistence. This approach is based on: (1) the likely response of an area to disturbance or stress due to threats and management actions (i.e., resilience to disturbance and resistance to invasive annual grasses), (2) the capacity of an area to support target species or resources, and (3) the predominant threats. A geospatial process is used that involves overlaying key data layers including resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes (Maestas et al. 2016), GRSG breeding habitat probabilities (Doherty et al. 2016) or habitats of other sagebrush dependent species, and the primary threats for the ecoregions or Management Zones in the assessment (Part 1, sections 8.1 and 8.2).

Geospatial data on invasive plant species distribution and abundance can be used in conjunction with other threats in the analyses to: (1) evaluate the level of risk of vegetation types and communities to invasion, (2) further refine target areas for management, and (3) determine the most appropriate type of management actions (e.g., Part 1, section 9.2.2, example 2: southwestern Wyoming). Data layers or methods for remotely sensing invasive plants exist for cheatgrass in portions of the Cold Deserts (Boyte and Wylie 2015, 2016; Boyte et al. 2017), spotted knapweed and babysbreath (*Gypsophila paniculata*) (Lass et al. 2005), and rush skeleton weed (*Chondrilla juncea*) (Kesoju et al. 2015). Data layers on roads and other vectors can be used to evaluate the level of risk for future spread of the invasives. Data on interacting threats (e.g., wildfire) can help provide an understanding of the patterns and spread of the invasive plant. Available data layers to consider are in Part 1, section 8.1 and Appendix 8.

The GRSG habitat resilience and resistance matrix (table 1.3) illustrates an area's relative resilience to disturbance and resistance to invasive annual grasses in relation to its probability of providing breeding habitat for GRSG. This matrix, along with table 5.1, provides a decision-support tool that helps to prioritize areas for invasive plant management actions and develop effective management strategies. Management strategies to address the predominant threats for sagebrush ecosystems including invasive plants are found in table 1.4 and table 5.2. The maps and analyses that managers derive from the geospatial approach described in the Science Framework are used along with table 1.3 to prioritize areas for management actions and develop management strategies.

Coordination and Collaboration

Coordination and collaboration provide an effective, strategic approach for managing invasive plant threats across land ownerships and jurisdictions by developing shared priorities and leveraging resources. Collaborative spatial analyses conducted with partners and stakeholders can help identify the extent and scope of invasive plants and identify priority areas for management. A participatory process guided by common, strategic approaches can be used to prioritize what, where, how, when, and by whom actions are implemented at the project level (Beier et al. 2016).

Areawide invasive plant management coordination provides an opportunity for diverse interests and multiple stakeholders to work collaboratively across the landscape to prevent and control nonnative plant invasions, and accomplish mutually beneficial landscape restoration goals. Coordination among stakeholders is critical when there are limited resources, and when management activities are redundant, are not in alignment with partners, or conflict with recommended invasive plant management strategies. One mechanism to increase coordination and collaboration is to develop and participate in local organizations that integrate noxious weed management resources across jurisdictional boundaries and benefit entire communities. An example is Cooperative Weed Management Area (CWMA) partnerships, voluntary organizations that increase communication, share resources, and ultimately increase capacity to manage the invasive plant threat and meet restoration goals. For instance, the Utah-Idaho CWMA partnership has treated medusahead by burning prior to spring herbicide application. The partnership worked with over 200 landowners for more than 10 years to control invasive plants (http://www.utahweed.org/PDF/U&ICWMA.pdf). Several resources for establishing a CWMA are provided online (e.g., http://www.weedcenter.org/management/ guidelines/tableofcontents.html and http://invasivespecies.idaho.gov/2017-cost-share-app); an example of a CWMA is at: http://www.utahweed.org/cwma.htm. Although there is no single model, most functional and effective CWMAs have adequate and sustainable funding, strong core leadership, and clearly defined boundaries and management roles. They often include a diversity of private, county, State, Federal, and tribal members.

CWMAs are established in many areas in the West to address invasive plant management issues. In the sagebrush biome, full geographic coverage of CWMA partnerships would be advantageous in preventing management and coordination gaps across the broader landscape. CWMA membership is difficult to sustain as financial limitations are increasing across rural land ownerships in most regions of the West. Although funding has drastically declined over the last several years, the National Fish and Wildlife Foundation, in cooperation with the Federal Interagency Committee for the Management of Noxious and Exotic Weeds, established the Pulling Together Initiative grant program (http://www.nfwf.org/pti/Pages/home.aspx) in part to encourage the development and sustainability of CWMAs across the United States (FICMNEW 1998). This national grant program is vital in supporting establishment and sustainability of local CWMAs. If financial support continued and increased, the Pulling Together Initiative grant program could expand the establishment and functional effectiveness of CWMAs across the sagebrush biome.

CWMAs could be strategically located to maximize their ability to address the full range of invasive plant species threats in the highest priority areas and to maximize restoration effectiveness. However, CWMAs have not consistently been invited, encouraged, or financially supported to become involved in setting management priorities for sagebrush conservation or invasive plant management within fire and fuel management planning. In some cases, CWMAs are hampered because of policy or procedural roadblocks that prevent establishment of formal agreements with the CWMAs or transfer of Federal or State funds to either the group or individual members within the CWMA. These roadblocks should be evaluated for a more responsive approach through governmental and nongovernmental coordination groups, such as State and county weed management agencies, interagency State-Federal coalitions, or other authorities.

A web-based networking system to connect the activities of individual CWMAs and share information across the sagebrush biome could be established and supported through partnerships with State agriculture departments, Landscape Conservation Cooperatives, Federal land management agencies, tribes, and other stakeholders in the public and private sector. Various programs exist for reporting noxious weed infestation (e.g., Early Detection and Distribution Mapping System [EDDMapS; http://www.eddmaps.org/]). However, State and Federal agencies differ in their level of compliance and consistency for sharing data and utilizing a centralized clearinghouse of invasive plant species occurrence data. Federal, State, and county agencies, nongovernmental organizations, and researchers interested in using these data are working together to address these needs (e.g., Western Governors Association Invasive Species Initiative, North American Invasive Species Management Association, EDDMapS, several western States).

Prevention, Early Detection, and Rapid Response

Prevention is the key to a successful invasive species program as it ensures that the management burden is not continually increased as a result of new invasions (table 5.1). Prevention is generally low cost and has a high return on investment because preventive measures are less costly than funding efforts to control infestations over multiple years. Identifying invasion-free areas allows land managers to focus resources where they are most needed and will have the greatest chance of success. Coordination with partners can help identify invasion-free areas across regions by conducting collaborative monitoring inventories and surveys (Mealor et al. 2013; Rew and Pokorny 2006). Uninvaded areas at a higher risk of invasion, such as those with low resilience and resistance to invasive plants or higher amounts of disturbance, should be considered for frequent monitoring to help keep them invasion free (tables 5.1, 5.2).

Geospatial analyses of the distribution and abundance of invasive plants can help identify uninvaded areas and other areas at increased risk for invasion. Data layers may include current invasion extent, resilience and resistance to invasive annual grasses (Part 1, fig. 33), vectors such as roads (Part 1, fig. 20), and disturbances such as oil and gas wells (Part 1, fig. 16), human development (Part 1, fig. 18), and wildfires (Part 1, fig. 34). Distinguishing between **surveyed uninvaded** areas and **unsurveyed** areas when recording occurrence of invasive plants and analyzing their distribution is necessary to evaluate management and monitoring efforts in uninvaded areas and determine future actions.

Prevention strategies help minimize the risk of expansion of invaded areas and maintain connectivity of intact, uninvaded areas; these strategies should be applied across the sagebrush biome. Considering consequences for new invasions when implementing management and development activities in invasion-free areas can help prevent invasion. For example, using certified weed-free straw, hay, and gravel for development or restoration projects is critical to prevent unintended introductions (table 5.1). The Great Basin portion of the sagebrush biome has substantial areas with low resilience and resistance to invasive annual grasses that are now invaded by these annual grasses. In contrast, the eastern portion of the biome contains large areas of moderate to high resistance to invasive annual grasses. However, uninvaded areas in the eastern portion of the range, especially those with lower resilience and resistance, are still at risk and should be identified for prevention strategies to keep “clean areas clean” and avoid large-scale invasion and dominance of invasive annual grasses as in the Great Basin. Both the Great Basin and the eastern portion of the range also have other invasive plants, such as medusahead, ventenata (*Ventenata dubia*), leafy spurge, and Russian knapweed, that should be monitored for expansion and prevented from further spread. Stringent triage measures based on impact and risk need to be developed for these species to assist with prevention.

Table 5.1—General management strategies for cheatgrass and other invasive plants based on the invasion state with an estimate of cost:benefit of return depending on site and neighboring conditions. Management strategies are based on the level of invasion for cheatgrass, but many of the concepts also apply to annual and perennial invasive forbs. The strategies for invasive plant management are prevention, Early Detection and Rapid Response (EDDR) (USDOI 2016), eradication, suppression, containment, and restoration. The invasion state is adapted from Mealor et al. (2013). Several best management practices for prevention were adapted from Cal-IPC (2012).

	Invasion state				
	Invasion free	**Trace (1–5%) with perennials**	**Mild (6–25%) with perennials**	**Moderate (26–50%) with perennials missing**	**Invasion dominated state**
Management strategies based on invasion level	**Prevention** • Manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts • Monitor high-risk priority areas for new invaders • Use certified weed-free straw, hay, mulch, and gravel for development or restoration • Avoid use of invasive species in fuel breaks • Minimize road and infrastructure development and disturbance • Clean clothing, footwear, equipment, and vehicle of invasive plant material for land or fire management activities (Cal-IPC 2012, Checklist E) • Provide training on invasive plant awareness • Incorporate invasive plant information and management into Fire Incident Action Plans	**Prevention** • Manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts • Limit soil disturbance and revegetate bare soil post-fire **EDRR** • Early Detection monitoring • Rapid Response treatment of new invasions **Eradication** • Consistent and multiple year treatments with monitoring • Promote desirable, native vegetation	**Prevention** • Manage for native perennial grasses and forbs and prevent further disturbance of biological soil crusts • Limit soil disturbance and revegetate bare soil post-fire **Suppression/ Containment** • Implement control treatments • Seed post-treatment and implement restoration where appropriate • Monitor for invasive plants post-fire and post-treatment • Monitor and manage invasive plants to maintain fuel management sites **Restoration** • Monitor and maintain desirable vegetation • Identify native seed sources • Consider revegetation after invasive plant or fire management	**Prevention** • Manage for native perennial grasses and forbs and prevent further disturbance of biological soil crusts **Suppression/ Containment** • Monitor for invasives post-fire with restoration • Locate fire lines to reduce additional disturbance and invasive plant spread where feasible **Restoration** • Implement restoration with seeding in areas lacking perennial grasses and forbs	**Containment or restoration** • For areas with high fire probability, consider fuel breaks adjacent to, not intersecting, relatively uninvaded areas and restored areas • Consider significant and consistent control treatments for high priority areas or areas adjacent to uninvaded areas • Consider restoration when invasion-dominated site is located between intact sagebrush habitat patches or between high priority areas
Cost:Benefit	Low cost:Highest return	Low cost:Very high return	Moderate cost:High return	Moderate to high cost:High return	High cost:Moderate return

Table 5.2—Management strategies for cheatgrass and other invasive plants based on the area's relative resilience to disturbance, resistance to invasive annual grasses, and the invasion state. Management strategies are based on the level of invasion for cheatgrass, but many of the concepts also apply to annual and perennial invasive forbs. The invasion state is adapted from Mealor et al. (2013); resilience and resistance (R&R) categories are based on Chambers et al. (2017a).

	Invasion free	**Trace (1–5%) with perennials**	**Mild (6–25%) with perennials**	**Moderate (26–50%) with perennials missing**	**Invasion dominated state**
High resilience and resistance	• Monitor priority areas for new invaders, especially with disturbance or wildfire • Identify uninvaded areas and minimize disturbance to prevent new introductions • Manage livestock to maintain or increase perennial native grasses and forbs • Possibly no action post-disturbance (wildfire)	• Conduct EDRR monitoring every 3–5 years until detected • For new, small populations that are detected, herbicide use may be most efficient, but repeated application is required until control is achieved • Support natural recovery	• Manage for native perennials • Implement periodic grazing deferment • Prioritize treatment areas to maximize effectiveness • Use spot herbicide treatment for 3–5 years • Seed natives post-herbicide treatment	• Implement periodic grazing deferment • Evaluate site conditions for integrated weed management when grazing or fire management used • Use spot herbicide treatments, rather than broadcast treatments, for at least 5–10 years • Seed natives post-herbicide treatment	• Restoration success possible both pre- and post-fire • Avoid seeding introduced species to prevent spread • Use integrated herbicide application and seeding • Consider sagebrush transplants • Locate and maintain fuel breaks to prevent invasive plant introduction and spread and avoid intersecting uninvaded areas
Recovery potential		Very high	High	High to moderate	Moderate
Moderate resilience and resistance	*Management strategies for moderate R&R depend on soil temperature and moisture regimes. Treat relatively cool and moist areas similarly to high R&R areas. Treat relatively warm and dry areas similarly to low R&R areas.*				
Recovery potential		High	Moderate	Moderate	Moderate to low
Low resilience and resistance	• Identify uninvaded areas and prioritize prevention • Conduct EDRR annually • Monitor areas that are high priority or adjacent to high priority areas frequently • Monitor disturbed areas frequently • Avoid fuel break placements that connect invaded and uninvaded areas and avoid intersecting uninvaded areas	• Develop an EDRR network in high priority areas • Promote desirable native vegetation • Monitor herbicide treatments and continue treating as needed • Minimize disturbance and suppress wildfire to prevent new introductions • Locate and maintain fuel breaks to prevent invasive plant spread • Prioritize postfire monitoring for invasive plants	• Identify high fire risk areas and identify invasive plant populations in these areas and travel routes to minimize spreading invasives • Use significant and consistent treatments to prevent crossing threshold into heavy infestation and manage for native perennials • Minimize disturbance and suppress wildfire • Locate and maintain fuel breaks to prevent invasive plant introduction and spread • Prioritize postfire monitoring for invasive plants with subsequent treatment and revegetation	• Identify high fire risk areas and invasive plant populations in these areas • Use significant and consistent treatments for containment and suppression in high priority areas to prevent crossing threshold into heavy infestation and to protect adjacent high quality habitat • Suppress wildfire • Avoid fuel breaks that connect invaded and uninvaded areas and try not to intersect uninvaded areas	• Restoration not feasible for most areas. Restoration in high priority area will require significant and long-term funding • Consider targeted grazing to reduce invasive annual grass fuels to reduce fire risk to adjacent higher priority areas • Consider herbicide application and integrated biocontrol at perimeter to prevent spread • Consider fuel breaks around perimeter of invaded area to contain fine fuels • Restoration may require repeated interventions • Consider seeding nonnatives where natives fail to establish
Recovery potential		Moderate	Low	Low	Low to none

Early Detection and Rapid Response (EDRR) strategies survey for those new invasive plants most likely to increase in abundance (text box 5.1, Appendix 3) and pursue treatment as quickly as possible. An overview of the National Framework for Early Detection and Rapid Response to invasive plants is available on the USDA National Invasive Information Center website (https://www.invasivespeciesinfo.gov/toolkit/detection.shtml). An example of how EDRR can be incorporated into a monitoring strategy is in text box 5.1. Early detection and rapid response strategies are cost-effective and successful because they focus on eliminating new, small invasions, which are less costly to treat and easier to eliminate (Chippendale 1991 in Hobbs and Humphries 1995; Keller et al. 2007; Leung et al. 2002). The removal of small, separate populations of invasive plants (table 5.1) is a high priority because they often expand more rapidly and cover potentially greater areas than the edge of a large, single source population (Cousens and Mortimer 1995; Moody and Mack 1988). Most invasive plants have a long lag period before they spread following introduction, so they can usually be eradicated if treated as soon as possible after detection. Early detection can make the difference between employing feasible offensive strategies versus retreating to defensive strategies, which usually result in an infinite financial commitment (Rejmanek and Pitcairn 2004).

Extensive outreach and communication about new invaders, their identification, and life history characteristics and identifying the areas that are most at risk can help foster detection, reporting, and rapid response (see Appendix 3). Establishing a communication network among landowners, public land management agencies, recreation groups, conservation organizations, botanists, horticulturalists, and weed organizations to report new invasive plant infestations will help meet detection and monitoring objectives. Targeting species of known concern and high-risk invasion pathways, such as low resistance areas, roadsides, and areas disturbed by human development, can be a successful detection strategy (table 5.2).

Text Box 5.1—Monitoring for Early Detection of Invasive Species

Early Detection and Rapid Response (EDRR) provides an opportunity to control the spread of invasive species (USDOI 2016). Monitoring for early detection of invasive species requires the following:

1. Identify known high-risk invasive species and provide training for rapid species detection and identification.
2. Coordinate priority monitoring areas across land management jurisdictions.
3. Identify locations of existing invasions and likely invasion pathways to identify areas where invasive species may first establish (e.g., recreation sites, trails, and roadsides, and in areas with treatments, recent fires, energy development, and other types of disturbance).
4. Survey, report, and verify the presence of invasive species before the population becomes established or spreads so widely that eradication is no longer feasible.
5. Utilize early detection tools that can be readily accessed and allow data to be recorded and shared among networks of Federal, State, private and nongovernmental partners (e.g., Early Detection and Distribution Mapping System [EDDMapS]).
6. Use invasive plant species presence and abundance as monitoring indicators in other vegetation monitoring programs (e.g., the Bureau of Land Management’s Assessment, Inventory, and Monitoring [AIM] and the Natural Resources Conservation Service’s National Resources Inventory [NRI]).
7. Develop management triggers designed to address early invasions. Monitoring plans can be greatly improved when an invasive species list or georeferenced abundance data are available (Brooks and Klinger 2009).

Agency programs such as forestry, grazing, energy development, recreation, wildlife, and wildfire management have the responsibility to incorporate invasive species management strategies (Federal Noxious Weed Act, 7 U.S.C. §§ 2801-2814, January 3, 1975, as amended 1988 and 1994) and coordinate management actions with CWMAs. These management programs can identify geographic areas within their program jurisdictions that have either known populations of invasive plants or low resistance to certain species. They can also identify areas that serve as sources of invasive plants and conduits for their spread. Source areas for invasive plants include recent ecosystem disturbances, such as wildfire or die-offs due to drought, and anthropogenic developments, such as oil and gas wells or cropland conversion. Mapping overlays of resilience and resistance with known populations of invasive plants, disturbed areas, and road and trail networks can provide a broad-scale assessment of where to focus invasive plant prevention and control measures. For example, suppression and control of invasive plants along roads that link invaded areas to non-invaded areas can help to prevent or minimize movement along this vector. Similarly, the potential for spread of invasive plants can be considered when siting linear firebreak networks and determining follow-up actions. Monitoring programs that involve multiple management jurisdictions and program areas can be used to evaluate both the spread of invasive plants and the effectiveness of control measures.

Local Scale Considerations

Management Strategies

Management of invasive plants and restoration of native species require the capacity to address the full suite of management activities spanning inventory and mapping, prevention, EDRR, suppression/reduction and containment, collaboration and partnership development, data collection and sharing, and restoration and rehabilitation. General project priorities for invasive plant management exist (text box 5.2), but alignment of regional strategic goals for conservation and restoration of sagebrush ecosystems and the involvement of partnerships (e.g., CWMA, State and county governments) are needed. There also may be areas within the sagebrush biome that require immediate invasive plant management actions to reduce threats to other rare or unique plants. This kind of need can be highlighted with coordination and communication at the local scale.

Resilience and resistance concepts and decision matrices can be used in project selection and design for invasive species management. At the project scale, specific ecological site description information (e.g., precipitation and temperature regimes, soil characteristics, vegetation composition), state-and-transition models, and available invasive plant assessment data (inventory and monitoring data, risk assessments, predicted occurrence) help set priorities for management actions (see Miller et al. 2014, 2015). Because invasions can vary in distribution and abundance across project areas, a critical first step in diagnosing the level of threat is to complete inventories and assessments within the project boundary.

Once the size and impact of the invasion are determined, an evaluation of the recovery potential (resilience and resistance to the specific invader) will help determine and prioritize treatment activities with the highest chance of success for invasive plant eradication, suppression, reduction, or containment (table 5.1). New invasions, low density invasions, and invasions in areas of high to moderate resilience align well with the strategies of early detection, rapid response, and

Text Box 5.2—Invasive Plant Management Priorities and Limitations

Invasive plant management priorities and limitations need to be considered when developing broad-scale approaches.

Invasive Plant Management Priorities

1. Assess the extent of the invasion for spatial distribution and abundance.
2. Prevent new infestations and implement Early Detection and Rapid Response to maintain areas without invasive plant infestations that are ecologically intact.
3. Reduce densities and cover of invasive plants with invasive plant management while native plant species are available to respond and before the invaders dominate.
4. Consider containment of large, well-established infestations to prevent perimeter spread, rather than full-scale costly control efforts that may have a low chance of success.
5. Conduct revegetation efforts in high priority areas with a high probability of success based on ecological condition when sufficient resources are available.

Invasive Plant Management Limitations

1. Competing priorities among land managers that prevent common regional and local prioritization of project areas may create multiple, inconsistent efforts.
2. For many invasive species, detailed ecological knowledge on climatically suitable areas for their establishment and spread is lacking. Thus, it is difficult to characterize ecosystem resistance to these species, identify areas most at risk of invasion, or determine the most appropriate and effective management tools and methods.
3. Inconsistent and incompatible administrative procedures for operations, datasets, and databases among partners can slow or hinder effective communication and implementation (Ielmini et al. 2015).

suppression or reduction (table 5.2). Multi-year, consistent treatments in areas with high to moderate resilience and resistance to invasive plants may achieve eradication of new or small infestations (table 5.2). Larger, well-established infestations are likely to need long-term treatment measures for potential suppression or containment on the perimeter of large invaded patches.

If funding is available and it is a high priority conservation area, it may be feasible to try to restore areas that have large, well-established infestations using an integrated approach which includes invasive control measures and revegetation (tables 5.1, 5.2). Restoration to desired conditions may be feasible in areas with moderate to high resilience. However, in areas with low resilience, repeated interventions and greater levels of financial resources may be necessary. In areas dominated by invasive annual grasses, it may not be possible to establish perennial plants without significant and costly investments. In these cases, managers should consider the return on restoration investment carefully and work with scientists to test new methods for protecting restored areas that have low resilience to fire. The conservation value of a site and the associated cost:return ratio and likelihood of success are used to determine where to place resources for invasive species management (table 5.1). Identification of treatment options is then based on site-specific characteristics, the invasive species, the degree of invasion, potential for native plant recovery, and resources available (table 5.2).

Maintain Intact Native Communities. The most successful tool for maintaining resistance to plant invasions is generally to manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts to prevent the establishment or population growth of the invader (Chambers et al. 2014a,b). For example, research shows that about 20 percent cover of perennial native grasses and forbs is needed in Wyoming big sagebrush sites to prevent significant increases in cheatgrass and other exotic annuals after management treatments (sagebrush mowing and prescribed fire) (Chambers et al. 2014b). Similarly, about 18 percent cover of perennial native grasses and forbs or 10 perennial grasses per square meter (about 1 perennial grass per square foot) is needed to exclude medusahead rye from these sites (Davies 2008).

Decreases in perennial herbaceous species and biological soil crusts and reductions in resistance to invasive plants result from improper livestock grazing (Adler et al. 2005; Reisner et al. 2013, 2015), high severity wildfire, and juniper and piñon expansion into sagebrush ecosystems (Miller et al. 2013). Reductions in perennial native grasses and forbs are associated with increases in sagebrush density and cover (Chambers et al. 2017b; Cooper 1953), and juniper and piñon densities, canopy cover, or basal area (Guenther et al. 2004; Madany and West 1983; Shinneman and Baker 2009; Soulé et al. 2004). The increases in woody fuels can cause higher severity wildfires with the potential to increase mortality of perennial native species (Miller et al. 2013).

Carefully managed livestock grazing is crucial to maintain perennial herbaceous species, forbs, and biological soil crusts and thus resistance to invasive plants. The livestock grazing strategies identified in the Science Framework are broadly applicable to the sagebrush biome (table 1.4 and section 7). Implementing livestock grazing strategies that incorporate periodic deferment from use during the critical growth period, especially for cool season grasses, can help ensure maintenance of a mixture of native perennial grasses. Adjustments in timing, duration, and intensity of livestock grazing may be needed to reduce invasive species. Livestock grazing that creates patches of bare ground can result in avenues for invasion of species such as spotted and Russian knapweed and is associated with increases in cheatgrass (Reisner et al. 2013).

Other threats to maintaining intact native communities will require diligence in monitoring for new invasions in response to land use and land management practices. Oil and gas development, road maintenance, construction, and potentially even fuel breaks may create disturbances that foster colonization of invasive plants or bring in material contaminated with weed seed. The extent and placement of fuel breaks to reduce fire risk need to be considered and designed carefully to ensure that they do not inadvertently increase subsequent fire risk by creating disturbances conducive to new invasions, especially in uninvaded areas (table 5.1 and section 4). Other measures for preventing new invasions include sanitizing equipment and vehicles pre- and post-access; requiring certified weed-free seed, gravel, topsoil, and hay for construction or restoration; and education and outreach to public, staff, and partners in identification and management of invaders (Mealor et al. 2013; Pyke et al. 2016).

No Action Post-Disturbance. Areas characterized as having moderate to high resilience and resistance (table 1.3: cells 1B, 1C, 2B, 2C) with no current invasions may not require management intervention following disturbances such as wildfire (tables 5.1, 5.2). If these areas have sufficient perennial native grasses and forbs prior to disturbance, they are likely to maintain resistance to most invasive plant species, and invasive species management resources may be better spent in other areas. For example, in relatively cold and moist areas with high ecosystem resilience, allowing the area to recover after wildfire without intervention may be the most effective strategy for preventing increases in invasive plants. However, if invasive plants occur in the area or there are significant fire management activities including access roads and vehicles, then resources should be spent on a monitoring strategy to determine whether the invasive plants increase or colonize. Funding mechanisms should remain available for restoration activities if a no-action approach is not successful.

Invasive Plant Removal and Treatment. Control measures shown to be successful in reducing and removing invasive plants include biological, cultural, physical, and chemical treatments. The 2017 Weed Management Handbook (Peachey 2017) and Weed Control in Natural Areas in the West (DiTomaso et al. 2013) are comprehensive guides to invasive plant management that provide summaries of the requirements and advantages of different tools. Selection of the appropriate tool will vary based on the invasive plant species, extent of the invasion, and resilience of the site. The integration of different controls in treating invasive plants may offer more success over the long term at project scales. When using control methods, practitioners need to consider health, environmental, and economic risks. Selection of controls based on consensus building for common threat-reduction objectives, biology of invader, site conditions, environmental factors, and best available technology can achieve desired outcomes while minimizing effects to nontarget species and the environment. Individual controls that can be used at the project scale are summarized next.

(1) Biological control is the use of natural enemies—predators, parasites, pathogens, and competitors—to control invasive plants over multiple years. Invasive plants have many natural enemies including insects and plant pathogens. Biological control is often considered when the invasion is large and well established (table 5.1) because host plant density is a determinant of whether the biological control agent can become established (table 1.3: cells 1A, 1B, 2A, 2B, 3A, 3B; table 5.2). In practice, biological control options are best determined when the land manager and biological control practitioner coordinate closely to build a long-term biological control plan that includes a strong monitoring component for the targeted invasive plant and the respective biological control agent(s). Site conditions are important for selecting the appropriate biological control agent(s) for the targeted invasive species. Several resources exist for biological control information, including the reference compendium of information available online at https://www.ibiocontrol.org/catalog/.

Other types of control agents for invasive annual grasses, especially cheatgrass, may include fungal pathogens (Meyer et al. 2016) and bacterial agents (Kennedy et al. 2001). These are often mistaken for biocontrol, but they do not function in the same way as predation or feeding behavior, which is typical of classic biocontrol. Applying bacterial agents (e.g., weed suppressive bacteria) may be considered a biopesticide application and requires different application guidelines and policy compliance under State and Federal regulations than classic biocontrols. Multiple trials are underway to evaluate the effectiveness and application guidelines for the use of fungal pathogens and bacterial agents as biopesticides. However, there is currently very limited information demonstrating the effectiveness of either fungal pathogens or bacterial agents for cheatgrass control or the potential effects of these controls on native species. Fungal pathogens do result in large cheatgrass die-off areas that may provide restoration opportunities (Meyer et al. 2016).

Species such as knapweeds and leafy spurge have several biological control agents that may provide support for strategies of containment and suppression (Anderson et al. 2000). Integration of biocontrols with other control measures can have advantages and disadvantages. For example, herbicides could be used around the perimeter of large invaded patches with biocontrols released in the center of the patches to increase overall control. In contrast, release of the biocontrol with herbicide application at the time when biocontrols emerge may result in loss of the biocontrol.

(2) Cultural controls are management practices that reduce establishment, reproduction, dispersal, or survival of the invasive plant. For example, management actions that maintain or increase native perennial herbaceous species can help control many invasive plant species. Other cultural controls, such as prescribed fire or targeted grazing, can impact native communities and are best applied in areas dominated by the invasive plant. Typically, these are lower priority areas for sagebrush conservation and restoration (table 1.3: cells 2A and 3A; table 5.2), but they may be used to meet habitat objectives such as increasing habitat connectivity or establishing fuel breaks.

Prescribed fire may serve as a cultural control for cheatgrass dominated areas if applied during seed maturation in the spring; however, it is rarely an option due to narrow implementation requirements (Mealor et al. 2013). Prescribed fire may also be used as part of an integrated management strategy. Prescribed fire implemented when conditions are safe for burning can reduce standing litter and litter mats in cheatgrass dominated areas (Jones et al. 2015a,b). Reducing the litter in areas dominated by invasive plants can improve effectiveness of certain types of herbicide applications by allowing the herbicide to reach the soil surface (DiTomaso and Johnson 2006). It can also facilitate an integrated restoration approach that includes reducing litter through repeated burning (Jones et al. 2015b) or through prescribed grazing (Frost and Launchbaugh 2003); seeding with sterile cover crops such as common wheat (*Triticum aestivum*) to decrease cheatgrass reproduction and, thus, seedbanks; and then seeding the desired native perennial species (Jones et al. 2015a). If properly implemented, prescribed fire can provide some level of reduction for both invasive perennial and annual grasses and annual forbs. However, prescribed fire does not decrease, and may increase, perennial and biennial invasive forbs (DiTomaso and Johnson 2006).

The removal of cheatgrass by fire or livestock grazing may create conditions that allow release of perennial invasive plants, resulting in a bigger issue. Native species may take many years to increase from low densities following the removal of landscape disturbances such as grazing, perhaps due to seed limitation (Seabloom et al. 2003) or adverse interactions at seed and seedling stages (DiVittorio et al. 2007). In addition, prevention and early detection methods may be needed for recent prescribed fire (and wildfire) operations to ensure that suppression activities do not inadvertently increase risk for invasive plant colonization and spread.

Targeted grazing is the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals (Launchbaugh and Walker 2006). Sheep and goats are effective tools for reducing invasive plants such as leafy spurge, spotted knapweed, and cheatgrass (Mosely 1996; Mosely et al. 2016). Intense sheep grazing of cheatgrass dominated sites can effectively suppress or even eliminate cheatgrass stands in as little as 2 years as was done in the urban interface above Carson City, Nevada (Mosley 1996). However, the effects of correctly applied targeted grazing are generally slow and cumulative (Launchbaugh and Walker 2006) and still need to be tested for applicability across broad areas.

Managed grazing may also reduce the risk and extent of wildfire in cheatgrass dominated areas (Diamond et al. 2009, 2012; Walker 2006). Because livestock grazing reduces herbaceous vegetation (fine fuels), grazing may reduce the extent of wildfire (Walker 2006) (table 5.2). Further, livestock tend to graze some areas more intensely than others, so grazing may create patchy vegetation that reduces the continuity of fuel loads and the fires that might burn those fuels (Walker 2006). In sagebrush ecosystems, exploratory high intensity targeted grazing to create fuel breaks can be tested by confining livestock to a strip of land with temporary fencing. In a fenced Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) ecosystem, cattle removed 80 to 90 percent of *B. tectorum* biomass in May during the boot phenological stage (Diamond et al. 2009). Grazing resulted in reductions in flame length and rate of spread compared to nongrazed plots in the first year; cheatgrass biomass and cover were reduced to the point that fires did not carry in the grazed plots in the second year (Diamond et al. 2009). However, grazing resulted in an increase of invasive annual forbs and Sandberg bluegrass (*Poa secunda*) (Diamond et al. 2012). This demonstrates there may be tradeoffs that will require secondary or additional management actions for other invasive species, such as the invasive annual forbs that responded to the grazing.

Effective grazing programs for invasive plant control require a clear statement of the kind of animal, timing, and rate of grazing necessary to suppress the invasive plant (Launchbaugh and Walker 2006). A successful grazing prescription should: (1) cause significant reduction in the target plant, (2) limit effects on the surrounding vegetation, and (3) be integrated with other control methods as part of an overall management strategy. Because targeted grazing by livestock is typically focused on heavily invaded areas, follow-up management such as seeding of the target area with the desired species may be needed. In big sagebrush areas with a cheatgrass understory where grazing is used to suppress cheatgrass, it may be possible to interseed the sagebrush with perennial grasses and forbs after treatment (Huber-Sannwald and Pyke 2005).

(3) Mechanical and physical controls such as hand pulling, mowing, or disking before seed production kill invasive plants directly, block establishment, or make the environment unsuitable for establishment. To date, these methods have not been widely applied to invasive annual grasses or perennial invasive plants in sagebrush ecosystems. There are potential tradeoffs of destroying biological soil crusts with some of these methods.

(4) Chemical control is the use of pesticides, which include herbicides, fungicides, or biopesticides (as mentioned in the discussion of biocontrols). Pesticides are typically used as an efficient and cost-effective approach to control invasive plant infestations, and, like other integrated pest management techniques, are best used in combination with other treatment approaches for more effective, long-term control. Ecological type or site descriptions and state-and-transition models that integrate information on resilience and resistance to invasive annual grasses (see Part 1, Appendices 5 and 6) can help determine whether herbicides are the best control method for larger invasions. Herbicides can be very useful for eradicating small patches of invasive plants or interrupting the spread of large patches along advancing fronts by containing the perimeter (Rinella et al. 2009) (tables 5.1, 5.2). In some situations, large-scale herbicide applications have been used to treat well-established plant invasions before implementing native plant restoration actions, in order to maximize effectiveness across large landscapes or along border areas. Evaluating the degree and extent of neighboring invasions can provide information on whether the invasive species can recolonize from a neighboring untreated area. Additionally, evaluating the existing seedbanks within a treated area can provide information to help determine whether repeated treatments are needed and, if so, for how long (e.g., 3–15 years).

Several basic elements should be included in all pesticide (herbicide) use proposals and application plans prior to implementing any herbicide application by trained and experienced personnel. These include proper selection of the appropriate herbicide product and adjuvants for the targeted invasive species, site condition, and the appropriate application technique and timing. Detailed knowledge of the soil and water conditions and other environmental concerns in the treatment area is also needed. Proper application of appropriate herbicidal products can be an effective solution for managing established invasive plant populations. Although there may be short-term collateral damage, proper herbicide application planning greatly reduces the chance of unintended negative impacts to nontarget native plants and associated fish and wildlife in the treatment area. For example, to minimize effects, herbicide applications may involve spot-spraying of localized invasive patches within the area by using a backpack sprayer, rather than aerial spraying the entire area, which may increase the risk of nontarget impacts. Further, while broadcast spray is a method for treating large, well-established invasions, the level of reduction in density or coverage accomplished and the effects on nontarget native plant communities, soils, or biological crusts, and costs of multi-year treatments needed should be carefully considered before implementation.

Conclusions

Sagebrush ecosystem conservation must recognize the need for greater investment in preventing additional plant invasions and limiting the spread of existing invasions across the entire sagebrush biome. This type of investment will support land owners and managers in a proactive management approach rather than the reactionary approach that is currently in place. Without prevention and a proactive approach, the ongoing expansion of invasive plants will continue to outpace restoration efforts and resources. Areas could be prioritized for proactive invasive plant management based on resources of concern, community needs, and opportunities for success according to resilience and resistance to invasion and current ecological site conditions such as the level of invasion. Uninvaded areas could be identified and monitored for new plant invasions and, if invasions occur, quickly treated and eradicated. Invasive annual grass control is the key to preventing and reducing uncharacteristic fuel and fire regimes. Partnerships are critical and must be developed to provide consistent invasive plant management to maintain weed-free areas and prevent mild invasions from spreading and crossing thresholds into heavy infestations. An all-hands-on-deck effort to leverage resources for restoration efforts is needed in high priority areas. Combating invasive plants pre- and postfire and addressing the technical, policy, communication, and operational challenges needs to be a priority. Addressing these challenges will help to prevent negative effects to ranching livelihoods and recreational opportunities and protect the sagebrush biome from overall ecosystem degradation.

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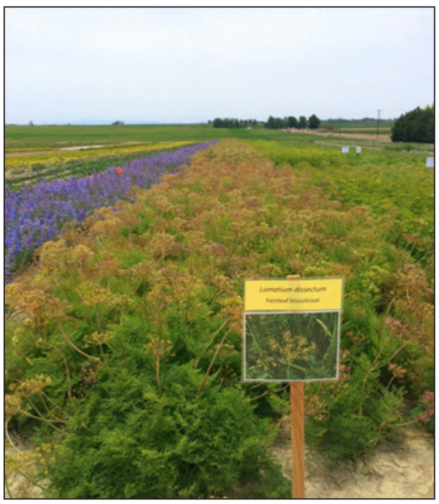
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6. APPLICATION OF NATIONAL SEED STRATEGY CONCEPTS

Fred Edwards, Sarah M. Kulpa, and Francis F. Kilkenny

Introduction

Native plant species are the foundation of sagebrush ecosystems and provide essential habitat for wildlife species, such as Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG). The National Seed Strategy for Rehabilitation and Restoration (hereafter, Seed Strategy) (PCA 2015) strives to provide all land managers—Federal, tribal, State, county, private, and nongovernmental organization—the tools they need to address ecological restoration across the United States. The Seed Strategy provides a coordinated approach to improving the use of native seed, building Federal and private capacity, and increasing the supply of genetically appropriate native seed (PCA 2015). The Seed Strategy recognizes the value of existing native plants and soil seedbanks and acknowledges that not all disturbances or management treatments require active seeding to restore habitat. The Seed Strategy also recognizes that although many nonnative species have been seeded successfully and economically to provide forage and soil stabilization, their ability to support diversity and provide functioning ecosystems to meet multiple use and sustained yield mandates is limited (PCA 2015). Successful rehabilitation and restoration must always take into consideration compatibility of species in a seed mix, planting season, and appropriate seeding rates, techniques, technologies, and practices; that information is available elsewhere (e.g., Madsen et al. 2012, 2014; Monsen et al. 2004a,b,c; Ott et al. 2016; Pyke et al. 2015a,b, 2017).

Genetically appropriate native plant materials have been historically underdeveloped within the sagebrush biome. This section focuses on the logistics, challenges, opportunities, and considerations for procuring and using native seed in sagebrush ecosystems at broad (sagebrush biome), mid- (level III ecoregions), and local (project to site) scales. It also discusses local scale tradeoffs that should be considered when managers decide to use nonnative seeds within the sagebrush biome. It does not address restoration practices and techniques.

Top left: Bee on a native fiddleneck flower in Nevada (photo: USDOI Fish and Wildlife Service). Top center: Intern collecting Indian ricegrass seed (photo: Sophia Heston, USDOI Fish and Wildlife Service). Top right: Owen Baughman and Lauren Porensky preparing to fill the drill seeder (photo: Beth Leger, University of Nevada, Reno). Middle left: Native forbs in a seed increase field (photo by Anne Halford, USDOI Bureau of Land Management). Middle center: Sagebrush seedlings being grown for bare root stock at USDA Forest Service, Lucky Peak Nursery (photo: USDA Forest Service). Middle right: Western hawksbeard (photo: USDA Forest Service). Bottom left: Drill seeding in the snow (photo: Susan Fritts, USDOI Bureau of Land Management). Bottom right: Successful postfire seeding in a sagebrush ecosystem (photo: USDA Forest Service).

Conceptual Basis

Most gardeners and growers are familiar with the 2012 USDA Plant Hardiness Zone map (https://planthardiness.ars.usda.gov/PHZMWeb/) that is found on the back of almost every seed pack sold in the United States. This is the standard by which gardeners and growers can determine which plants are most likely to thrive at a location based on average annual minimum winter temperature, divided into 10-degree Fahrenheit zones. In this context, seed transfer guidelines, which include mapped seed zones (fig. 6.1), are just a more sophisticated and accurate way to understand what seeds and plants thrive best at a location. Seed transfer guidelines are management tools that define acceptable distances seed can be moved from the point of origin, while considering genetic adaptation (Bower et al. 2014; Kilkenny 2015; St. Clair et al. 2013). For more detail, see Part 1, Appendix 11 of the Science Framework (Chambers et al. 2017; hereafter, Part 1).

Variations in biotic and abiotic factors cause plants to experience natural selection across their range. When adaptive evolution occurs in response to local selective pressures, populations are considered to be locally adapted (Leimu and Fischer 2008; McKay et al. 2005). Common garden studies and reciprocal transplant studies have shown that plant populations are often adapted to local environmental conditions (e.g., Clausen et al. 1941; Hiesey et al. 1942; Joshi et al. 2001; Turesson 1922). For restoration projects, this means locally adapted plants can generally outperform nonlocal plants (e.g., Bischoff et al. 2006; Humphrey and Schupp 2002; Leimu and Fischer 2008; Rice and Knapp 2008; Rowe and Leger 2012).

Ecosystem resilience to disturbance and resistance to invasive annual grasses can be increased by considering both seed source and genetic diversity, in combination with other factors, when selecting seeds and plant materials. Besides project failure, poor seed mix choices may have long-term consequences including genetic degradation of the surrounding plant population, loss of fitness, and loss of evolutionary potential and, consequently, reduction of future

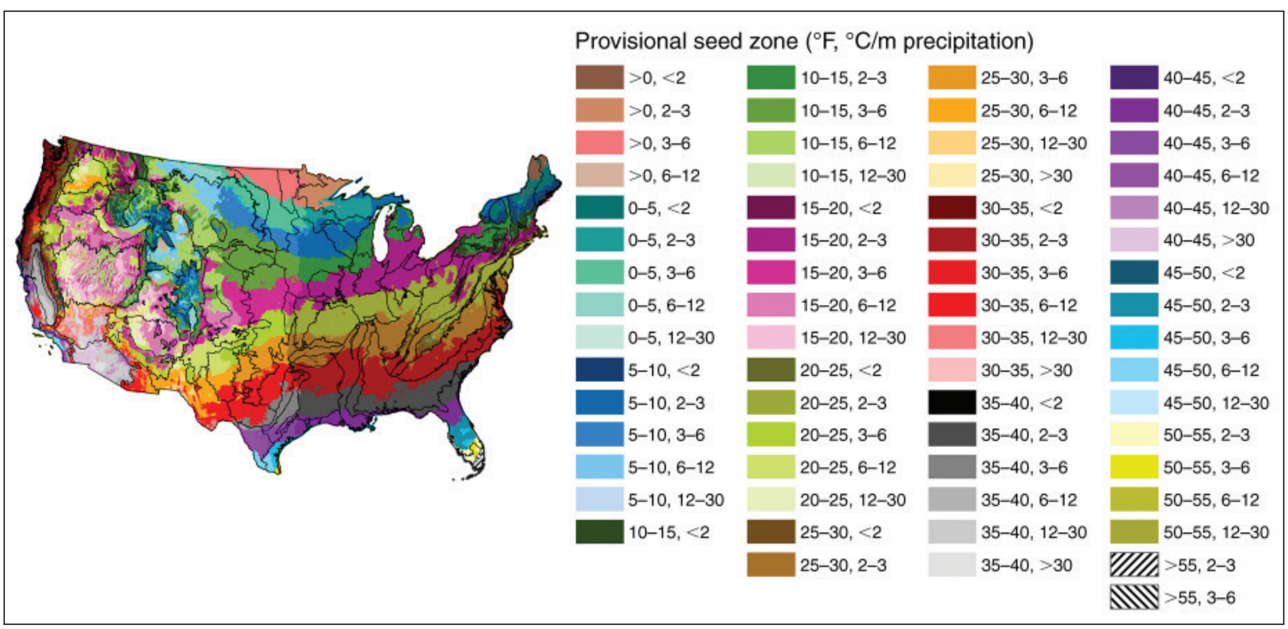

Figure 6.1—Provisional seed zones for native plants (color polygons) overlain with Omernik's (1987) level III ecoregion boundaries (black lines). Provisional seed zones are the first step in defining seed transfer guidelines. Level III ecoregions can be used to refine seed movement within a provisional seed zone. In the legend, the first range of numbers is the temperature class band (°F) and the second range of numbers is the annual heat:moisture (AH:M) index class bands (°C/m precipitation; from Bower et al. 2014) (Chambers et al. 2017, Appendix 11 fig. A.11.2).

plant community resilience and resistance to invasive annual grasses (Crémieux et al. 2010; McKay et al. 2005; Mijnsbruggea et al. 2010; Schröder and Prasse 2013). The Seed Strategy provides a path forward for developing and procuring genetically appropriate native seed sources that have the best genetic fit for individual restoration and vegetation management projects by identifying the research, technology, and monitoring needs for integrating and managing genetic diversity across the sagebrush biome.

Considerations for Enhancing Resilience and Resistance Using Seed Strategy Concepts

Broad- to Mid-Scale Considerations

Prioritizing Native Seed Development

The geospatial data layers and analyses described in Part 1, sections 8.1 and 8.2 of the Science Framework can help prioritize sagebrush ecosystems for native plant materials development, postfire rehabilitation, and restoration. Analyses are conducted at the ecoregion scale because similarities in ecoregional climate, soil properties, resilience to disturbance, and resistance to invasive annual grasses can provide economies of scale compatible with seed development. Collectively, the sagebrush biome includes most of 14 different Omernik (1987) level III ecoregions: Eastern Cascades Slopes and Foothills, Columbia Plateau, Blue Mountains, Idaho Batholith, Snake River Plain, Northern Basin and Range, Central Basin and Range, Wasatch and Uinta Mountains, Middle Rockies, Wyoming Basin, Colorado Plateaus, Southern Rockies, Northwestern Great Plains, and Northwestern Glaciated Plains. Omerick's level III ecoregions served as the basis for the U.S. Environmental Protection Agency (EPA) level III ecoregions described in Part 1 and are synonymous with EPA level III ecoregions (fig. 1.1). For example, warmer and drier areas with low resilience and resistance to invasive annual grasses might require additional seeding after a disturbance to supplement natural recovery. Therefore, ecoregions with predominantly warm and dry soil temperature and moisture regimes, such as the Columbia Plateau, Northern Basin and Range, Central Basin and Range, Snake River Plain, and Colorado Plateaus, may be a higher priority for the development of native plant materials.

Key data layers for prioritizing areas for native plant materials development include: (1) resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes, (2) GRSG breeding habitat probabilities and densities or habitats of other sagebrush obligate habitats, (3) the primary threats for the ecoregion (see Part 1, section 8), and (4) generalized or provisional seed zones (fig. 6.1) (Bower et al. 2014; Part 1, Appendix 11). For example, in the Great Basin, Jensen and Stettler (2012) reported that over the last 30 years, 90 percent of fire rehabilitation projects on Federal land occurred in three major generalized or provisional seed zones. In the eastern range 78 percent of oil and gas development occurs in six major generalized or provisional seed zones (see Part 1, Appendix 8 for data sources). Thus, initial seed development efforts should focus on developing native plant materials for the most appropriate species (most likely native perennial grasses) for these provisional seed zones.

Primary considerations in prioritizing areas for native plant materials development based on resilience and resistance to invasive annual grasses follow (see tables 1.3 and 1.4, especially the sections on postfire rehabilitation and climate change).

- In general, areas with moderate and, especially, high resilience and resistance often recover without seeding following wildfire and vegetation management. Shrubs, particularly sagebrush, may or may not require seeding or transplanting. These areas are relatively low priority for development of native plant materials (table 1.3: cells 1B, 1C, 2B, 2C).
- Priority increases as resilience and resistance decrease and habitat probability for GRSG increases. High priorities include ecological types with low to moderate resilience and resistance that (1) may lack sufficient native perennial grasses and forbs to recover on their own, but (2) have nearby areas still supporting GRSG habitat (table 1.3: cells 2B, 2C, 3B, 3C).
- Areas of low habitat probability for GRSG (table 1.3: cells 1A, 2A, 3A) are generally lower priority, but may become higher priority if they support other species or resources at risk or can be used to increase connectivity among areas with intact sagebrush.
- Areas may be considered for prioritization regardless of resilience and resistance if repeated large fires or other habitat disturbances are causing habitat fragmentation and seeding or transplanting of sagebrush is needed to maintain habitat connectivity.

Because resilience and resistance to invasive annual grasses increase along soil temperature and moisture gradients, an understanding of the relationship of major sagebrush taxa to soil temperature and moisture regimes can help in prioritizing sagebrush and their associated species for seed development by using seed zones and seed transfer guidelines. Within the big sagebrush complex in the western portion of the range, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) occurs on cold to cool moist sites, while in the eastern portion of the range it occurs on cold and cool wet, summer moist, or winter moist sites. In the western portion of the range, Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) and basin big sagebrush (*A. tridentata* ssp. *tridentata*) typically occur on relatively warm and dry sites, whereas in the eastern portion of the range, these species occur on a spectrum of sites, ranging from cool and summer moist to warm and dry. Thus, Wyoming big sagebrush and basin big sagebrush may be considered a higher priority for native plant materials development in the western portion of the range based on low resilience and resistance to invasive annual grasses on the sites where they grow.

Some dwarf sagebrush species, such as warm springs low sagebrush (*Artemisia arbuscula* ssp. *thermopola*), alkali sagebrush (*A. longiloba*), and Wyoming threetip sagebrush (*A. tripartita* ssp. *rupicola*) occur on relatively cold to cool sites with high resistance and resilience to invasive annual grasses (Miller et al. 2014) and, therefore, are a lower priority for native plant materials development and restoration. However, other Dwarf sagebrush species—black sagebrush (*A. nova*), pygmy sagebrush (*A. pygmaea*), low sagebrush (*A. arbuscula* ssp. a*rbuscula*), and alkali sagebrush (*A. arbuscula* ssp. *longiloba*)—grow on relatively warm and dry sites (Miller et al. 2014). Although this appears to indicate that the ecosystems where these species are most abundant have low resilience and resistance to invasive annual grasses, soil and vegetation community characteristics need to be taken into account. For example, black sagebrush grows on shallow, stony, calcareous soils which are sparsely vegetated, and thus has a low fuel load and low likelihood of needing restoration. Therefore, black sagebrush is typically a lower priority for native plant materials development and restoration. However, monitoring of all sagebrush ecological types is needed to determine whether declines are occurring due to climate, wildfire, improper grazing, disease, or other perturbations.

Developing the Mechanism for Seed Increase

Vegetation community lists from the available ecological site descriptions for Natural Resources Conservation Service (NRCS) Major Land Resource Areas can be used to identify the native shrub, grass, and forb species needed to restore ecosystem function. Development of lists can be prioritized based on resilience and resistance concepts and the considerations just described. Vegetation community lists can also be used to prioritize species for native plant materials development and regional procurement objectives. One caveat is that ecological site descriptions tend to be dominated by later successional species. In some cases earlier successional species may need to be included in a seed mix to help establish initial site resistance to invasive annual grasses. To achieve this, local expertise and herbarium records coupled with ecological site descriptions should be used to develop the most comprehensive vegetation community lists.

Intact sagebrush communities with low and moderate resilience and resistance to invasive annual grasses can be identified for wildland seed collection or the establishment of commercial seed collection areas. These sagebrush communities can provide reliable, source-identified sagebrush seed for restoration projects. Alternatively, where local seed sources have been depleted or are not available for seed collection (such as Wilderness areas), the development of seed orchards based on seed transfer guidelines and seed zones may be useful.

Potential Tradeoffs and Management Challenges at the Broad and Mid-Scale

Changes in precipitation and temperature regimes are projected to have large consequences for species distributions across the sagebrush biome (see Part 1, section 4.2). This is a challenge for management because the vegetation communities we currently manage may or may not be the same in the future. Developing native plant materials that include the genetic diversity of a species by seed zones can help species seeded onto a site adapt to future changes in climate. Predictive models of changes in climate can be used to assess threats to important restoration species and identify opportunities for targeting, prioritizing, and implementing restoration projects that consider potential changes in species distribution and plant community composition. Modeling changes in species distributions and seed zone boundaries will help identify potential refugia areas and bottlenecks to species' movement and select appropriate plant populations for inclusion in restoration projects to reduce the risk of future maladaptation.

At the broad scale, prioritizing ecoregions and sagebrush ecological types within them (for example, Wyoming big sagebrush ecological types in the Columbia Plateau), may mean that seed needed for restoration within areas that have high and moderate resilience and resistance to invasive annual grasses may not always be as readily available as seed for areas with low resilience and resistance to invasive annual grasses. Therefore, when making seeding decisions, it is important not to waste seed, and seed only when necessary. In areas with high resilience and resistance to invasive annual grasses, not seeding or other passive restoration treatments may be more practical (Pyke et al. 2015a). In areas with lower resilience and resistance to invasive annual grasses that require seeding, individual project planning can help mitigate the need for seed. By building reasonable timelines within individual projects, local seed collection and seed increase can be conducted to ensure that sufficient genetically appropriate native seed is available.

Land managers may want to rehabilitate and restore rangelands that have low GRSG habitat value or other resource management value, but are currently dominated by cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyron cristatum*), or some other undesirable plant species, because these rangelands are prevalent at the mid-scale. Under these circumstances, where other range management objectives have a higher priority than GRSG management objectives, the financial costs to procure genetically appropriate native seed, the size and scale of the project, or adverse impacts to remaining local native seed sources (e.g., improper grazing) may preclude the use of native seed. Nonnative species and native cultivars that originate from sites with similar temperature and precipitation regimes may provide an acceptable management tradeoff. However, if native ecosystem restoration is the goal, seed of genetically appropriate native grasses is relatively inexpensive and can be the first step of a "staged planting" approach, whereby grasses and forbs are planted in successive years or forbs are added to a limited number of favorable areas (i.e., forb islands) (Benson et al. 2011) (see section on local-scale tradeoff).

Local Scale Considerations

In this section, local scale refers to individually funded vegetation management activities within a district or field office. At this scale, managers need to carefully consider seed mixes and seed sources because of the critical role they play in managing for resilience and resistance to invasive annual grasses. The importance of deciding when seeding is or is not needed cannot be overstated. Such decisions should be tied to site-specific assessments of current conditions, past management, and the potential for a site to recover without management intervention. Local monitoring data can be used to provide information on seed mixes and seed sources, as well as the need to seed (text box 6.1). Monitoring treatment effectiveness can provide the necessary information on species performance to adjust seed sources over time.

Planning for and initiating collection, seed increase, and long-term storage of native seed are important components of the management and development of native plant materials. Forward planning for the use of genetically appropriate

Text Box 6.1—Monitoring to Inform Selection of Species and Seed Sources and to Evaluate Seed Source Performance

Monitoring data play an important role in selecting species and seed sources and evaluating species performance. First, monitoring data from a project area or site prior to treatment can provide the necessary information on the species composition to select the most appropriate restoration species. Such data can also provide information on suitable areas for seed collection. Second, information about the seed source is essential for selecting plant materials that are genetically adapted to the site conditions. Selecting appropriate seed sources can ensure that the desired species establish and persist and is necessary for achieving successful and effective restoration projects.

Information on the seed sources used in a restoration project should be recorded and tracked in a systematic manner. Relating data on seed sources to seedling establishment as a part of effectiveness monitoring provides critical information on species and seed source performance that can be used to inform future restoration efforts. When only anecdotal data are available, project managers can draw or perpetuate erroneous conclusions regarding the effectiveness of seeding outcomes. Data on seed sources, along with other treatment information, could be recorded in the Land Treatment Digital Library, a catalog of information about land treatments on Federal lands in the western United States (https://ltdl.wr.usgs.gov/). This need is identified and described in the Seed Strategy under Action Item 2.4.1, "Analyze new and existing monitoring methodologies to evaluate restoration outcomes" (PCA 2015).

native seed based on quantities requested annually, number of acres seeded annually, fire projections, or some other metric is critical. Forward planning when seeding with cultivars or nonnatives is generally not crucial because of their widespread availability.

For the western range, Miller et al. (2014, 2015) provide a framework for evaluating postwildfire resilience and resistance to invasive annual grasses, potential successional pathways, and the need to seed at the local scale. A similar framework can be developed for the eastern range. Additionally, the Seedlot Selection Tool (https://seedlotselectiontool.org/sst/) can help with seed source decisionmaking based on climate information. General seeding strategies by resilience and resistance category are:

- **High Resilience and Resistance**. The potential for native shrubs, grasses, and forbs to recover after disturbance without seeding is typically high. Shrubs, particularly sagebrush, may or may not require seeding or transplanting. If sites require seeding, the use of locally sourced or source-identified seed from the same seed zone will improve project success while maintaining genetic adaptation and diversity.
- **Moderate Resilience and Resistance**. The potential for native shrubs, grasses, and forbs to recover after disturbance is usually moderately high, especially on cooler and moister sites. Seeding following disturbance or treatment may be needed in areas with depleted native perennial grasses and forbs. Including perennial grasses in seed mixes that can compete with and provide resistance to invasive annual grasses is recommended. Including locally sourced or source-identified forbs from the same seed zone may be necessary to meet habitat management objectives, but their seeding depends on the degree of site preparation, capabilities of the seeding equipment, and expectation of weed invasion.
- **Low Resilience and Resistance**. Recovery potential after overlapping disturbances (e.g., wildfire, improper grazing) is usually low and seeding is needed in areas with depleted native shrubs, grasses, and forbs. The use of perennial grasses in seed mixes is recommended to provide competition with invasive annual grasses. Decisions on the use of native (locally sourced or source identified from the same seed zone), grasses, native cultivars, or nonnative grasses depends on the availability of seed sources and degree of invasion by nonnative annual grasses. On degraded sites, forbs may be absent. Including locally sourced or source-identified forbs from the same seed zones may be necessary to meet habitat management objectives. However, to successfully seed forbs it is necessary to consider the degree of site preparation, capabilities of the seeding equipment, and expectation of weed invasion.

Good species selections and seed source choices can strengthen community resilience and resistance to invasive annual grasses, whereas poor species selections and seed source decisions can erode long-term community resilience and resistance. Management considerations for resilience and resistance at the local scale include:

- **Incorporating native perennial grasses in all seed mixes used on sites with moderate and low resilience and resistance to invasive annual grasses**. Native perennial grasses compete directly with cheatgrass and other introduced annual grasses for space, water, and nutrients (Blank and Morgan 2012; Chambers et al. 2007; Leger 2008). Including genetically appropriate native perennial grasses adapted to site-specific temperature and precipitation regimes increases resilience and resistance as well as site diversity. Empirical seed zones are available for many of the common native perennial grasses used in rehabilitation and restoration of sagebrush ecosystems.

- **Designing a diverse seed mix of native shrubs, grasses, and forbs for all project seed mixes.** Species diversity is the hallmark of a healthy ecosystem; diverse seed mixes of native shrubs, grasses, and forbs can increase site resistance by filling ecological niches and competing with nonnative invasive annual grasses. Seed mixes should integrate information about ecological site conditions and successional stage for best success. For example, if forbs are included in a seed mix, site preparation and management should prevent cheatgrass invasion, such as through the "staged planting" approach (Benson et al. 2011). Temperature and precipitation conditions that favor seed germination and seedling establishment vary from year to year, so seeding a diverse mix of early and late successional stage native shrubs, grasses, and forbs may increase resilience by providing a range of species capable of germinating and establishing in response to a variety of environmental conditions.
- **Using the right sagebrush in the right place.** With 27 sagebrush species and subspecies across the sagebrush biome, using the correct sagebrush species or subspecies source identified to the same seed zone in restoration projects is essential to creating sagebrush communities that are resilient and resistant to invasive annual grasses. Variations in biotic and abiotic factors cause plants to undergo natural selection and adaptive evolution; thus, individual sagebrush species and subspecies have evolved to grow best under different soil environments, temperature, and precipitation regimes (Dumroese et al. 2015; Miller et al. 2011). Consequently, sagebrush species and subspecies are not interchangeable in a restoration seed mix. For example, Richardson et al. (2015) found that Wyoming big sagebrush has a significantly greater seed weight than basin big sagebrush and determined that 83 percent of certified seed lots used in 2013 and 2014 were labeled as Wyoming big sagebrush but were actually basin big sagebrush. Furthermore, data indicate that local adaptation in sagebrush plays an important role in long-term survivorship. In an Idaho Department of Fish and Game study, Sands and Moser (2012) found locally sourced Wyoming sagebrush seed had 100 percent survivorship after 20 years, while non-locally sourced seed had less than 50 percent survivorship.
- **Including native forbs to create healthier food webs.** Complex and diverse food webs are a hallmark of intact ecosystems with high resilience and resistance to invasive annual grasses. Native forbs are a major component of sage-grouse chick diets (Dumroese et al. 2015), are critical to native pollinators (Pollinator Health Task Force 2015), and can be abundant in sagebrush communities (Humphrey and Schupp 2001; James et al. 2014). In healthy sagebrush ecosystems, native forbs have continuous and overlapping flowering and seed production throughout the growing season—meaning that a variety of ecological niches are filled by a diversity of species. On degraded sites, land managers can attempt to create or repair flowering phenology and reproduction through carefully planned seed mixes. Restoring the native plant community, especially the native forb component, is likely to result in a cascading response in which other native species increase. Thus, native forbs are an important component of sagebrush ecosystem restoration and should be included in seed mixes.

- **Considering use of ruderal or annual native forbs in project seed mixes to increase resistance to cheatgrass where they are naturally abundant and seed sources have been developed.** Some native annual species (such as bristly fiddleneck [*Amsinckia tesselata*]) have been shown to compete well and suppress nonnative invasive annual species due to phenological similarities (Leger et al. 2014; Uselman et al. 2014). Developing competitive, native annual species for use in future seed mixes may improve seeding outcomes in some disturbed rangeland ecosystems. However, the potential amount of seed required, availability, and costs of including native annuals should be carefully considered during project planning.
- **Considering long-term planning at the local scale to preserve seed sources from low resilience and resistance sites that are at high risk of cheatgrass invasion or wildfire.** In these cases, long-term planning can provide seed sources adapted at the seed zone level which will be adapted to site conditions within a seed zone.

Potential Tradeoffs and Management Challenges at the Local Scale

If a decision is made to seed, there are five major tradeoffs related to resilience and resistance concepts and implementation of Seed Strategy concepts. Tradeoffs should not be considered individually, but rather in the context of meeting project objectives while maintaining site resilience and resistance to invasive annual grasses. Local tradeoffs in the context of seed source choices (fig. 6.2) are discussed briefly.

The Tradeoff between Seed Source and the Need for Follow-up Management to Meet GRSG Habitat Objectives. Nonnative species, such as crested wheatgrass and forage kochia (*Bassia substrata*), are widely seeded for rangeland revegetation, postfire rehabilitation, invasive plant control, and green stripping, because they germinate and establish quickly, are readily available for purchase, are cheaper than native species, provide good livestock forage, and compete with nonnative invasive species (Brooks and Pyke 2001; Harrison et al. 2000; Monaco et al. 2003; Pellant 1994; Richards et al. 1998). These nonnative species are used as placeholder or bridge species to convert annual invasive grass-dominated rangelands into native perennial-dominated plant communities (Monaco et al. 2003); however, follow-up restoration rarely happens. Putting this concept into practice has not been widely realized and some of the positively perceived attributes of these species, such as competitive ability, can negatively impact native plant community structure and function.

The wide use of nonnative species in some circumstances represents a tradeoff for achieving diverse ecosystem and habitat management objectives for GRSG, pollinators, and other sagebrush dependent species. For example, crested wheatgrass can be highly competitive with native sagebrush and perennial grass species (Asay et al. 2001; Bakker and Wilson 2001; Hull and Klomp 1967; Marlette and Anderson 1986). Crested wheatgrass can dominate the soil seedbank (Marlette and Anderson 1986) and limit the growth and establishment of native plants (Gunnell et al. 2010; Heidinga and Wilson 2002; Hendersen and Naeth 2005). Attempts to reintroduce native species into crested wheatgrass monocultures suggest that costly and time-intensive repeated treatments are required because this species recovers rapidly from mechanical and chemical control treatments (Davies et al. 2013; Fansler and Mangold 2011; Hulet et al. 2010; McAdoo et al. 2016). Short and long-term (13 years) studies suggest that even if seeded at low rates in a seed mix, crested wheatgrass may ultimately

Project Seed Options

	Will follow-up management be needed to meet sage-grouse habitat objectives?	Could there be negative affects to the adjacent plant community?	Will established plants reproduce?	Will seed establish?	Can seed be procured quickly?
Locally sourced seed	High certainty additional management not needed	High certainty there will be no impacts	High certainty will reproduce	Moderate certainty will establish	Requires advance planning and dedicated funding
Source identified to the same seed zone	High certainty additional management not needed	Moderate certainty there will be no impacts	Moderate certainty will reproduce	Moderate certainty will establish	Seed availability unknown; depends on species and project seed zone
Native cultivated commercial variety	Moderate certainty additional management not needed	Low or unknown certainty due to potential genetic dilution or hybridization of local populations	Reproduction depends on germplasm origin and climactic similarities to target site	Establishment depends on germplasm origin and climactic similarities to target site	High certainty seed available
Persistent nonnative species like crested wheatgrass or forage kochia	Additional management needed to diversify the plant community and meet habitat objectives	Low or unknown certainty because can potentially spread beyond the project area	High certainty will reproduce but has potential to form a monoculture	High certainty will establish	High certainty seed available
Non-persistent, nonnative place holder species (such as sterile wheatgrass)	Additional management needed to diversify the plant community and meet habitat objectives	Moderate certainty there will be no impacts	Not expected to reproduce	Moderate certainty will establish	High certainty seed available

Local Level Implementation Considerations

High certainty
Moderate certainty
Low or unknown certainty
Not applicable

Figure 6.2—Seed source and local-level considerations for selecting seed sources and types.

become the most abundant grass in a mixed bunchgrass community (Bakker and Wilson 2004; Nafus et al. 2015).

The Tradeoff between Seed Source and Potential Impacts to the Adjacent Plant Community. Plants established as part of a seeding project interact with the surrounding environment and interbreed with native, resident (local) plant populations. Local seeds or seed sources identified by seed zone are advantageous because they are unlikely to be invasive or overly competitive with other native plants. Local seeds or seed sources identified by seed zone should be most genetically similar to the existing native plant populations and have the lowest potential for adverse genetic impacts.

Seeding with nonnatives may represent an ecological tradeoff because they have the potential to invade and spread beyond a project boundary. For example, Gray and Muir (2013) found that on sites seeded 3 to 24 years earlier, forage kochia spread as much as 710 meters (2,330 feet) into both intact and disturbed plant communities for an estimated rate of 25 meters (82 feet) per year.

Just as individual plants may spread, genes are also capable of spreading into adjacent, resident plant populations. Seeding with native cultivars may represent a genetic tradeoff because of potential adverse impacts to local population genetics through hybridization, potentially affecting overall species fitness

(Hereford 2009; Leimu and Fischer 2008). Seed source is often not a criterion for developing native cultivars. Native cultivars have been developed over many years in an agronomic setting and are often selected for specific traits (see next paragraph), which may or may not align with restoration success (Johnson et al. 2010; Jones and Larson 2005; Leger and Baughman 2015). Introduced seed has the potential to hybridize with native populations and result in maladaptation or negative long-term impacts that could affect a plant community's ability to adapt to changing environmental conditions.

The Tradeoff between Seed Sources and Seed Germination, Establishment, and Reproduction. Traits selected for and often prioritized in native cultivars are: forage quality and yield, seed yield, seedling vigor, ability to establish and persist, and drought tolerance across a range of environmental conditions (Leger and Baughman 2015). Nonnative species are selected for traits similar to those selected in native cultivars. For example, the crested wheatgrass germplasm 'Ephraim' was selected for forage quality and yield, ability to establish, and a rhizomatous growth form for site stabilization (USDA NRCS 2012). In contrast, locally sourced native seeds and seed sources are more likely to be adapted to the environmental conditions in the seed zones where they are collected.

Locally sourced, native seed may need one or more growing seasons to germinate and establish on a site due to seed dormancy or other physiologic mechanisms. Seed of nonnatives and native cultivars typically germinate and establish quickly because they are selected for little or no seed dormancy. However, this represents a tradeoff because nonnatives and native cultivars may not meet long-term habitat objectives for sage-grouse, pollinators, other wildlife species, or special status plant species. Additionally, using a nonnative species like crested wheatgrass will support site resistance to invasive annual grasses because it is a good competitor with cheatgrass. However, it is less likely to support long-term site resilience because of the low species diversity it maintains (see preceding discussion). Treatment effectiveness monitoring that tracks native seed sources and their performance in the field can be used to inform both native species and seed source selection (text box 6.1).

The Tradeoff between Seed Sources and Procurement. Until the seed market can be fully developed, there is a tradeoff between the species desired for a seed mix and their availability. Anticipating and planning for native species needed to develop a seed mix is an important aspect of project management because seed of desired native plant species and seed sources usually are not immediately available. At the local scale, it is possible to plan and collect local seed that can be sent to a grower to increase it to the desired quantities. Advance planning (such as performing project-specific seed collections and seed increase with a commercial grower) will make species more available, but this represents a tradeoff in how quickly a project can be implemented. Purchasing and using native cultivars or nonnative species is a tradeoff that saves time and money, allowing a project to move forward quickly. Native cultivars (such as 'Sherman' Sandberg bluegrass *[Poa secunda*] or 'Magnar' basin wildrye [*Leymus cinereus*]) or nonnative species (such as crested wheatgrass and forage kochia) are often immediately available and can be bought from the commercial market in large quantities. However, using native cultivars or nonnative species results in tradeoffs regarding potential adverse impacts to future resilience and resistance to invasive annual grasses and a need for follow-up management (see earlier discussion).

Conclusions

Balancing locally adapted seed sources, cultivars, and nonnative species against the realities of implementing a project in the field is a series of tradeoffs. Every project is unique and a one-size-fits-all approach will not work. Sometimes seeding is used as a way to mitigate management risk or simply as insurance. Regardless of why and what is being seeded, the judicious use of seed will not only save money, but also minimize the risk of unintended ecological consequences to naturally recovering native plant communities. As part of any decision to seed, potential tradeoffs should be carefully weighed against the potential future economic and ecosystem costs. Seeding should not always be the first choice. For example, where prescriptive treatments are desired to minimize erosion risks to infrastructure, one-time physical barriers (such as straw wattles and straw mulch) may be more desirable and cost-effective where sufficient native perennial plants exist to promote recovery (e.g., Robichaud et al. 2010).

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7. LIVESTOCK GRAZING MANAGEMENT

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Introduction

Part 1 of the Science Framework identifies livestock grazing as the most widespread land use in the sagebrush biome (Chambers et al. 2017a; hereafter, Part 1). In the Conservation Objectives Team Report (USDOI FWS 2013) improper livestock grazing is considered a present and widespread threat to Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) for most GRSG populations. Livestock grazing affects the composition and structure of plant communities across the sagebrush biome and, consequently, the habitats of GRSG, other species at risk, and high value resources (Boyd et al. 2014). Livestock grazing can also affect habitat restoration efforts and thus the capacity to achieve broad-scale conservation and restoration goals.

The effects of livestock grazing on ecosystem composition, pattern, and function are well recognized (Beck and Mitchell 2000; Boyd et al. 2014; Cagney et al. 2010; Freilich et al. 2003; Fuhlendorf and Engle 2001; Knick et al. 2011). Major differences in plant responses to livestock grazing exist among ecoregions due to evolutionary adaptations to grazing and browsing, plant phenology relative to the timing of grazing, and selectivity of grazers for different plant species within the community (see Part 1, section 5.3.7). The effects of livestock grazing are strongly influenced by season of grazing relative to plant tolerance to grazing and the availability of water for plant regrowth after grazing. In the Cold Deserts water storage and plant growth depend on winter precipitation, and cool season plants (see definitions in Appendix 1) dominate plant communities (Part 1, sections 4.2 and 4.3). In the Cold Deserts both stocking rates (Briske et al. 2011) and grazing season affect plant responses to grazing (Briske and Richards 1995). Grazing of perennial grasses during inflorescence development (late spring) when moisture is becoming limited can negatively affect plant regrowth and recovery (Briske and Richards 1995). In contrast, in the West-Central Semiarid Prairies more moisture is available during summer and a mixture of cool season plants and warm season grasses, which have greater water use efficiency, dominate plant communities (Part 1, section 4.1). In both the West-Central Semiarid Prairies and Western Cordillera, precipitation during the growing season may increase tolerance to grazing, but cool season grasses can be eliminated by seasonal grazing that impacts them but not warm season plants.

Livestock grazing has the greatest potential to affect GRSG habitat by changing the composition, structure, and productivity of the herbaceous plants used by GRSG for nesting and early brood-rearing (Part 1, section 5.3.7; Beck and Mitchell 2000; Boyd et al. 2014; Cagney et al. 2010; Hockett 2002). The available research indicates that GRSG nest and early brood microhabitat selection and brood-rearing success are closely tied to areas with greater

Left: Utah rancher Bill Kennedy (photo: Jesse Bussard. USDA Forest Service). Top right: Livestock grazing in a sagebrush ecosystem (photo: Joe Smith, Sage Grouse Initiative/ University of Montana). Middle right: Placing fence markers to prevent sage-grouse strikes (photo: USDA Forest Service). Bottom right: Cattle and Greater sage-grouse in a sagebrush ecosystem (photo: USDA Forest Service).

sagebrush and grass canopy cover and height than are randomly available in sagebrush landscapes (Dinkins et al. 2016; Doherty et al. 2011, 2014; Hagen et al. 2007; Kirol et al. 2012; Thompson et al. 2006). However, the reported effects of grass-related variables on nest site selection and nest survival have been less consistent in the literature (Part 1, section 5.3.7; Coates et al. 2017; Smith 2016). Thus, it has been suggested that management prescriptions for livestock grazing within nesting habitats consider the potential regional variation in grass-related variables and the effects associated with plant phenology. Current vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, consider key plant community indicators such as sagebrush cover, sagebrush height, sagebrush shape, and perennial grass and perennial forb cover and height (Stiver et al. 2015). These vegetation habitat objectives also consider how plant community indicators vary between wetter and drier ecological sites (Stiver et al. 2015). Livestock grazing management is key to either maintaining or attaining these habitat objectives.

Livestock, primarily cattle and sheep, are grazed across the sagebrush biome on Federal, State, tribal, and private lands. Grazing practices and flexibility in those practices can vary according to the land manager or owner. Because many livestock grazing operations span multiple management jurisdictions, it is necessary to consider management opportunities and restrictions on each parcel that the operator uses.

Federal and State agencies are working together with private landowners to maintain or improve sagebrush habitat on rangelands in a manner appropriate for the site conditions and landowner interests. The Federal Land Policy and Management Act of 1976 stated that Federal land management agencies must "manage the public lands under principles of multiple use and sustained yield" (Public Law 94–579, Sec. 302). The Public Rangelands Improvement Act of 1978 (Public Law 95–514) further commits Federal land management agencies to providing regular updates on the condition and trend of rangelands. These legislative actions typically translate into management of livestock use in ways that sustain other land uses (e.g., wildlife conservation) and involve monitoring of livestock grazing effects.

This section begins by discussing the administration of livestock grazing on public and private lands and the ongoing review of grazing authorization (permits and leases) and processing in GRSG habitat. Then information is provided on the use of resilience and resistance concepts and the Science Framework to inform livestock grazing management. Considerations for the use of this information are presented for both the mid-scale (ecoregion or Management Zone) and local scale (field office or district), with an emphasis on grazing management practices to improve habitats of GRSG and other species and values at risk. Finally, select ecological types and state-and-transition models (STMs) (see Appendix 1 for definitions) are used as the basis for identifying livestock grazing management practices within the GRSG range that can be implemented to maintain or improve the resilience and resistance of sagebrush plant communities and the quality of GRSG nesting and early brood-rearing habitat.

Livestock Grazing Management on Public and Private Lands

The Bureau of Land Management (BLM) manages livestock grazing on 155 million acres (73 million hectares) of public land and administers nearly 18,000 permits and leases held by ranchers who graze their livestock at least part of the year on more than 21,000 allotments. A grazing permit is a document authorizing grazing use of the public lands within an established grazing district. A grazing lease is a document authorizing grazing use outside of an established grazing district. A grazing allotment is an area of land designated and managed for the grazing of livestock. Allotments may consist of BLM-administered lands as well as other Federally managed, State-owned, and private lands. Livestock numbers and periods of use are specified for each allotment. Permits and leases specify all authorized livestock grazing use including the total number of animal unit months (AUMS) and the area (allotment) authorized for grazing use.

Permits and leases generally cover a 10-year period and are renewable if the BLM determines that the terms and conditions of a permit or lease are being met. The terms and conditions for grazing on BLM-managed lands (such as stipulations on forage use and season of use) are set forth in the permits and leases issued by the BLM to public land ranchers. The amount of grazing that takes place each year on BLM-managed public lands can be affected by such factors as drought, wildfire, and market conditions.

The Forest Service manages livestock grazing on over 95 million acres (38 million hectares) of National Forest System lands on 7,275 allotments spread across 29 States. Grazing use is administered through a grazing permit system similar to that used by the BLM. Permits are issued for a 10-year period with the current permittee having the preference to reapply for the permit upon expiration provided that he or she has complied with the terms and conditions of the current permit. The Forest Service administers about 6,400 permits for 5,897 permittees. The majority (90 percent) of those permits are for cattle and sheep. The remaining 10 percent include bison, goat, donkey, burro, horse, and mule.

Potential livestock grazing management practices designed to improve sagebrush habitats can be incorporated into livestock grazing management alternatives during the grazing authorization (grazing permits and grazing leases) renewal process. When vegetation habitat objectives for GRSG and land health standards are not met because of current livestock grazing management, changes in livestock grazing management are needed to ensure significant progress toward achieving the vegetation habitat objectives for GRSG and land health standards. Current BLM livestock grazing regulations require that monitoring data or field observations, or both, be used to support decisions about stocking rates on allotments (43 CFR 4110.3) (text box 7.1).

Setting priorities for review and processing of grazing authorizations (permits and leases) is ongoing within the BLM (USDOI BLM 2017a) and other agencies. Priorities for review and processing of grazing authorizations are (1) areas where rangeland health standards have not been evaluated, and (2) areas that are not achieving rangeland health standards. In areas with GRSG habitat, BLM and its partners have developed specific vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG in Montana (USDOI BLM 2015a, table 2.3-2; USDOI BLM 2015c, table 2-6; USDOI BLM 2015d, table 2-2), North Dakota (USDOI BLM 2015f, table 2-2), South Dakota (USDOI BLM 2015h, table 2-6), the Wyoming Basin Ecoregion and northeast Wyoming (USDOI BLM 2015j, tables 2-2 and 2-3), Oregon and Washington (USDOI BLM 2015g, table 2-2), Utah (USDOI BLM 2015i, table 2-2), Nevada and northeastern California (USDOI BLM 2015e, table 2-2), and Idaho and southwestern Montana (USDOI BLM 2015b, table 2-2). In areas with GRSG habitat, managers will need to evaluate vegetation habitat objectives for GRSG when conducting an evaluation of rangeland

Text Box 7.1—Monitoring Livestock Grazing

In 1995, through regulation in 43 CFR 4180, livestock grazing on BLM-administered lands was required to ensure the attainment of Fundamentals of Rangeland Health. The Fundamentals of Rangeland Health address minimum standards for ecosystem functioning including: (1) properly functioning watersheds; (2) ecological processes of the hydrologic cycle, nutrient cycle, and energy flow; (3) water quality; and (4) wildlife habitat quality (43 CFR 4180.1). The BLM was required to develop rangeland health standards that would conform to the Fundamentals of Rangeland Health within individual regions in consultation with local Resource Advisory Councils (43 CFR 4180.2). To evaluate land health, BLM field office personnel are required to perform individual, on-the-ground evaluations of these rangeland health standards in all grazing allotments. Current livestock grazing use is monitored within grazing allotments to ascertain whether current livestock grazing use is allowing for achievement of rangeland health standards. Collection of monitoring data on the effects of current livestock grazing use constitutes a major priority for livestock grazing management on BLM-administered lands.

health standards. If the BLM finds that vegetation habitat objectives for GRSG are not being achieved because of current livestock grazing, then the agency modifies the livestock grazing management practices to ensure that progress will be made toward achieving the vegetation habitat objectives for GRSG. It may be necessary to modify and update the vegetation habitat objectives over time as additional information on GRSG habitat requirements and ecological site potentials to support GRSG habitat become available and additional policy direction is provided (USDOI BLM 2017b).

Private landowners generally use range management principles and tools provided by entities such as the Agricultural Research Service, Natural Resources Conservation Service, and State and university extension programs. Use of proven range management principles and tools can ensure that private lands are managed in a manner that maintains or improves rangeland resilience and resistance to invasive annual grasses and provides the necessary resources for GRSG and other wildlife species. Tools for private lands include range management plans that are based on local ecological site information and rangeland plant inventories. It is recommended that range management plans incorporate flexibility in season of use and stocking rates to allow for implementing adaptive management of GRSG habitat. It is generally recognized that by promoting diverse and productive native perennial plant communities, private landowners can ensure that rangelands remain resilient to disturbance and resistant to invasive plants. As a result, drought, annual grass invasions, and wildfires are less likely to impact GRSG and other sagebrush dependent species.

Using Resilience and Resistance Concepts and the Science Framework Approach to Inform Livestock Grazing Management

Designing livestock grazing management practices to improve habitats of GRSG and other species and values at risk requires a consistent approach that can be applied across jurisdictions. In Part 1 of the Science Framework, an approach is identified for determining the suitability of an area for a management action and the most appropriate management action that can be applied to livestock grazing management. At the mid-scale, geospatial analyses can be used to evaluate: (1) the likely response of an area to disturbance or management actions (i.e., resilience to disturbance and resistance to invasion by annual grasses), (2) the capacity of an area to support target species or resources, and (3) the predominant threats. Many of the data layers used in the mid-scale geospatial analyses for the Science Framework (see Part 1, sections 8.1 and 8.2) can be used to help inform livestock grazing administration and identify appropriate livestock grazing management practices. Key data layers include resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes (Maestas et al. 2016), GRSG breeding habitat probabilities (Doherty et al. 2016), and the primary threats within the assessment area.

At the local scale the Science Framework approach includes: (1) identifying the different ecological types or ecological sites that exist within the management area and determining their relative resilience to disturbance and resistance to invasive annual grasses; (2) evaluating the current ecological dynamics of the ecological types or ecological sites and, where possible, their restoration pathways; and (3) selecting livestock grazing management practices that have the potential to increase overall ecosystem functioning and habitat conditions. Ecological types or ecological site descriptions and STMs that explicitly consider ecosystem resilience to disturbance and resistance to invasive annual grasses provide the basis for selecting appropriate livestock grazing management practices (see Part 1, section 9). Consideration of habitat objectives for GRSG and other species and values at risk is used to assess whether the management area (e.g., grazing allotment) has the potential to attain the habitat objectives and, if so, the specific livestock grazing management practices needed to achieve the objectives (Beck and Mitchell 2000; Boyd et al. 2014; Hockett 2002).

In general, areas that support GRSG habitat or other important species or resources are high priorities for livestock grazing management that maintains or improves GRSG habitat values (tables 1.3, 1.4). Areas with moderate to high resilience and resistance to invasive annual grasses often have the potential to recover from disturbances through successional processes. These areas represent significant opportunities to use livestock grazing management and other management activities to direct plant succession to improve habitat. Areas with low resilience and resistance often lack the potential to recover from improper livestock grazing without significant intervention, and are among the highest priorities for improved livestock grazing management.

To step down to the local scale, ecological types or ecological site descriptions and their associated STMs can be used to evaluate current ecological dynamics and determine appropriate livestock grazing management practices (text box 7.2). In the Science Framework, generalized ecological types and STMs have been described for the range of environmental conditions in the eastern and western portions of the sagebrush biome. These ecological types and STMs are characterized according to their resilience to disturbance and resistance to invasive annual grasses based on soil temperature and moisture regimes and other biophysical characteristics (Part 1, Appendices 5 and 6). They provide information on the alternative states, ranges of variability within states, and processes that cause plant community shifts within states as well as transitions among states. Examples of how to use these resilience-based ecological types and STMs for managing ecosystem threats across the sagebrush biome are in Part 1, section 9.2. Information on using the ecological types and STMs in sagebrush and juniper (*Juniperus* spp.) and piñon (*Pinus* spp.) ecosystems of the Great Basin for selecting appropriate treatments is in Miller et al. (2014). Information on assessing postwildfire recovery potential and making restoration decisions is in Miller et al. (2015) and Pyke et al. (2017).

Text Box 7.2—Using Ecological Site Descriptions and State-and-Transition Models

Ecological site descriptions and their associated state-and-transition models (STMs) provide essential information for determining treatment feasibility and type of treatment. Ecological site descriptions are part of a land classification system that describes the potential of a set of climate, topographic, and soil characteristics and natural disturbances to support a dynamic set of plant communities (Bestelmeyer et al. 2009; Stringham et al. 2003). Ecological site descriptions have been developed by the Natural Resources Conservation Service and its partners to assist land management agencies and private landowners with making resource decisions. For a detailed description of ecological site descriptions and access to available ecological site descriptions see: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/.

STMs are a central component of ecological site descriptions that are widely used by managers to illustrate changes in plant communities and associated soil properties, causes of change, and effects of management interventions (Briske et al. 2005; USDA NRCS 2015; Stringham et al. 2003). STMs use the concepts of **states** (a relatively stable set of plant communities that are resilient to disturbance) and **transitions** (change among alternative states caused by disturbances or other drivers) to describe the range in composition and function of plant communities within ecological site descriptions (Stringham et al. 2003) (see Appendix 1 for definitions). The reference state is based on the natural range of conditions associated with the historical range of variation and often includes several plant communities (**phases**) that differ in dominant plant species relative to type and time since disturbance (Caudle et al. 2013). Alternative states describe new sets of communities that result from factors such as improper livestock use, invasion by nonnative species, or changes in fire regimes. Changes or transitions among states often are characterized by **thresholds** or conditions that may persist over time without active intervention, potentially causing irreversible changes in community composition, structure, and function. **Restoration pathways** are used to identify the environmental conditions and management actions that will facilitate return to a previous state.

Examples of Using Resilience-Based State-and-Transition Models to Identify Potential Livestock Grazing Management Practices

The dominant ecological types and STMs provide the basis for identifying livestock grazing management practices that can be implemented to maintain or improve the resilience and resistance of sagebrush plant communities and the quality of GRSG nesting and early brood-rearing habitat. Here, examples of ecological types and STMs are provided for different ecoregions and sage-grouse management zones (fig. 1.1). The examples were chosen to illustrate the differences in potential management strategies for ecological types that support GRSG populations and can often benefit from improved livestock grazing management. Some states within the STMs, and plant community phases within the states, do not provide the vegetation necessary for nesting and early brood-rearing habitat for GRSG as identified in vegetation habitat objectives for breeding and nesting seasonal habitat and brood-rearing and summer seasonal habitat (e.g., USDOI BLM 2015a, table 2.3-2; 2015b, table 2-2; 2015c, table 2-6; 2015d, table 2-2; 2015e, table 2-2; 2015f, table 2-2; 2015g, table 2-2; 2015h, table 2-6; 2015i, table 2-2; 2015j, tables 2-2 and 2-3). Potential livestock grazing management practices are presented that can be implemented to help improve ecological conditions and achieve the vegetation habitat objectives for nesting and early brood-rearing habitat for GRSG.

West Central Semi-Arid Prairies—Frigid Bordering on Cryic/Ustic Bordering on Aridic, Grass Dominated with Silver Sagebrush (Management Zone I)

Potential Livestock Grazing Management Practices for the Reference State

There are two primary goals for livestock grazing management practices in the reference state of the silver sagebrush (*Artemisia cana*), 10–14 inch (25–36 centimeter) precipitation zone ecological type (fig. 7.1). The first is to maintain the reference state and prevent a transition to the unsustainable grazing state. The second is to facilitate achievement of vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG in Montana (USDOI BLM 2015a, table 2.3-2; 2015c, table 2-6; 2015d, table 2-2), North Dakota (USDOI BLM 2015f, table 2-2), and South Dakota (USDOI BLM 2015h, table 2-6).

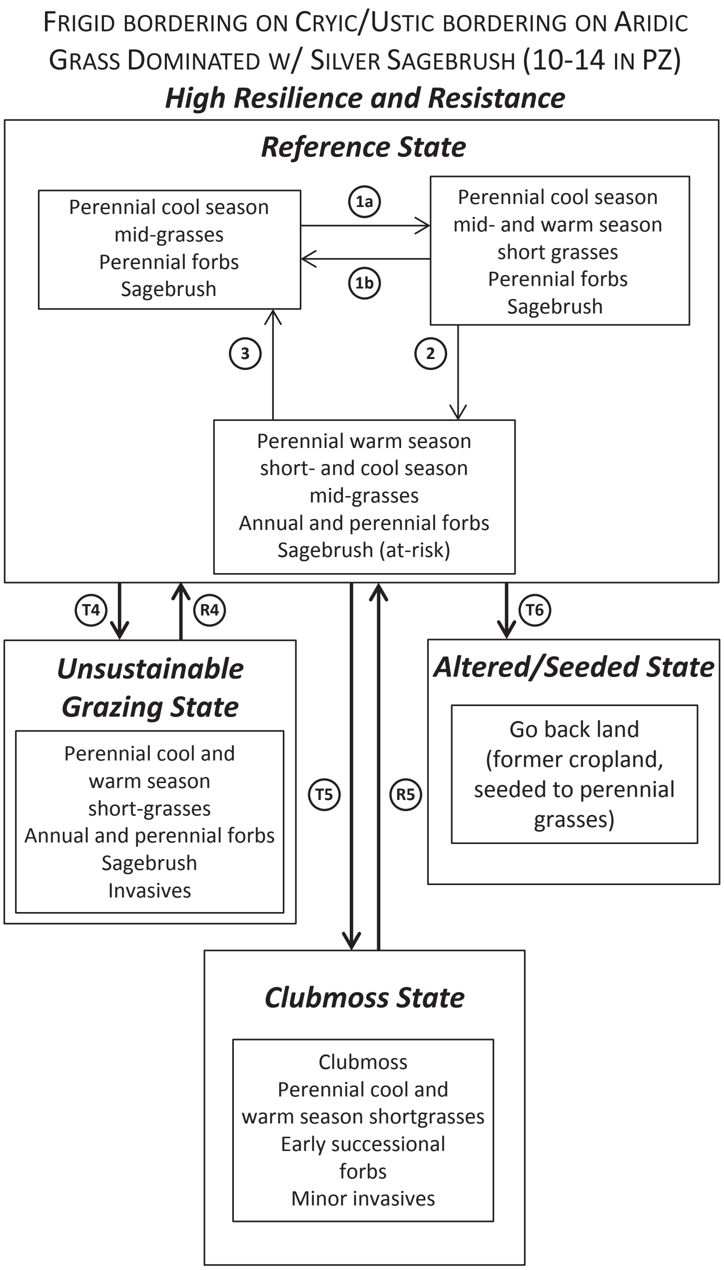
Plant communities in the reference state provide nesting and early brood-rearing habitat for GRSG. Plant communities in the reference state are dominated by perennial cool-season mid-grasses, with less abundance of perennial warm-season short grasses and silver sagebrush. Silver sagebrush is present within a matrix of perennial cool-season mid-grasses and perennial warm-season short grasses.

Consistent year to year, early spring use by livestock will reduce the abundance of perennial cool-season mid-grasses (Adams et al. 2004) and cause a transition to the unsustainable grazing state. Livestock grazing that is deferred to a late spring onset of grazing can improve plant vigor and productivity of the perennial cool-season mid-grasses and provide increased plant cover, reducing the potential conflict between livestock and GRSG during breeding and nesting (Adams et al. 2004). Managing for light grazing intensity of no more than about 25 to 40 percent annual utilization of the perennial grasses can maintain the productivity of the perennial grasses, provide cover to conceal GRSG nesting sites, and improve breeding and brood-rearing habitat (Adams et al. 2004).

Deferred rotation grazing systems can reduce the impacts of livestock to GRSG nesting sites by resting pastures from livestock grazing in the nesting and brood-rearing seasons and rotating early-season grazing among pastures (Adams et al. 2004). Rest-rotation grazing systems can increase perennial grass height in these plant communities compared with season-long grazing (Smith 2016).

In central Montana GRSG nesting habitat comprising mixed stands of silver sagebrush/Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) with perennial cool-season mid-grasses, the cover of silver sagebrush and Wyoming big sagebrush was comparatively more important than the cover and height of herbaceous vegetation, for GRSG nest site selection and nest survival (Smith 2016). Maintaining or increasing the cover of sagebrush in these plant communities is important to maintain breeding habitat for GRSG (Smith 2016). Grazing by livestock does not have direct effects on the cover of silver sagebrush. However, silver sagebrush is often low in stature and can be vulnerable to trampling by livestock, particularly if livestock congregate within silver sagebrush stands in winter (Adams et al. 2004).

To improve early brood-rearing habitat, large flood plain and overflow sites composed of western wheatgrass (*Pascopyrum smithii*)/silver sagebrush plant communities can be fenced off and managed separately as riparian pastures. Forb production can be stimulated with periodic light grazing in spring, at light stocking rates for a short duration, and then grazed again in late summer or fall after the brood-rearing season (Adams et al. 2004).



(1a) Sagebrush increases and proportion of cool season mid-grass Functional/Structural Group decreases due to disturbances such as drought (3-5 years) and spring grazing.

(1b) Normal precipitation patterns favor herbaceous understory. Grazing intensity and/or duration is reduced to allow for herb recovery.

(2) Sagebrush increases and proportion of cool and warm season mid-and short-grass Functional/Structural Groups increases due to prolonged drought (5-7 years), increased grazing intensity and duration, and lack of fire. Plant community is at-risk of leaving reference state with extended drought and continued grazing pressure.

(3) With favorable precipitation, disturbance such as fire, and a grazing system that provides rest and recovery of preferred species, cool season mid-grass Functional/Structural Groups increase.

(T4) Extended drought (>7 years) along with high intensity and long duration grazing result in transition to a state resistant to grazing that is dominated by cool and warm season short-grass Functional/Structural Groups. Silver sagebrush cover is at its highest, and early seral forbs are present. There is potential for invasive species such as field brome in high moisture years and/or due to removal of grazing, lack of fire, and other conditions causing accumulation of excessive litter.

(R4) Normal precipitation patterns, fire or fire surrogates (herbicides and/or mechanical treatments), and a grazing regime with proper timing and intensity that varies season of use can return the site to the reference state.

(T5) Extended drought (>7 years) may result in dense stands of clubmoss. However, no grazing, light grazing, and rotational grazing combined with drought can result in more rapid increase in clubmoss than drought alone. Lack of fire may contribute to this transition as well. Potential for invasives such as field brome is minor, and this transition occurs more often on older, more developed soils with an argillic horizon.

(R5) Extended periods of normal and above average precipitation, mechanical renovation, chemical treatment, fertilizer/manure application, seeding (if an adequate seedbank does not exist), fire, and/or periods of rest or light grazing can return the site to the reference state.

(T6) Former cropland seeded to introduced and/or native perennial grasses, largely funded by government programs. In the 1960-1970s seedings were primarily introduced species such as crested wheatgrass, intermediate wheatgrass, and smooth brome. From 1985 to present both introduced and native species were used, mainly under the Conservation Reserve Program. Sagebrush is largely absent from this state. There is potential for invasive species such as field brome in high moisture years and/or due to removal of grazing, lack of fire, and other conditions that would result in an accumulation of excessive litter.

Figure 7.1—State-and-transition model for a silver sagebrush, 10–14 inch precipitation zone ecological type applicable to the West Central Semiarid Prairies in the eastern part of the sagebrush biome and GRSG range in Montana, North Dakota, and South Dakota (Management Zone I). Large boxes illustrate states that are made up of community phases (smaller boxes). Transitions among states are shown with arrows starting with T; restoration pathways are shown with arrows starting with R. The "at risk" community phase is most vulnerable to transition to an alternative state (figure source: Chambers et al. 2017a, Appendix 5).

Potential Livestock Grazing Management Practices for the Unsustainable Grazing State

Livestock grazing management practices in the unsustainable grazing state (fig. 7.1) have the goal of stimulating a transition of the unsustainable grazing state to a reference state. Plant communities in the reference state provide improved nesting and early brood-rearing habitat for GRSG. Livestock grazing management practices should facilitate achievement of vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG in Montana (USDOI BLM 2015a, table 2.3-2; 2015c, table 2-6; 2015d, table 2-2), North Dakota (USDOI BLM 2015f, table 2-2), and South Dakota (USDOI BLM 2015h, table 2-6).

Grazing management practices that increase the amount of rest in a pasture can be useful in providing more cover for GRSG (Adams et al. 2004). Adams et al. (2004) recommend rest-rotation grazing systems to improve grass and silver sagebrush plant communities that are depauperate in perennial cool-season mid-grasses and aid regeneration of silver sagebrush plants if moisture is available to support resprouting.

Cold Deserts—Frigid/Ustic Bordering on Aridic Wyoming Big Sagebrush (Management Zones II and VII)

Potential Livestock Grazing Management Practices for the Reference State

Livestock grazing management practices in the reference state in the Wyoming big sagebrush, 10–14 inch precipitation zone ecological type (figs. 7.2, 7.3) have two primary goals. The first goal is to maintain the reference state and prevent a transition to the grazing resistant state. The grazing-resistant state results from continuous spring grazing with cattle during the critical growth period for cool season grasses and eventual dominance of grazing-tolerant species: perennial cool-season rhizomatous grasses, short or sod-forming warm-season grasses, and mat-forming forbs. The second goal is to facilitate achievement of vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG in the Wyoming Basin ecoregion (USDOI BLM 2015j, tables 2-2 and 2-3). Plant communities in the reference state provide nesting and early brood-rearing habitat for GRSG.

A livestock grazing strategy that prevents grazing of the perennial cool-season bunchgrasses during the critical growing season (mid-May through mid-June) in at least two out of every three consecutive years is likely to maintain the reference state and prevent a transition to a grazing resistant state (Cagney et al. 2010).

Late season and winter grazing of the reference state may help promote the long-term persistence of perennial cool-season bunchgrasses, but can cause a reduction in the residual herbaceous material of these bunchgrasses that is needed for nesting cover for GRSG the next spring. Residual grasses remaining from the previous year provide the initial herbaceous cover available for nesting GRSG. Thus, late season and winter grazing is not always a grazing management practice that would allow for achieving nesting habitat objectives for GRSG (Cagney et al. 2010).

Potential Livestock Grazing Management Practices for the Grazing Resistant State

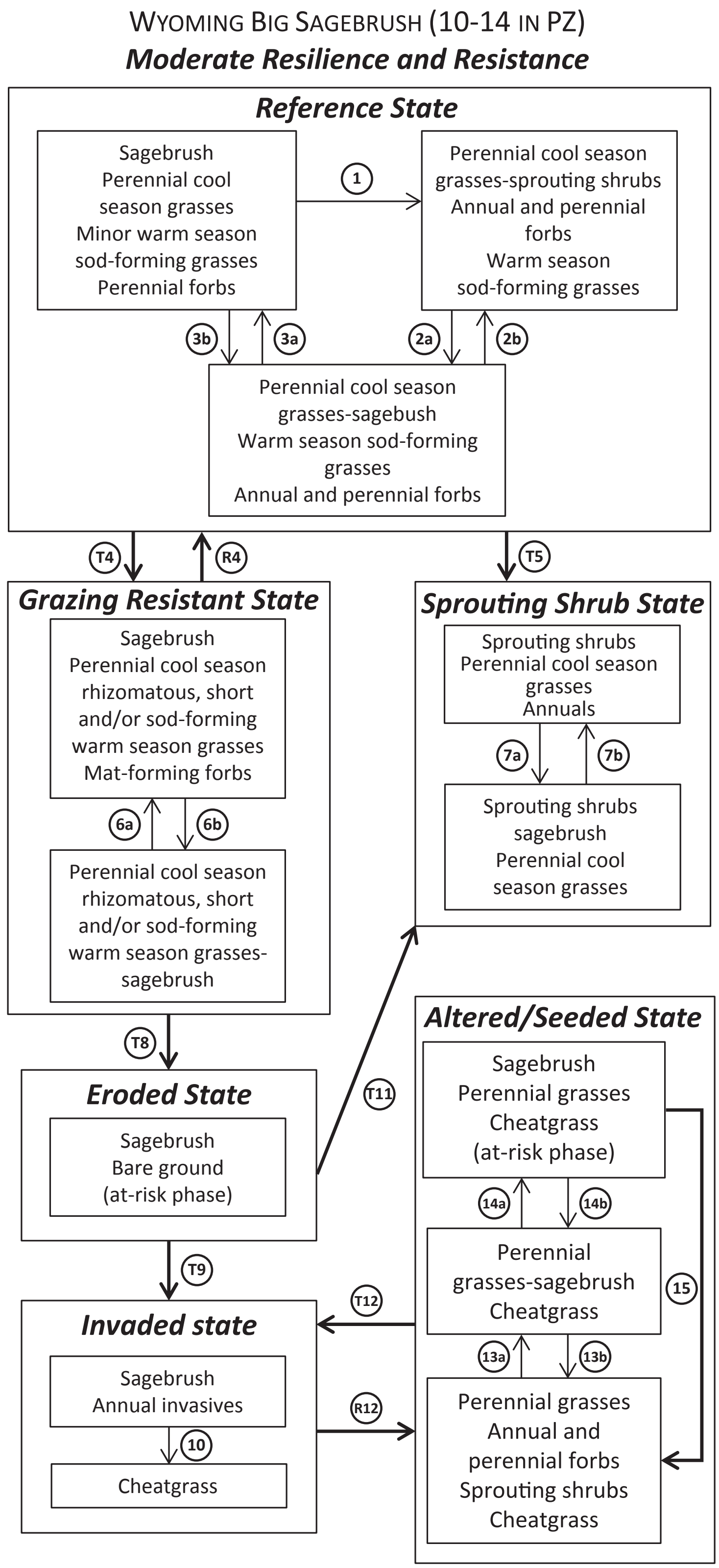
Livestock grazing management practices in the grazing resistant state (figs. 7.2, 7.4) have the goal of stimulating a transition of the grazing resistant state to a reference state. Plant communities in the reference state provide improved nesting and early brood-rearing habitat for GRSG. Livestock grazing management practices should help to achieve the vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG in the Wyoming Basin ecoregion (USDOI BLM 2015j, tables 2-2 and 2-3).

Grazing resistant grasses, specifically rhizomatous grasses and bluegrasses, are unlikely to decrease in abundance with changes in livestock grazing management alone (Cagney et al. 2010). Further, changing livestock grazing management, or eliminating grazing, is likely to have a limited effect on increasing the abundance of large bunchgrasses (Cagney et al. 2010). However, light to moderate grazing with periodic rest during critical growth periods along with fire, herbicides, mechanical treatments, or a combination thereof, may result in return to the reference state. If the grazing resistant state is burned or is treated with herbicides, causing a decrease in the canopy cover of sagebrush, it is advisable to defer livestock grazing during at least the first two growing seasons after fire or herbicide disturbance on these sites. Grazing deferment for two or more growing seasons will allow the remaining perennial, cool season bunchgrasses in this grazing resistant state to increase in abundance (Cagney et al. 2010). Heavy, continuous livestock grazing can cause a decrease in the herbaceous species and a more rapid increase in sagebrush, which will cause the site to progress back to the grazing resistant state (Cagney et al. 2010).

Targeted livestock grazing by domestic sheep in the grazing resistant state can cause browsing of sagebrush that decreases the canopy cover of sagebrush. It also opens up niches for establishment and increases in abundance of the grazing resistant rhizomatous grasses and bluegrasses as well as any remaining cool-season perennial bunchgrasses (Cagney et al. 2010). This treatment is applied in fall or winter when perennial cool-season bunchgrasses are not actively growing. Supplemental feeding of livestock in the winter on this grazing resistant state may be necessary to effectively implement this strategy. However, if these systems are grazed too intensely or too often, they can convert to a sprouting shrub state.

Potential Livestock Grazing Management Practices for the Eroded State

Changes in livestock grazing management alone are unlikely to cause an increase in perennial grasses on the eroded state (figs. 7.2, 7.5) (Cagney et al. 2010). Moreover, livestock grazing management practices alone cannot be used to achieve the vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, for GRSG on the eroded state in the Wyoming Basin ecoregion (USDOI BLM 2015j, tables 2-2 and 2-3). Interseeding with native perennial grasses and forbs may be needed to meet habitat objectives (Huber-Sannwald and Pyke 2005). Grazing deferment for two or more grazing seasons is recommended for seedling establishment.



(1) Perennial grass, sprouting shrubs, and forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens.

(2a) Sagebrush increases with time until co-dominant with the herbaceous understory.

(2b) Perennial grass, sprouting shrubs, and forbs become dominant due to disturbances that decrease sagebrush.

(3a) Sagebrush increases with time until dominant.

(3b) Perennial grass and forbs increase due to disturbances that decrease sagebrush.

(T4) Continuous spring grazing with cattle during the critical growth period of cool season grasses results in dominance of grazing tolerant species that may include warm season grasses (e.g., blue grama). As bare ground increases, surface erosion (e.g., rills, sheet erosion) and pedestalled plants (especially bunchgrasses) may result.

(R4) Light to moderate grazing with periodic rest during critical growth periods along with fire, herbicides, and/or mechanical treatments can result in return to reference state.

(T5) An increase in the disturbance cycle by fire, fire surrogates, mechanical types of disturbance, and/or high density/frequency grazing will favor sprouting shrubs such as rabbitbrush. Annual invasives can occur.

(6a) Sagebrush increases with time. Cheatgrass and other weeds can be present, but do not dominate.

(6b) Perennial cool season grasses increase due to disturbances that decrease sagebrush. A temporary flush of annual invaders is expected.

(7a) Sagebrush increases with time and removal of disturbances until co-dominant with herbaceous understory.

(7b) Perennial cool season grasses and sprouting shrubs increase due to disturbances that decrease sagebrush.

(T8) Perennial grasses and forbs are eliminated and sagebrush increases with high density/frequency grazing by cattle, resulting in altered biotic, hydrologic, and soil function. This state is at-risk to invasion by annuals such as cheatgrass, especially after a stand-replacing, sagebrush killing event.

(T9) If a cheatgrass seed source is introduced, and weather conditions are conducive to establishment (warm wet spring), it will invade, especially after a stand-replacing event that eliminates sagebrush.

(10) Fire and fire surrogates that kill sagebrush will dramatically increase cheatgrass.

(T11) Multiple chemical and/or mechanical treatments or biological disturbances that reduce sagebrush will result in a shift toward sprouting shrub dominance with potential for cheatgrass to invade.

(T12) Catastrophic climatic events and/or fire can result in cheatgrass dominance, especially when in the sagebrush dominant phase of the altered state.

(R12) A restoration treatment, including chemical treatment for cheatgrass and seeding can restore a perennial grass community and eventually support an altered sagebrush community with invaders.

(13a) Sagebrush increases with time and no disturbances until co-dominant with the herbaceous understory, but cheatgrass will be present.

(13b) Perennial grass and forbs become dominant due to disturbances that decrease sagebrush.

(14a) Sagebrush increases with time and no disturbances until dominant, but cheatgrass may be present.

(14b) Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush.

(15) Perennial grass and annual/perennial forbs become dominant due to disturbances that decrease sagebrush.

Figure 7.2—State-and-transition model for a Wyoming big sagebrush, 10–14 inch precipitation zone ecological type applicable to the Cold Deserts in the eastern part of the sagebrush biome and GRSG range in the Wyoming Basin in the western and central portions of Wyoming (Management Zones II and VII). Large boxes illustrate states that are made up of community phases (smaller boxes). Transitions among states are shown with arrows starting with T; restoration pathways are shown with arrows starting with R. The "at risk" community phase is most vulnerable to transition to an alternative state (figure source: Chambers et al. 2017a, Appendix 5).

Figure 7.3—Example of a plant community phase in the reference state in the Wyoming big sagebrush, 10–14 inch precipitation zone ecological type (fig. 7.2) in Wyoming. The site is dominated by Wyoming big sagebrush with an herbaceous understory dominated by cool-season perennial bunchgrasses. This plant community phase provides nesting and early brood-rearing habitat for GRSG (photo by Jim Cagney, used with permission).

Cold Deserts—Mesic/Aridic Bordering on Xeric Wyoming Big Sagebrush (Management Zones III, IV, and V)

Potential Livestock Grazing Management Practices for the Invaded State

Livestock grazing management practices in the invaded state (figs. 7.6, 7.7) can be used to promote an increase of perennial grasses to increase resistance to invasive annual grasses. Livestock grazing management practices can also help achieve the vegetation habitat objectives for nesting and brood-rearing seasonal habitat for GRSG in Oregon and Washington (USDOI BLM 2015g, table 2-2), Utah (USDOI BLM 2015i, table 2-2), Nevada and northeastern California (USDOI BLM 2015e, table 2-2), and Idaho and southwestern Montana (USDOI BLM 2015b, table 2-2).

Effects of grazing on the abundance of annual grasses such as cheatgrass (*Bromus tectorum*) depend on multiple factors including: (1) the relative resilience of the site as indicated by soil temperature and moisture regimes, (2) the relative resistance of the site as indicated by its climatic suitability for cheatgrass (fig. 7.8) (Strand et al. 2014), and (3) the relative abundance of competitive perennial grasses and forbs (Chambers et al. 2014a,b). If sufficient

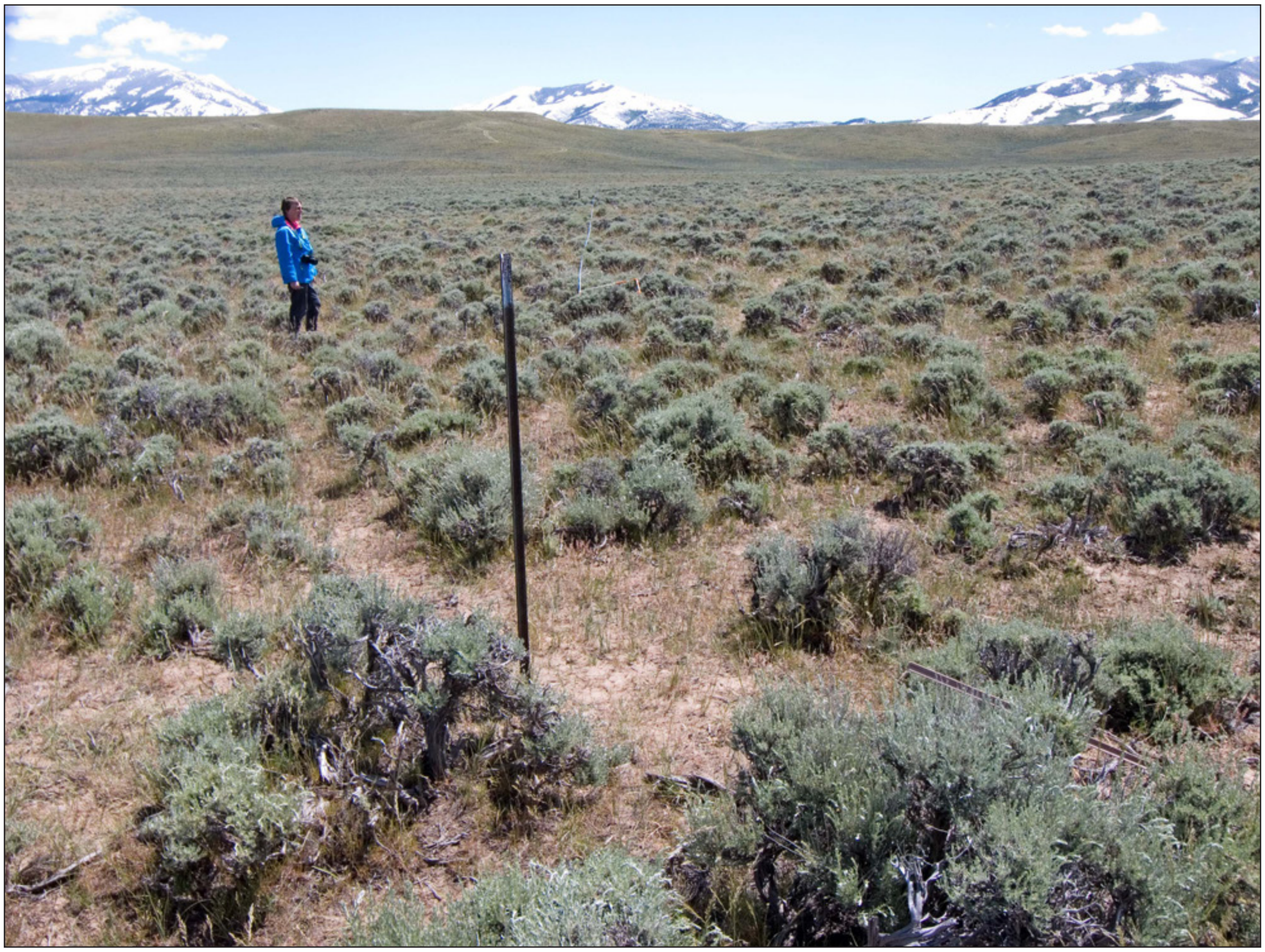


Figure 7.4—Example of a plant community phase in the grazing resistant state in the Wyoming big sagebrush, 10–14 inch precipitation zone ecological type (fig. 7.2) in Wyoming. The site is dominated by Wyoming big sagebrush with an herbaceous understory dominated by rhizomatous grasses and bluegrasses. If the herbaceous understory is not depleted, this plant community phase can provide nesting habitat for GRSG. With a depleted herbaceous understory, this plant community phase does not provide nesting habitat for GRSG (photo by Jim Cagney, used with permission).

perennial native grasses remain on the site, managed livestock grazing may result in an increase in perennial grasses and forbs and a decrease in invasive annual grasses, especially on relatively cool and moist sites. Grazing when perennial grasses are beginning to flower is likely to cause a decline in perennial grasses and an increase in cheatgrass (fig. 7.8) (Strand et al. 2014). Early spring grazing may suppress the abundance of cheatgrass and promote an increase of perennial grasses if grazing is applied when the annual grasses are starting to produce seeds but before the perennial grasses begin to bolt (fig. 7.8) (Strand et al. 2014). Livestock grazing persisting into the time when perennial grasses are beginning active growth can be detrimental to the perennial grasses (fig. 7.8) (Strand et al. 2014). Early spring grazing of cheatgrass can be difficult to plan for year after year and can be challenging to implement in a livestock grazing permit or lease on Federal land. This is because the amount of cheatgrass forage available in the early spring depends on the amount and timing of precipitation and varies considerably from year to year (Chambers et al. 2014b; West and Yorks 2002). Thus, the length of time that cheatgrass forage is available to be grazed in the early spring will vary from year to year, and permittees and lessees will have a difficult time planning ahead for how many animals will be required to consume the cheatgrass (Schmelzer et al. 2014).

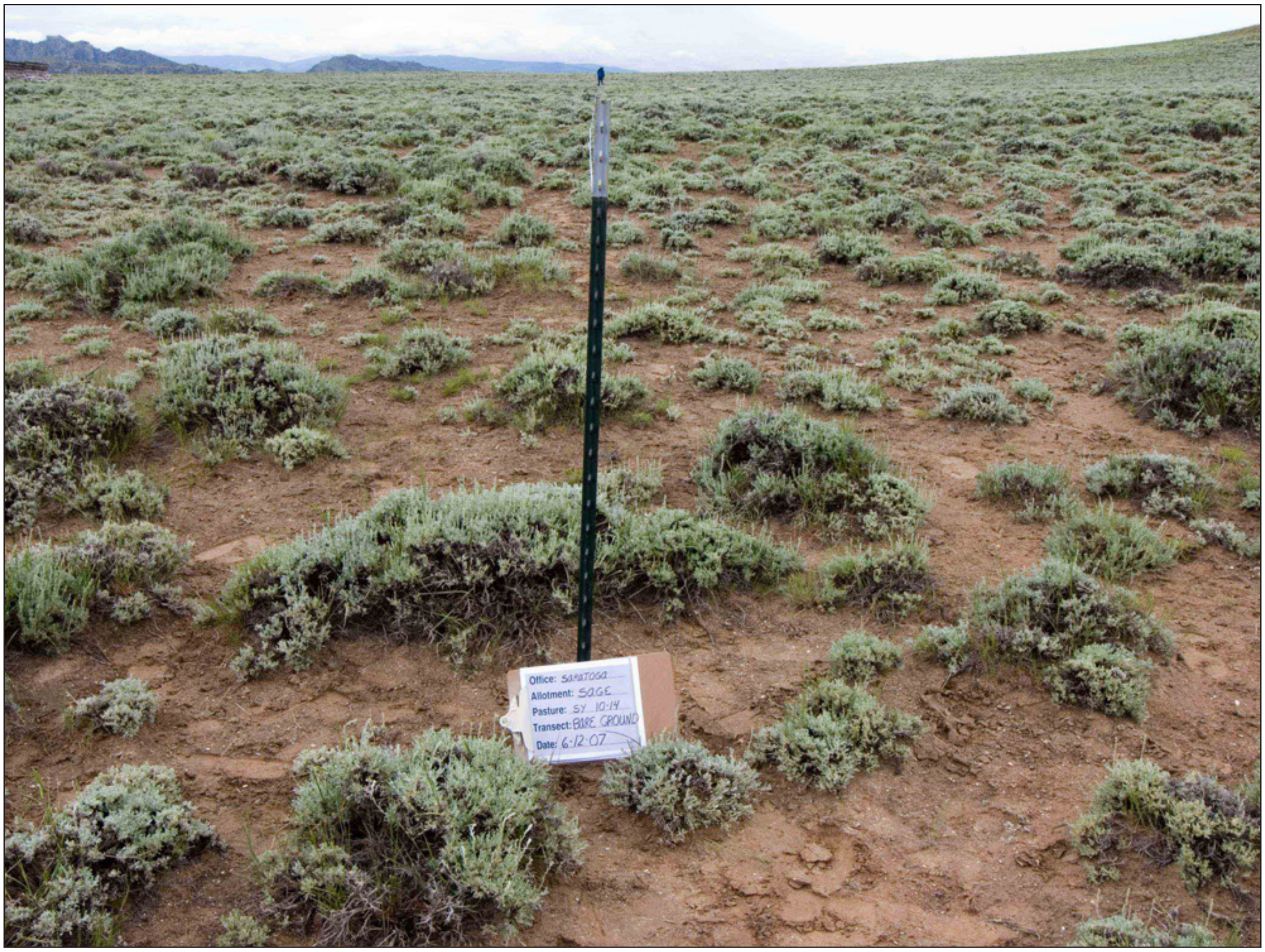
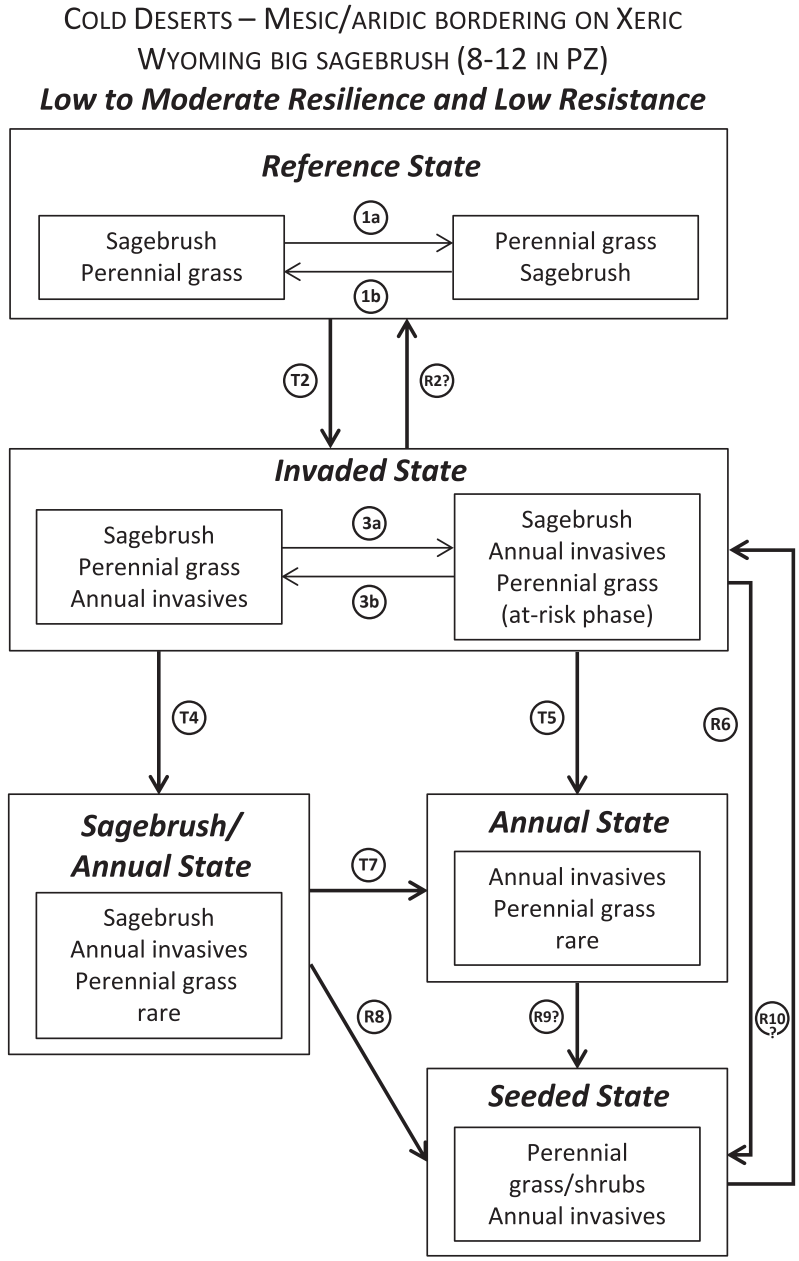


Figure 7.5—Example of a plant community phase in the eroded state in the Wyoming big sagebrush, 10–14 inch precipitation zone ecological type (fig. 7.2) in Wyoming. The site is dominated by Wyoming big sagebrush and bare ground. Herbaceous vegetation is located primarily beneath shrubs or cactus. This plant community phase is not providing nesting or early brood-rearing habitat for GRSG (photo by Jim Cagney, used with permission).

Grazing with cattle during the fall at appropriate levels repeatedly over time may reduce the abundance of cheatgrass and will probably not decrease the abundance of the perennial grasses. But few longer-term data exist (Schmelzer et al. 2014; Strand et al. 2014) (see fig. 7.8).

Once the perennial native herbaceous species have been depleted, recovery of perennial native grasses is likely to be a slow process in this ecological type even with long-term rest from livestock grazing (e.g., West et al. 1984). Further, once the perennial native herbaceous species have been depleted, sagebrush and other shrubs may continue to increase in abundance for a decade or more even with removal of livestock (Chambers et al. 2017b; West et al. 1984). Thus, for areas within the invaded state with moderate cover of perennial native grasses, grazing practices to maintain or increase the cover of these species is a priority.

The effects of livestock grazing on wildfire potential in the invaded and other states depend on the relative proportion of sagebrush to herbaceous fuels combined with weather conditions. The potential for grazing to be effective in reducing the risk of fire initiation and spread is greatest when sagebrush cover is low and fire weather severity is low to moderate (fig. 7.9) (Strand et al. 2014). Long-term removal of grazing may increase the likelihood of wildfire-induced mortality of perennial bunchgrasses in some ecological sites because of fuel



(1a) Perennial grass increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.

(1b) Sagebrush increases with time.

(T2) An invasive seed source and/or improper grazing trigger an invaded state.

(R2) Proper grazing, fire, herbicides and/or mechanical treatments are unlikely to result in return to the reference state on all but the coolest and wettest sites.

(3a) Perennial grass decreases and both sagebrush and invasives increase with improper grazing resulting in an at-risk phase. Decreases in sagebrush due to insects, disease or pathogens can further increase invasives.

(3b) Proper grazing and herbicides or mechanical treatments that reduce sagebrush may restore perennial grass and decrease invaders on wetter sites (10-12”). Outcomes are less certain on drier sites (8-10”) and/or low abundance of perennial grass.

(T4) Improper grazing triggers a largely irreversible threshold to a sagebrush/annual state.

(T5) Fire or other disturbances that remove sagebrush result in an annual state.
(T7) Perennial grass is rare and recovery potential is low due to low precipitation and competition from annual invasives. Repeated fire can cause further degradation.

(R6) Seeding following fire and/or invasive species control results in a seeded state.
(R8) (R9) Sagebrush may recolonize depending on patch size, but annual invasives are still present.

(R10) Seeding effectiveness and return to the invaded state are related to site conditions, seeding mix, and post-treatment weather.

Figure 7.6—State-and-transition model for a Wyoming big sagebrush, 8–12 inch precipitation zone ecological type applicable in the Cold Deserts in the western part of the sagebrush biome and GRSG range in the Snake River Plain, Northern Basin and Range, and Central Basin and Range ecoregions (Management Zones III, IV, and V). Large boxes illustrate states that are made up of community phases (smaller boxes). Transitions among states are shown with arrows starting with T; restoration pathways are shown with arrows starting with R. The “at risk” community phase is most vulnerable to transition to an alternative state (figure source: Chambers et al. 2017a, Appendix 6).

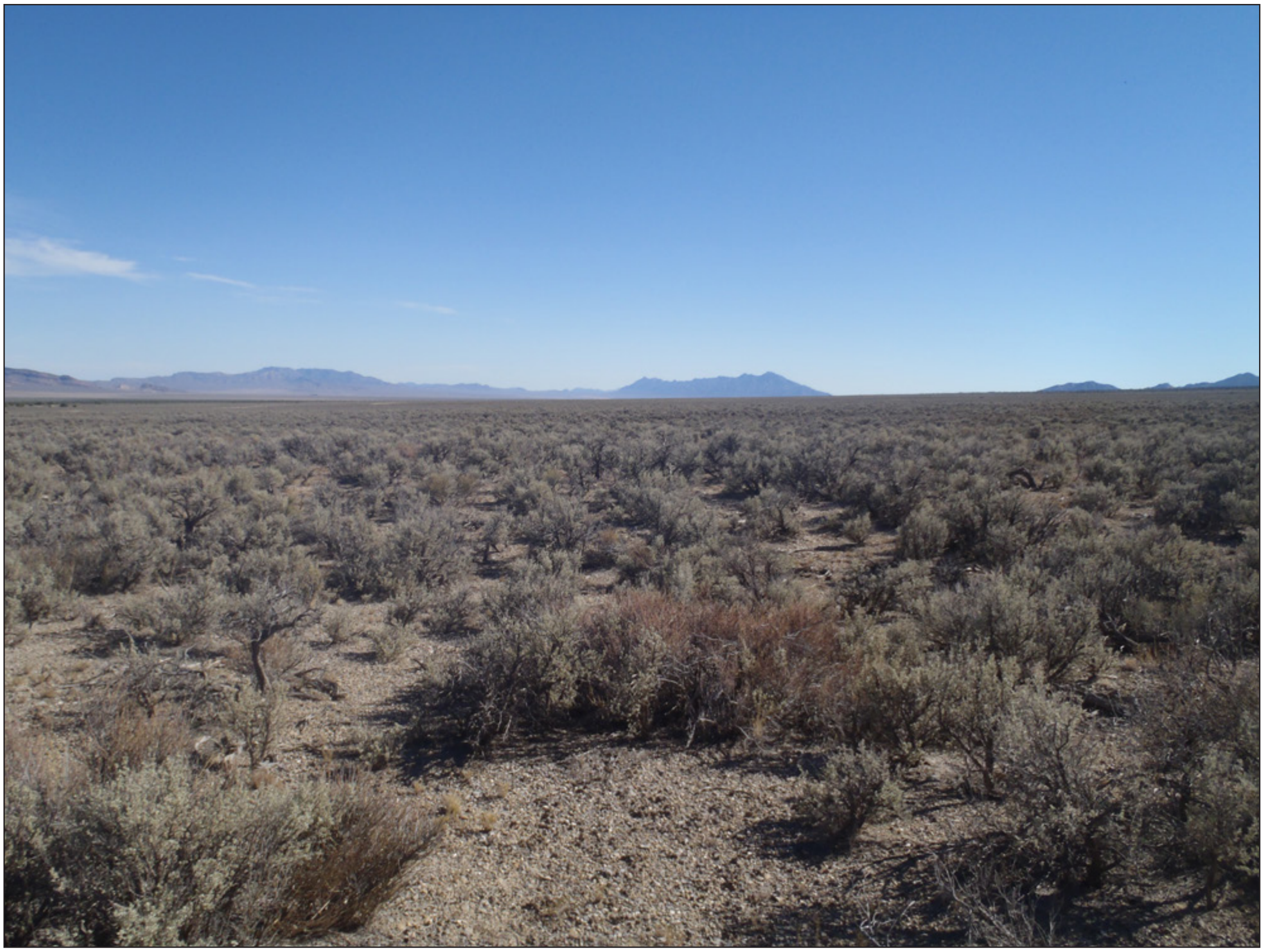


Figure 7.7—Example of a plant community phase in the invaded state in the Wyoming big sagebrush, 8–12 inch precipitation zone ecological type (fig. 7.6) in Nevada. The plant community phase is dominated by Wyoming big sagebrush and cheatgrass with some perennial grasses. This site is not providing optimum nesting or early brood-rearing habitat for GRSG (photo by BLM).

buildup on the root crown of perennial bunchgrasses (Davies et al. 2009, 2010). While grazing may decrease fuels and reduce wildfire severity or extent in some cases (fig. 7.9), as weather conditions become extreme, the potential role of grazing in wildfire behavior decreases and may become meaningless (Strand et al. 2014).

Potential Livestock Grazing Management Practices for the Annual State

Shifts in plant communities in sagebrush ecosystems toward invasive annual grass dominance were caused in part by historical improper livestock grazing (Davies et al. 2014). However, changes in grazing practices in the annual state (figs. 7.6, 7.10) are not likely to aid conversion of annual grass-dominated plant communities back to native species-dominated communities (Davies et al. 2014; Strand et al. 2014). Similarly, changes in grazing practices in the annual state cannot be used to achieve vegetation habitat objectives for nesting and brood-rearing seasonal habitat for GRSG in Oregon and Washington (USDOI BLM 2015g, table 2-2), Utah (USDOI BLM 2015i, table 2-2), Nevada and northeastern California (USDOI BLM 2015e, table 2-2), and Idaho and southwestern Montana (USDOI BLM 2015b, table 2-2).

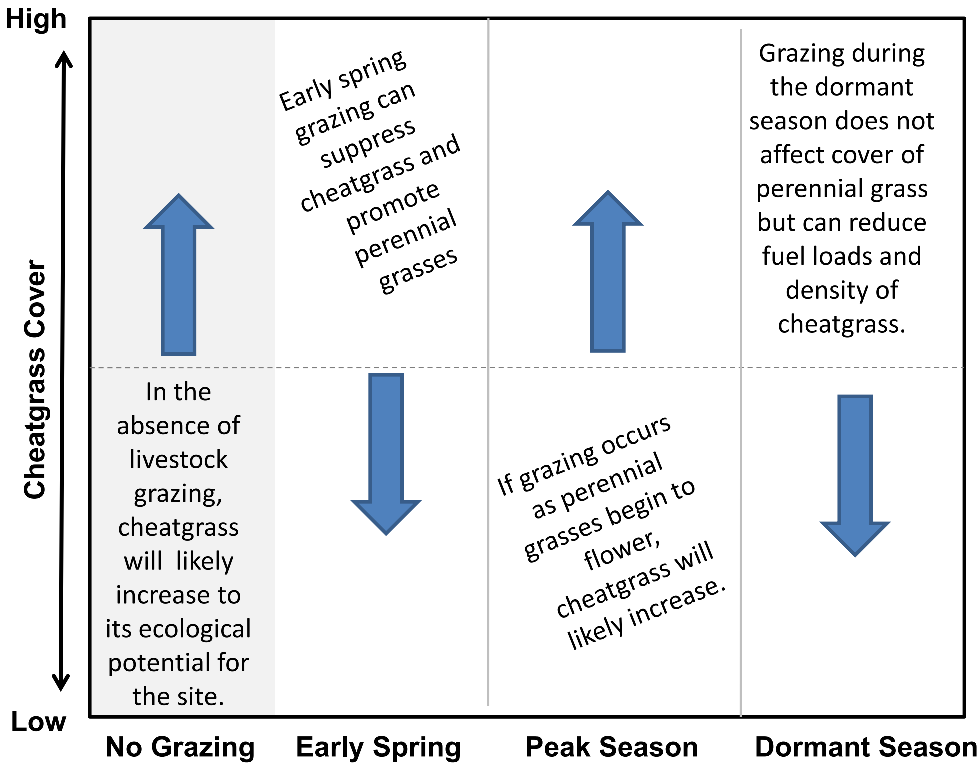


Figure 7.8—Conceptual depiction of how livestock grazing can influence cheatgrass abundance in sagebrush dominated ecosystems with a significant component of perennial grasses. Grazing can suppress or promote cheatgrass depending primarily on the season of grazing. Grazing suppresses cheatgrass when applied (1) in early spring when annuals begin to produce seeds and before native perennial grasses initiate bolting, and (2) during the dormant season (figure source: Strand et al. 2014, used with permission).

Grazing of the annual state can be effective in reducing the risk of fire initiation and spread (fig. 7.9). Targeted grazing, or the application of a specific kind of livestock at a determined season, duration, and intensity, can be used to achieve defined vegetation or broad-scale goals within annual states (Launchbaugh and Walker 2006; Mosley and Roselle 2006). For example, intense sheep grazing of cheatgrass dominated sites can effectively suppress or even eliminate cheatgrass stands in as little as 2 years, as was done in the urban interface above Carson City, Nevada (Mosley 1994). Managed grazing may also reduce the risk and extent of wildfire in cheatgrass dominated areas (Diamond et al. 2009, 2012; Walker 2006).

In sagebrush ecosystems, high intensity targeted grazing may best be used to create firebreaks by confining livestock to a strip of land with temporary fencing. This type of grazing may reduce the spread of wildfire by reducing herbaceous vegetation (fine fuels that carry fire) (Walker 2006). Further, because livestock tend to graze some areas more intensely than others, grazing may create patchy vegetation that reduces the continuity of fuel loads and the fires (Walker 2006). However, this reduction in fuel continuity is influenced strongly by multi-year precipitation patterns (Pilliod et al. 2017) and timing of grazing.

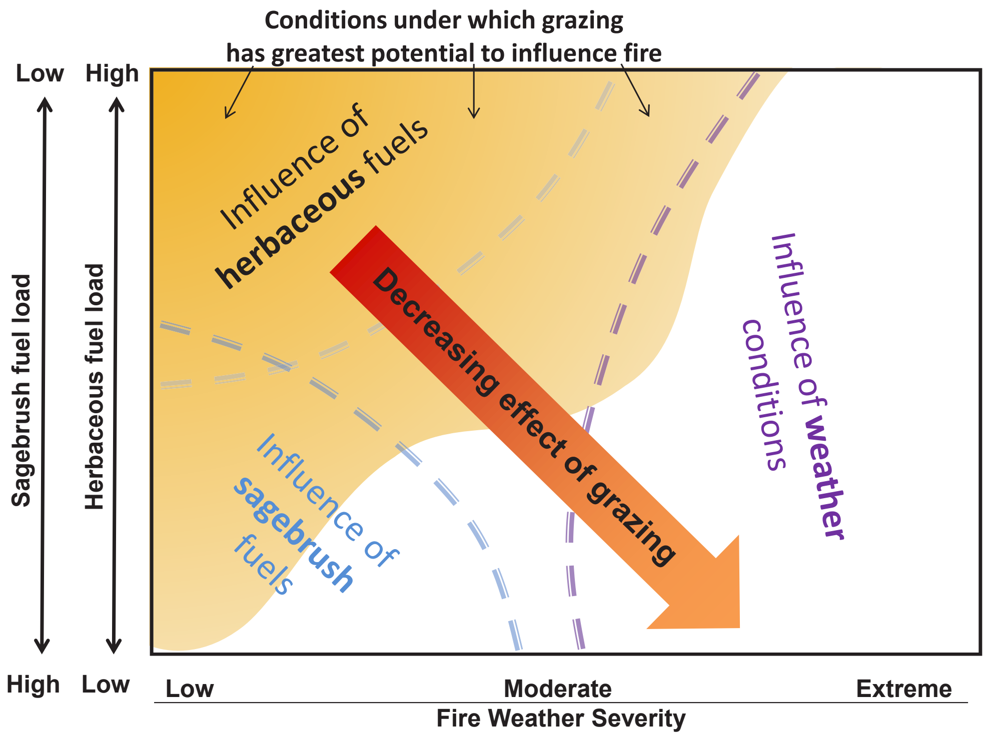


Figure 7.9—Conceptual model illustrating how the potential for grazing to influence fire behavior occurs along continuums of fuel and weather conditions. Fuel composition is displayed on the y-axis and fire weather condition is displayed on the x-axis. Low fire weather severity is characterized by high fuel moistures, high relative humidity, low temperature, and low wind speeds, whereas extreme fire weather is characterized by the opposite conditions. The potential for grazing to be effective in reducing the risk of fire initiation and spread is greatest when the sagebrush cover is low and the fire weather severity is low to moderate (figure source: Strand et al. 2014, used with permission).

Effective grazing programs for invasive plant control require a clear statement of the kind of animal and timing and rate of grazing necessary to suppress the invasive plant (Launchbaugh and Walker 2006). A successful targeted grazing prescription should: (1) cause significant reductions in the target plant(s), (2) limit effects to the surrounding vegetation, and (3) be integrated with other control methods as part of an overall management strategy. Because targeted grazing by livestock is typically focused on heavily invaded areas, follow-up management, such as seeding the target area with the desired perennial species, may be needed.

Potential Livestock Grazing Management Practices for the Seeded State

After wildfire, areas within the Wyoming big sagebrush, 8–12 inch (20–30 centimeter) precipitation zone that support GRSG are often a priority for seeding because residual perennial native grasses are typically insufficient to promote recovery (fig. 7.11). Seeding with a diverse mix of native shrubs, grasses, and forbs can increase resilience to disturbance as well as resistance to invasive annual grasses through increased competition with the invaders over the long term (see section 6).

Grazing rest and deferment schedules are needed to ensure establishment of the seeded species and recovery of the site after postwildfire rehabilitation (Pyke et al. 2017). Newly seeded and surviving plants are at risk of repeated defoliation due to animal preference for foraging in burned areas (Veblen et al. 2015). Thus,

Figure 7.10—Example of a plant community phase in the annual state in the Wyoming big sagebrush, 8–12 inch precipitation zone ecological type (fig. 7.6). The plant community phase is dominated by exotic annual grasses and forbs such as cheatgrass, medusahead (*Taeniatherum caput-medusae*), and tumblemustard (*Thelypodiopsis* spp.). The site is located in the Jackies Butte allotment in the Jordan Resource Area of the BLM's Vale District in Oregon. This site is not providing nesting or early brood-rearing habitat for GRSG (photo by Jon Sadowski, used with permission).

grazing should be resumed only after perennial grasses have established and are producing viable seed at levels equal to grasses on unburned sites. Failure to implement a program of grazing rest or deferment may slow or prevent site recovery (Kerns et al. 2011) and promote invasive annual grasses and other undesirable plants.

Once postfire grazing resumes on a site, use should be deferred until after seed maturity or shatter to promote bunchgrass recovery (Bates et al. 2009; Bruce et al. 2007). In addition, postfire grazing after rest or during deferment periods will probably need to be lighter than grazing recommendations for unburned areas, which are no more than 50 percent utilization during active growth, and no more than 60 percent during dormancy (Guinn and Rouse 2009). Under certain conditions (e.g., in warm or dry areas, after high severity fires, or during low precipitation years), even lower utilization may be required to allow seeded species to establish and soils to recover. Options for mitigating livestock distribution problems in large grazing units include fencing, herding, and strategic placement of water, salt, and supplements.

Careful monitoring and assessment is an integral part of a grazing program to determine when grazing may be resumed, whether postfire grazing management has been effective, and whether changes in grazing management are needed.

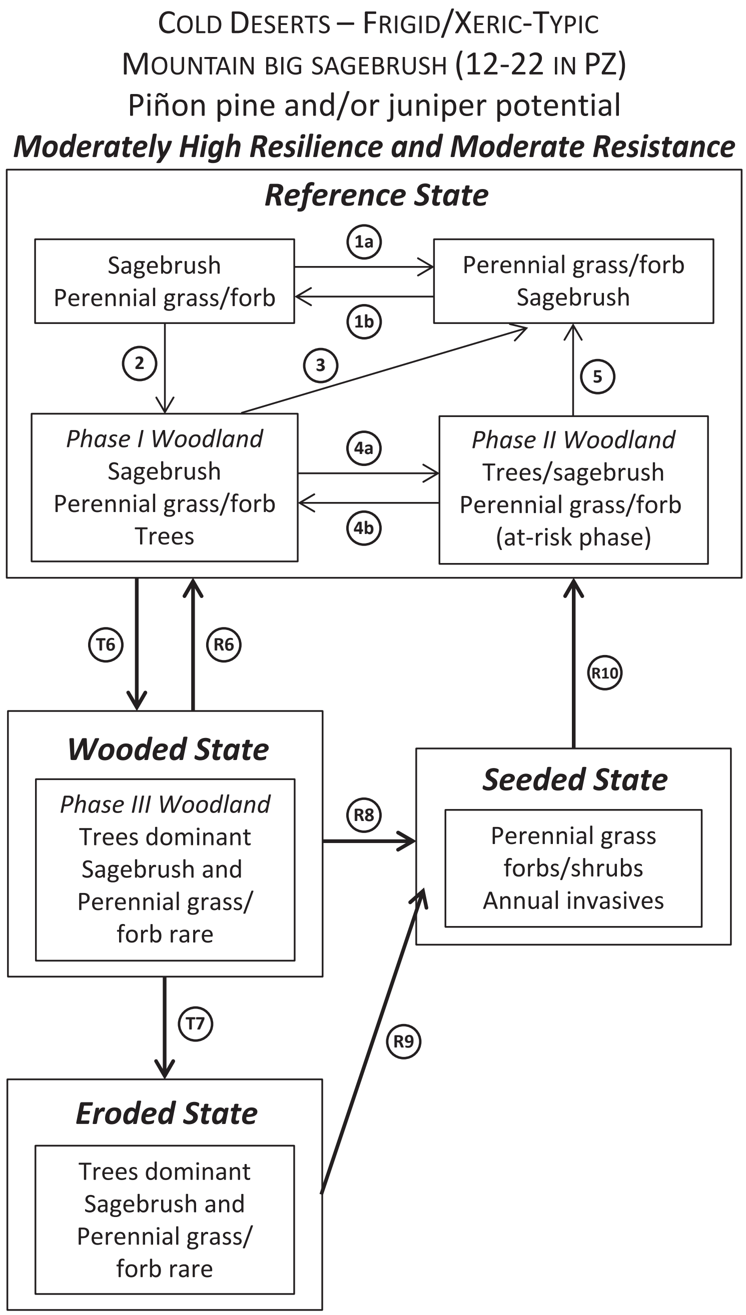
Figure 7.11—Example of a plant community phase in the seeded state in the Wyoming big sagebrush, 8–12 inch precipitation zone ecological type (fig. 7.6). Plant community phase is a seeding dominated by Fairway crested wheatgrass. The site is located in the Jackies Butte allotment in the Jordan Resource Area of the BLM's Vale District in Oregon. This site is not providing nesting or early brood-rearing habitat for GRSG (photo by Jon Sadowski, used with permission).

Cold Deserts—Frigid/Xeric-Typic Mountain Big Sagebrush with Piñon Pine and/or Juniper Potential (Management Zones III, IV, and V)

Potential Livestock Grazing Management Practices for the Reference State—Phase I and II Woodland

Managing livestock grazing in plant communities with phase I and II juniper and piñon in the reference state (figs. 7.12, 7.13) to maintain perennial grasses can decrease the rates of juniper and piñon expansion and infill into adjacent sagebrush ecosystems (Guenther et al. 2004; Madany and West 1983; Shinneman and Baker 2009; Soulé et al. 2004). Grazing management to maintain perennial grasses can increase the resilience of these plant communities and their capacity to recover after wildfire (Chambers et al. 2014a). It can also increase resistance to invasive annual grasses on warmer and drier sites (Chambers et al. 2014a,b).

In studies that compared adjacent grazed and historically ungrazed areas, juniper and piñon densities, canopy cover, or basal area were greater in the grazed than ungrazed pastures (Guenther et al. 2004; Madany and West 1983; Shinneman and Baker 2009; Soulé et al. 2004). Further, shrubs often act as nurse plants for juniper and piñon by modifying temperatures and increasing resource availability (Chambers 2001; Johnsen 1962; Miller and Rose 1995; Soulé and Knapp 2000, Soulé et al. 2004). Shrub abundance can increase after fire in



- **1a** Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial grass/forb.
- **1b** Sagebrush increases with time.
- **2** Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland.
- **3, 5** Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.
- **4a** Increasing tree abundance results in a Phase II woodland with depleted perennial grass/forb and shrubs and an at-risk phase.
- **4b** Fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.
- **T6** Infilling of trees and/or improper grazing can result in a biotic threshold crossing to a wooded state with increased risk of high severity crown fires.
- **R6** Fire, herbicides and/or mechanical treatments that remove trees may restore perennial grass/forb and sagebrush dominance.
- **T7** An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.
- **R8, R9** Seeding after treatments or fire may be required on sites with depleted perennial grass/forb, but seeding with aggressive introduced species can decrease native perennial grass/forb. Annual invasives are typically rare. Seeded eroded states may have lower productivity.
- **R10** Depending on seed mix and grazing, return to the reference state may be possible if an irreversible threshold has not been crossed.

Figure 7.12—State-and-transition model for a mountain big sagebrush, 12–22 inch precipitation zone ecological type applicable in the Cold Deserts in the western part of the sagebrush biome and GRSG range in the Snake River Plain, Northern Basin and Range, and Central Basin and Range ecoregions (Management Zones III, IV, and V). Large boxes illustrate states that are made up of community phases (smaller boxes). Transitions among states are shown with arrows starting with T; restoration pathways are shown with arrows starting with R. The "at risk" community phase is most vulnerable to transition to an alternative state (figure source: Chambers et al. 2017a, Appendix 6).

Figure 7.13—Example of a phase II woodland plant community in the reference state of the mountain big sagebrush, 12–22 inch precipitation zone ecological type (fig. 7.12) in Nevada. This woodland is dominated by piñon pine. Piñon pine is continuing to expand and increase in density and canopy cover, and mountain big sagebrush and bluebunch wheatgrass (*Pseudoroegneria spicata*) are declining in canopy cover. This plant community phase is not providing nesting or early brood-rearing habitat for GRSG (photo by Jeanne Chambers).

response to grazing that removes perennial grasses in mountain big sagebrush ecological types (Chambers et al. 2017b). A recent simulation model that evaluated woodland expansion across the Intermountain West identified grazing as the key factor leading to juniper expansion through reduction of perennial grass and shrub cover as well as decreases in fire occurrence (Caracciolo et al. 2017).

Areas with more than 2 percent conifer cover severely compromise GRSG habitat use and can result in greater bird mortality (Coates et al. 2017; Severson et al. 2016). Thus, changes in grazing management alone in phase I or phase II plant communities in the reference state (figs. 7.12, 7.13) cannot be used to achieve vegetation habitat objectives for nesting and brood-rearing seasonal habitat for GRSG in Oregon and Washington (USDOI BLM 2015g, table 2-2), Utah (USDOI BLM 2015i, table 2-2), Nevada and northeastern California (USDOI BLM 2015e, table 2-2), and Idaho and southwestern Montana (USDOI BLM 2015b, table 2-2). However, phase I and phase II expansion woodlands are often targeted for conifer removal treatments to improve GRSG habitat. Treatments may include cutting and leaving the trees, shredding or masticating the trees, and in some cases, prescribed fire. Bunchgrasses and other perennial vegetation may exhibit increases in cover, but may take several years to fully

Figure 7.14—Example of a plant community phase in the wooded state in the mountain big sagebrush, 12–22 inch precipitation zone ecological type (fig. 7.12) in Nevada. The site is a phase III woodland dominated by piñon pine that was dominated in the past by sagebrush and Thurber's needlegrass (*Achnatherum thurberianum*). This plant community phase is not providing nesting or early brood-rearing habitat for GRSG (photo by Jeanne Chambers).

recover, especially on warmer and drier sites and following prescribed fire (Williams et al. 2017). During the recovery period, many of the same livestock grazing management practices as used after fire and rehabilitation seeding may be used, including rest and deferment, decreased levels of utilization, changes in the timing of livestock grazing, and increased emphasis on livestock distribution.

Potential Livestock Grazing Management Practices for the Wooded State—Phase III Woodland

Because GRSG do not use phase III woodland (fig. 7.14) (Severson et al. 2017), changes in grazing management alone cannot be used to achieve vegetation habitat objectives for nesting and brood-rearing seasonal habitat for GRSG in the wooded state in Oregon and Washington (USDOI BLM 2015g, table 2-2), Utah (USDOI BLM 2015i, table 2-2), Nevada and northeastern California (USDOI BLM 2015e, table 2-2), and Idaho and southwestern Montana (USDOI BLM 2015b, table 2-2). However, following wildfire and postfire rehabilitation seeding or tree removal in these areas to increase connectivity of sagebrush habitat, many of the same livestock grazing management practices as used after wildfire and postfire rehabilitation seeding may be used.

Conclusions

Livestock grazing management is a critical aspect of maintaining and improving resilience to disturbance and resistance to invasive annual grasses in sagebrush ecosystems and GRSG habitat. Livestock grazing has well-recognized effects on ecosystem structure and function that vary among ecoregions and GRSG Management Zones. Consideration of the potential regional variation in grass-related variables and the effects associated with plant phenology can help in the development of management prescriptions for livestock grazing to attain habitat objectives within nesting habitats. Potential livestock grazing management practices designed to improve sagebrush habitats can be incorporated into livestock grazing management alternatives during the grazing authorization (grazing permits and grazing leases) renewal process, which is ongoing within the BLM (USDOI BLM 2017a) and other agencies. Specific vegetation habitat objectives for breeding and nesting seasonal habitat, and brood-rearing and summer seasonal habitat, have been developed by BLM and its partners. But it may be necessary to modify and update these as additional information on GRSG habitat requirements and ecological site potentials to support GRSG habitat become available and additional policy direction is provided (USDOI BLM 2017b).

The Science Framework provides an approach for managing sagebrush ecosystems based on their relative resilience and resistance to invasive annual grasses. This approach can be used to evaluate the likely response of an area to disturbance or management actions and the capacity of an area to support target species or resources at the mid-scale. At the local scale, ecological types or ecological site descriptions and their associated STMs can be used to evaluate current ecological dynamics and determine appropriate livestock grazing management practices. In this section, examples of ecological types and STMs illustrate the use of these tools for identifying livestock grazing management practices that can be implemented to maintain or improve the resilience and resistance of sagebrush plant communities and the quality of GRSG nesting and early brood-rearing habitat.

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8. WILD HORSE AND BURRO CONSIDERATIONS

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Introduction

Wild horses (*Equus caballus*) and wild burros (*E. asinus*), like domestic livestock, can alter sagebrush ecosystem structure and composition and affect habitat quality for sagebrush dependent species (Beever and Aldridge 2011). The presence of Federally protected wild horses and wild burros can also have substantial effects on the capacity for habitat restoration efforts to achieve conservation and restoration goals. In the Conservation Objectives Team Report (USDOI FWS 2013), the presence of wild horses and burros was considered a threat to Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) habitat quality, particularly in the sage-grouse's western range (USDOI FWS 2013). Four years after the Conservation Objectives Team Report was published, wild horse population sizes on Bureau of Land Management (BLM) and Forest Service lands have almost doubled (USDOI BLM 2017).

Lands with Federally protected wild horses and burros are managed for multiple uses, so it can be difficult to separate their ecological effects. However, scientific studies designed to isolate the effects of various land uses lead to the conclusion that landscapes with greater wild horse and burro abundance tend to have lower resilience to disturbance and resistance to invasive plants than similar landscapes with herds at or below target levels (Beever and Aldridge 2011; Chambers et al. 2017 [hereafter, Part 1], section 5.3.8). Many studies corroborate the general understanding that wild horses can lead to biologically significant changes in sagebrush ecosystems, particularly when their populations are overabundant relative to forage and water resources. In the Great Basin, areas without wild horses had higher shrub cover, plant cover, species richness, native plant cover, and overall plant biomass, and lower cover of grazing-tolerant, unpalatable, and invasive plant species such as cheatgrass (*Bromus tectorum*), when compared to areas with horses (Beever et al. 2008; Boyd et al. 2017; Davies et al. 2014; Smith 1986; Zeigenfuss et al. 2014). There were also measurable increases in soil penetration resistance and erosion, decreases in ant mound and granivorous small mammal densities, and changes in reptile communities (Beever et al. 2003; Beever and Brussard 2004; Beever and Herrick 2006; Ostermann-Kelm et al. 2009).

Top: Wild horses at Cherry Spring in the Maverick-Medicine Herd Management Area, Nevada (photo: USDOI Bureau of Land Management). Middle left: Wild horses in Divide Basin Horse Management Area, Wyoming (photo: USDOI Bureau of Land Management). Middle right: Wild burros at Wood Hills spring in the Elko, Nevada, BLM District (photo: USDOI Bureau of Land Management). Bottom left: Wild Horses at Victoria spring in the Antelope Triple B complex (photo: USDOI Bureau of Land Management). Bottom right: Wild horse gather by the BLM (photo: USDOI Bureau of Land Management).

Wild horses can have severe impacts on water source quality, aquatic ecosystems, and riparian communities (Barnett 2002; Beever and Brussard 2000; Earnst et al. 2012; Kaweck 2016; Nordquist 2011; USDOI FWS 2008, 2012) and can sometimes exclude native ungulates from water sources (Gooch et al. 2017; Hall et al. 2016; Ostermann-Kelm et al. 2008; Perry et al. 2015; USDOI FWS 2008). Bird nest survival may be lower in areas with wild horses (Zalba and Cozzani 2004), and bird populations have recovered substantially after livestock or wild horses, or both, have been removed (Batchelor et al. 2015; Earnst et al. 2005, 2012). Wild horses can spread nonnative plant species, including cheatgrass, and may limit the effectiveness of reseeding projects (Beever et al. 2003; Couvreur et al. 2004; Jessop and Anderson 2007; Loydi and Zalba 2009). Even after domestic livestock are removed, continued wild horse use above appropriate management levels can cause ongoing detrimental ecosystem effects (Davies et al. 2014; USDOI FWS 2008), which may require several decades for recovery (e.g., Anderson and Inouye 2001).

Wild burros can have grazing and trampling impacts that are similar to wild horses (Carothers et al. 1976; Douglas and Hurst 1983; Hanley and Brady 1977) and can substantially affect riparian habitats (e.g., Tiller 1997) and native wildlife (e.g., Seegmiller and Ohmart 1981). Where wild burros and GRSG co-occur, year-round use by burros in low elevation habitats may lead to a high degree of overlap between burros and GRSG (Beever and Aldridge 2011).

In contrast to managed domestic livestock grazing (see section 7), neither the seasonal timing nor the intensity of grazing by Federally protected wild horses and burros can be managed, except through efforts to manage their numbers and distribution. Wild horses roam freely on the range year-round, and wild horse populations have the potential to grow 15 to 20 percent or more per year (Dawson 2005; Eberhardt et al. 1982; Garrott et al. 1991; Roelle et al. 2010; Scorolli and Cazorla 2010; Wolfe 1980). Although annual growth rates may be marginally lower in some areas where mountain lions (*Puma concolor*) can take foals (Turner 2015; Turner and Morrison 2001), horses tend to favor use of more open habitats (Schoenecker et al. 2016) that are dominated by grasses and shrubs and where ambush is less likely. For the majority of wild horse herds, there is little evidence that population growth is significantly affected by predation. As a result of the potential for wild horse populations to grow rapidly, impacts of wild horses on water, soil, vegetation, and native wildlife resources can increase exponentially unless there is active management to limit their population sizes.

On lands administered by the BLM, there were an estimated 72,674 BLM-administered, Federally protected wild horses and burros as of March 1, 2017, not including foals born in 2017 (USDOI BLM 2017). Approximately 60 percent of those are present within 13 million acres (5 million hectares) of GRSG habitat. Federal protections exist for an estimated 7,100 wild horses and 900 wild burros that occupy approximately 2 million acres (800,000 hectares) of Forest Service-administered lands. Approximately 446,065 acres (180,523 hectares) of active Territories administered by the Forest Service contain GRSG habitat, which is occupied by an estimated 3,400 wild horses and burros. Some wild horses also inhabit other Federal lands in the sagebrush biome, including lands administered by the National Park Service, U.S. Fish and Wildlife Service, or Department of Defense, and Native American reservations and tribal lands.

Although wild horses and burros can present challenges to achieving desired habitat conditions, wild horse management is a necessary requirement of planning for long-term sagebrush ecosystem and GRSG conservation. This section relates to management of Federal lands and the terms “wild horses” and “wild burros” are used throughout. However, the specific legal status for any given wild horse or burro population has a large influence on management objectives and the ability to manage wild horse and burro impacts.

In the biological sense, all free-roaming horses and burros in North America are feral, meaning that they are descendants of domesticated animals brought to the Americas by European colonists. Horses went extinct in the Americas by the end of the Pleistocene, about 10,000 years ago (MacFadden 2005; Webb 1984). Burros evolved in Eurasia (Geigl et al. 2016). The published literature refers to free-roaming horses and burros as either feral or wild. In the ecological context the terms are interchangeable, but the term “wild” horse is associated with a specific legal status. Wild and free-roaming horses and burros under the jurisdiction of the BLM and Forest Service are designated “wild” as legally defined by the Wild Free Roaming Horses and Burros Act of 1971 (WFRHBA) as amended (Public Law 92–195), and are under the protection, management, and control of the BLM and Forest Service. Only those horses whose unbranded and unclaimed ancestors were present on BLM and Forest Service lands at the time of the passage of the WFRHBA are managed in accordance with the WFRHBA, and only those lands where wild horses and burros were found when the WFRHBA was passed can be managed to maintain Federally recognized wild horse and burro populations.

Other populations of feral horses and burros on Federal lands (i.e., those on lands administered by the U.S. Fish and Wildlife Service, National Park Service, or Department of Defense; and Native American reservations and tribal trust lands) are generally subject to other Federal regulations and relevant State laws, but are not subject to provisions of the WFRHBA. This section draws on scientific studies of feral horses and burros, some of which also have wild horse or wild burro legal status. Clarification of which horses and burros are considered Federally protected is provided in the BLM regulation (43 CFR 4700 [FR 2011]), BLM wild horse and burro management handbook and manuals (USDOI BLM 2010a,b,c,d), Forest Service manual (FSM 2260.5), and Forest Service regulation (36 CFR 222.20(b)(13), 36 CFR 222.63 [FR 2012]). The legal designation of a particular herd is not expected to change the animals’ ecological effects, but it will influence management options. Discussions about management in this section reflect constraints for Federally designated wild horses and burros.

This section begins with information on wild horse and burro management structure, population estimates and spatial distribution, and management actions to maintain wild horses and burros at appropriate management levels. Then it discusses using resilience and resistance concepts to inform management of wild horses and burros. It concludes with management considerations at the project scale. This section refers mainly to wild horses because wild burros are not nearly as numerous as wild horses in most areas of the sagebrush biome.

Wild Horse and Burro Management Structure

For lands administered by the BLM, Herd Areas (HAs) are defined as areas where wild horses and burros existed at the time of passage of the WFRHBA. Herd Management Areas (HMAs)—the subset of lands designated for active management of wild horses and burros as part of multiple use management—can be designated only within HAs during land use planning activities. In most cases, each HMA is intended to support only wild horses or wild burros, but there are some HMAs that contain both. For HAs that do not have an HMA designation, it generally has been determined that resources are limiting and that wild horse and burro populations cannot be maintained for the long term. The Forest Service-administered Wild Horse Territories (WHTs), Wild Burro Territories (WBTs), and Wild Horse and Burro Territories (WHBTs) are designated according to the species that occupy the Territory. There are some Territories without any wild horses or burros that are considered "inactive," where it has been determined that there are not sufficient resources to maintain wild horses and burros, or where wild horses and burros no longer exist. The numbers of wild horses and burros in HMAs, WHTs, WBTs, or WHBTs and the overlap with GRSG habitat are in text box 8.1.

When two or more HMAs, WHTs, WBTs, or WHBTs are located close to one another, with the potential for wild horses and burros to move freely among them, those areas may be managed collectively as a "complex" (or "joint management area"). Complexes sometimes cross administrative boundaries between BLM field or district offices and Forest Service districts.

The spatial scales of wild horse management are the entire population at the West-wide scale; complexes or groups of HMAs or WHTs, WBTs, and WHBTs with interchange for the regional scale; and individual herds for the local scale. A National Academies of Science report (National Research Council 2013) suggested that wild horse management should be focused more broadly on meta-populations, in which HMAs, WHTs, WBTs, and WHBTs are grouped where interchange occurs, regardless of administrative boundaries. Thus, relative to the spatial scales presented in section 1 of this report, the BLM and Forest Service manage wild horses between the regional and local project levels. The actual spatial scale for any given wild horse population should be determined in consultation with the local staff that manages those populations (i.e., BLM wild horse and burro specialist; Forest Service rangeland management specialist).

Importantly, each HMA, WHT, WBT, and WHBT has an established target population size range for wild horses (and a separate target for wild burros, if they are present), known as the appropriate management level (AML). The BLM and Forest Service view AML as a target population size range which, if maintained, should allow for a thriving ecological balance and multiple use relationship (43 CFR 4710.3-1 [USDOI BLM 2010b]; 43 CFR 4770.3(c) [USDOI 2012]; 36 CFR 222.60(b)(3), 36 CFR 222.61(a)(1), 36 CFR 222.69(a)

Text Box 8.1—Wild Horse and Burro Population Sizes

The BLM manages wild horses and burros within a total of 177 Herd Management Areas (HMAs), which range in size from 3.0 square miles (777 hectares) to 2,033.8 square miles (526,754.2 hectares). As of March 1, 2017, the estimated number of wild horses and burros managed by BLM was 72,674. A total of 105 HMAs overlap with approximately 13 million acres (5 million hectares) of GRSG habitat.

The Forest Service manages 34 active and 19 inactive wild horse and burro administrative units that include: Wild Horse Territories (WHTs; 27 active, 16 inactive), Wild Burro Territories (WBTs; 4 active, 3 inactive), and Wild Horse and Burro Territories (WHBTs; 3 active). These range in size from 5.4 square miles (1,398.6 hectares) to 530.4 square miles (137,373.6 hectares). The Forest Service manages approximately 8,000 wild horses and burros. Thirteen active Territories overlap with approximately 446,000 acres (180,000 hectares) of GRSG habitat.

One thousand or more wild horses on three WHTs and five HMAs live on or near Bi-State GRSG habitat (about 70,000 Forest Service acres [28,000 hectares] and 82,403 BLM acres [33,348 hectares]) (Bi-State Technical Advisory Committee 2012). The Bi-State population has been identified as a Distinct Population Segment of GRSG and is managed under a separate conservation Action Plan.

[FR 2012]). This view reflects an assumption that wild horse and burro populations at AML should allow for land health standards to be met (USDOI BLM 2010a). The AML generally is a range between a low and high value, to allow for some variability in population size across years (USDOI BLM 2010a). The AML is typically determined at the activity planning level through site-specific analysis or, in some cases, through the land use planning process. Monitoring information that couples data on wild horse and burro populations and rangeland status and trends is used to establish or adjust AMLs (text box 8.2). Progress toward attainment of site-specific and landscape-level management objectives or multiple use objectives is also considered. Future studies at local scales could test the assumption that wild horse and burro populations at AML allow for land health standards to be met.

Text Box 8.2—Monitoring Considerations for Wild Horses and Burros

Reliable estimates of population sizes and habitat data provide the basis for management decisions regarding wild horses and wild burros. Understanding the annual growth rates of wild horse and burro populations and the status and trends of rangelands occupied by wild horses and burros is essential for making informed management decisions.

Inventory (monitoring) data for wild horse and burro populations include information on the numbers of animals, their use patterns, and spatial distribution. Habitat data include grazing utilization, range ecological condition and trend, actual use, and climate (weather) data. Habitat monitoring data collection should be coordinated with other resource programs (e.g., range, watershed, wildlife) to maximize efficiency and minimize duplication.

Data and analyses of populations and habitats are used in concert to:

- Establish or adjust Appropriate Management Levels (AMLs);
- Make a determination of excess wild horses or burros (i.e., establish the need to gather and remove excess animals in order to reach and stay at AML);
- Develop or revise Herd Management Area (HMA) boundaries; and
- Evaluate conformance with Land Health Standards, Land Use Plan goals and objectives, or other site-specific or landscape-level objectives.

Data and methods used to inform decisions should be scientifically defensible. The public should be able to understand the methods used and how they are implemented and also to access the data used to make decisions.

Data on Population Estimates and Spatial Distribution of Wild Horses and Burros

Population estimates for each HA and HMA are reported annually in the Public Land Statistics (http://www.blm.gov/public_land_statistics/); spatial data are available via the BLM GeoCortex, which is available to managers for analyses and planning and is useful in determining the number of excess animals present on the range (https://webmaps.blm.gov/Geocortex/Html5Viewer/Index.html?viewer=whb). The Forest Service reports population estimates for each territory on the Forest Service wild horse and burro program website (https://www.fs.fed.us/wild-horse-burro/territories/index.shtml). The BLM and Forest Service have recently adopted a statistically valid, standardized methodology for estimating wild horse population sizes (Lubow and Ransom 2009, 2016; Ransom 2012) that accounts for animals that were present, but not seen by observers. In most cases, reported population estimates are based on the statistical analysis of aerial survey data; BLM policy calls for each HMA (and complexes that include both BLM lands and Forest Service WHTs, WBTs, or WHBTs) to be surveyed at least once every 2 years (USDOI BLM 2010e). For both agencies, population size estimates are projected for intervening years based on the best available information about expected population growth rates for each area. As previously discussed, wild horse growth rates can typically be assumed to be about 15 percent to 20 percent per year (National Research Council 2013) unless there is a contraceptive project to limit reproduction. However, in some places the annual growth rate may be greater than 20 percent. The range-wide population estimates are used to develop BLM geospatial data (accessible at the BLM GeoCortex site) and the status of a population relative to high AML within a particular HMA.

Although it is the intended management goal that wild horses remain only on HMAs, WHTs, or WHBTs, the current reality is that Federally protected wild horses are also present on many HAs and on other Federal, State, tribal, and private lands outside of these administrative boundaries. As a result, the user must be cautiously aware that the data representing boundaries of and populations within HMAs, HAs, WHTs, WBTs, and WHBTs may not portray the actual spatial distribution of all wild horse and burro populations. Continued increases in wild horse and burro populations, relative to AML, will result in a more widespread distribution of herds, including into areas outside designated boundaries. In areas where road or trail access allows for observations and on-the-ground documentation of horse sign (e.g., trailing, scat piles, evidence of horse grazing and browsing), the local designated staff is likely to have a broad understanding of where the animals tend to go in different seasons, which water sources they rely on, and the general pattern of their movements.

Management Actions to Maintain Wild Horses and Burros at Appropriate Management Levels

The 1971 WFRHBA directs the BLM and Forest Service to remove excess animals from the range (43 CFR 4720.1 and 36 CFR 222.69, respectively) to maintain a thriving natural balance. The number of wild horses or burros greater than a designated high AML for a HMA, WHT, WBT, or WHBT is considered to be the number of "excess" animals in the area. In order to take management action, the agencies must make two determinations: (1) that an overpopulation exists, and (2) whether or not it will be necessary to remove excess animals.

Historically, the BLM and Forest Service reduced herd population sizes to the low value of AML. This was accomplished by removing excess animals from the range. The population would then typically grow to reach the high value of the AML range within 3 to 4 years, unless some form of contraception was used to limit population growth rates. Natural regulation via starvation or dehydration is generally not acceptable to many members of the public (National Research Council 2013).

After removal, animals were placed in holding facilities, offered to the public for adoption, and then kept in holding facilities indefinitely if there was no adoption demand. However, removing all excess wild horses and holding them in off-range facilities for the remainder of their lives would be prohibitively expensive (Garrott and Oli 2013). In many recent years, the BLM has not had the budgetary capacity to remove more than approximately 3,500 animals per year from the range. Further, the more than 45,000 BLM-administered, captive wild horses currently in long-term holding (of which about 850 are horses from Forest Service Territories) require over $50 million per year to maintain. As a result, populations of wild horses and burros across all BLM-administered lands (and on some Forest Service Territories) have not been gathered so frequently. Average population sizes are now more than three times greater than the high end of the total AML and these populations are growing.

In 2015, the BLM, the Forest Service, and other agencies identified certain areas as the most important habitats for GRSG and other sagebrush obligates. None of those areas overlapped with Forest Service-administered wild horse or wild burro populations. The BLM developed a 5-year gather schedule to achieve AML by 2020 in 22 HMAs that overlapped areas identified as the most important habitats for GRSG and other sagebrush obligates. However, under budget projections made in FY2017, the BLM will not have the fiscal capacity to conduct gathers within GRSG Priority Habitat Management Areas until 2020 or later, and has no capacity to manage wild horse populations that overlap with GRSG General Habitat Management Areas. Unless there are Congressionally directed changes to the BLM program, it is expected that the number of wild horses within GRSG habitat could surpass 65,000 horses in 2019. Furthermore, maintaining any wild horse population at or below AML will require an active and ongoing program of population growth suppression or scheduled removals (or both) of excess animals. Without such a program, habitat restoration will quickly be at risk as wild horse populations again grow to exceed AML.

Currently used population growth suppression methods include gelding and the immunocontraceptives porcine zona pellucida (PZP) and GonaCon (National Research Council 2013). Both vaccines may be effective for only 1 year, unless booster doses are given (National Research Council 2013). Repeated PZP boosters require annual darting or recapture of the vast majority of wild horses under BLM or Forest Service management, which is infeasible on many HMAs and Territories, would be prohibitively expensive to apply across the range of wild horses and burros, and may lead to more stress for wild horses as a result of frequent capture. The BLM is supporting ongoing research initiatives to develop and test longer-term contraception for wild horses and burros and to improve contraceptive efficacy and production (USDOI BLM 2015). However, planning decisions that propose to remove excess horses or utilize population growth suppression on any BLM lands are often appealed and litigated by interested members of the public. This results in a high degree of uncertainty about the ability of designated Federal agencies to maintain wild horse populations within AML.

Using Resilience and Resistance Concepts and the Science Framework to Inform Management of Wild Horses and Burros

Information on relative ecosystem resilience to disturbance and resistance to invasive annual grasses can be used to help understand the responses of sagebrush ecosystems, species at risk, and other resources to wild horse and burro use and to the interactions of wild horse and burro use with other potential disturbance factors such as wildfire and invasive plants. Information on resilience and resistance to invasive annual grasses, coupled with information on current and projected wild horse and burro population sizes relative to AML and other predominant threats and disturbance factors, can be used to inform conservation and restoration strategies in sagebrush ecosystems across scales.

Part 1 of the Science Framework provides an approach based on an understanding of ecosystem resilience to disturbance and resistance to invasive annual grasses that uses assessments at the mid-scale (ecoregional or GRSG Management Zone) (fig. 1.1) to help prioritize areas for management and determine effective management strategies (Chambers et al. 2017). The approach is based on: (1) the likely response of an area to disturbance or stress due to threats or management actions (i.e., resilience to disturbance and resistance to invasive annual grasses), (2) the capacity of an area to support target species or resources, and (3) the predominant threats. The geospatial data layers and analyses used in the approach are described in Part 1, sections 8.1 and 8.2. The process involves overlaying key data layers including resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes (Maestas et al. 2016), sage-grouse breeding habitat probabilities (Doherty et al. 2016), the densities or distributions of other sagebrush dependent species, and the primary threats for the ecoregions or Management Zones in the assessment. The maps and analyses that managers derive from this process are an essential component of prioritizing areas for management actions and developing management strategies.

Wild horse and burro densities and AMLs can be used similarly to other threats and disturbance factors in the analyses. Managers can devise categories to evaluate the degree to which wild horse and burro populations are within or exceed AMLs for HMAs, WHTs, WBTs, and WHBTs. Here, three abundance categories relative to AML were developed based on available abundance estimates for BLM lands and Forest Service lands: within AML, more than 100 percent to 200 percent of AML, and more than 200 percent of AML. The wild horse HMAs were overlaid with these three abundance categories (fig. 8.1). Note that this figure also depicts HAs where the target population for wild horses is zero, but where wild horses are present.

The three abundance categories were overlaid with: (1) the three resilience and resistance categories derived from soil temperature and moisture regime information, and (2) GRSG breeding habitat probabilities (see Part 1, sections 8.1 and 8.2). This analysis does not include areas outside the boundaries of HMAs, HAs, WHTs, WBTs, and WHBTs where horses and burros have expanded their use. The data used in the analyses can be found at: https://www.sciencebase.gov/catalog/item/576bf69ce4b07657d1a26ea2.

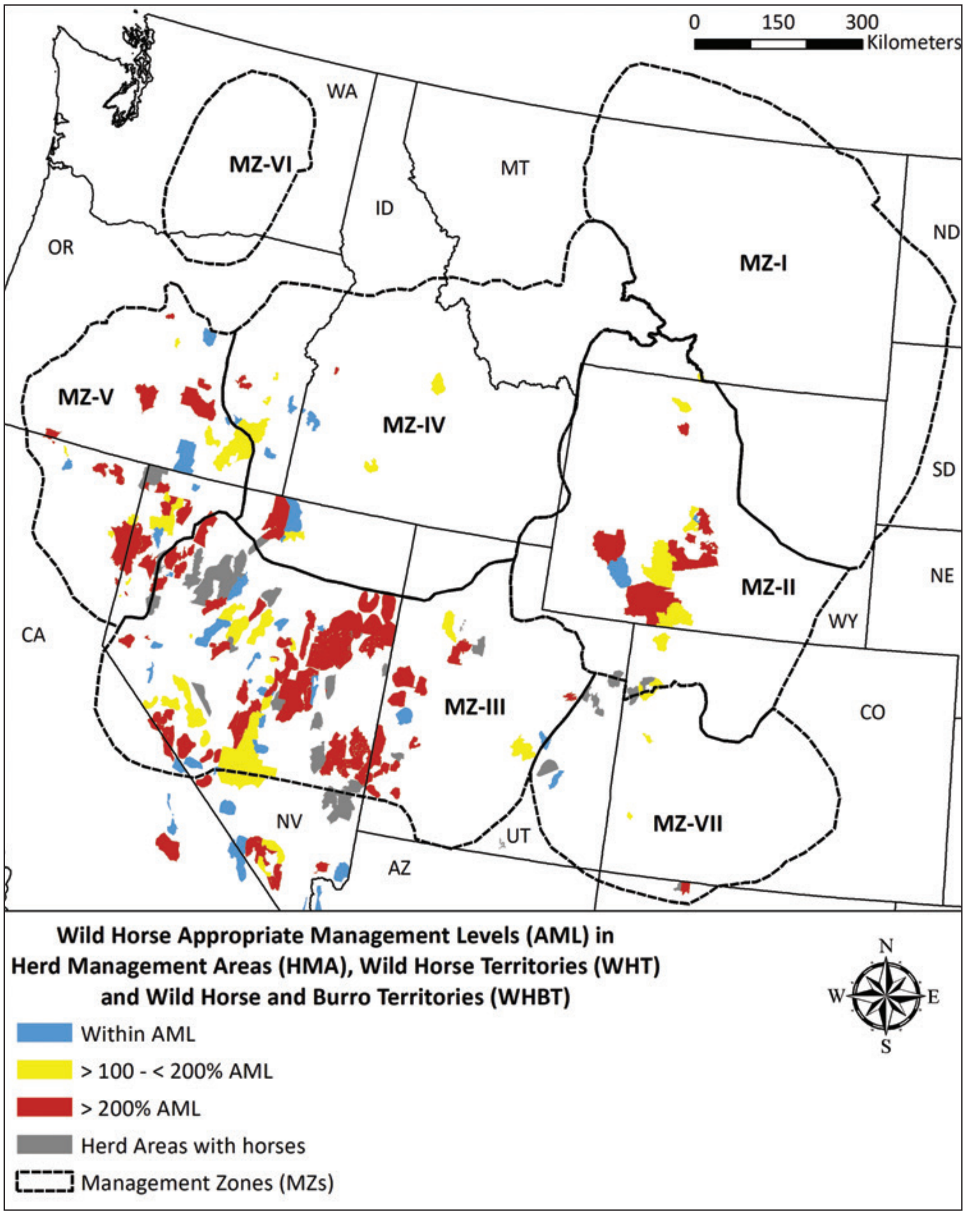

Figure 8.1—Categories of estimated wild horse abundance as of March 1, 2017 relative to Appropriate Management Level (AML) for wild horse Herd Management Areas (HMAs) on BLM lands and Wild Horse Territories (WHTs) and Wild Horse and Burro Territories (WHBTs) on Forest Service lands. Gray polygons indicate Herd Areas where the target population for wild horses is zero, but where wild horses are present. Estimated wild horse abundance exceeds AML in most HMAs, WHTs, and WHBTs.

Analyses of Appropriate Management Levels, Ecosystem Resilience and Resistance, and Breeding Bird Habitat Probabilities

Sixty percent of HMAs, WHTs, and WHBTs managed by the BLM and Forest Service are in areas categorized as having low resilience and resistance (fig. 8.2, table 8.1). In contrast, 33 percent have moderate resilience and resistance and only 7 percent have high resilience and resistance. In the area with low resilience and resistance, 60 percent has wild horse abundance that exceeds 200 percent of the horse AML.

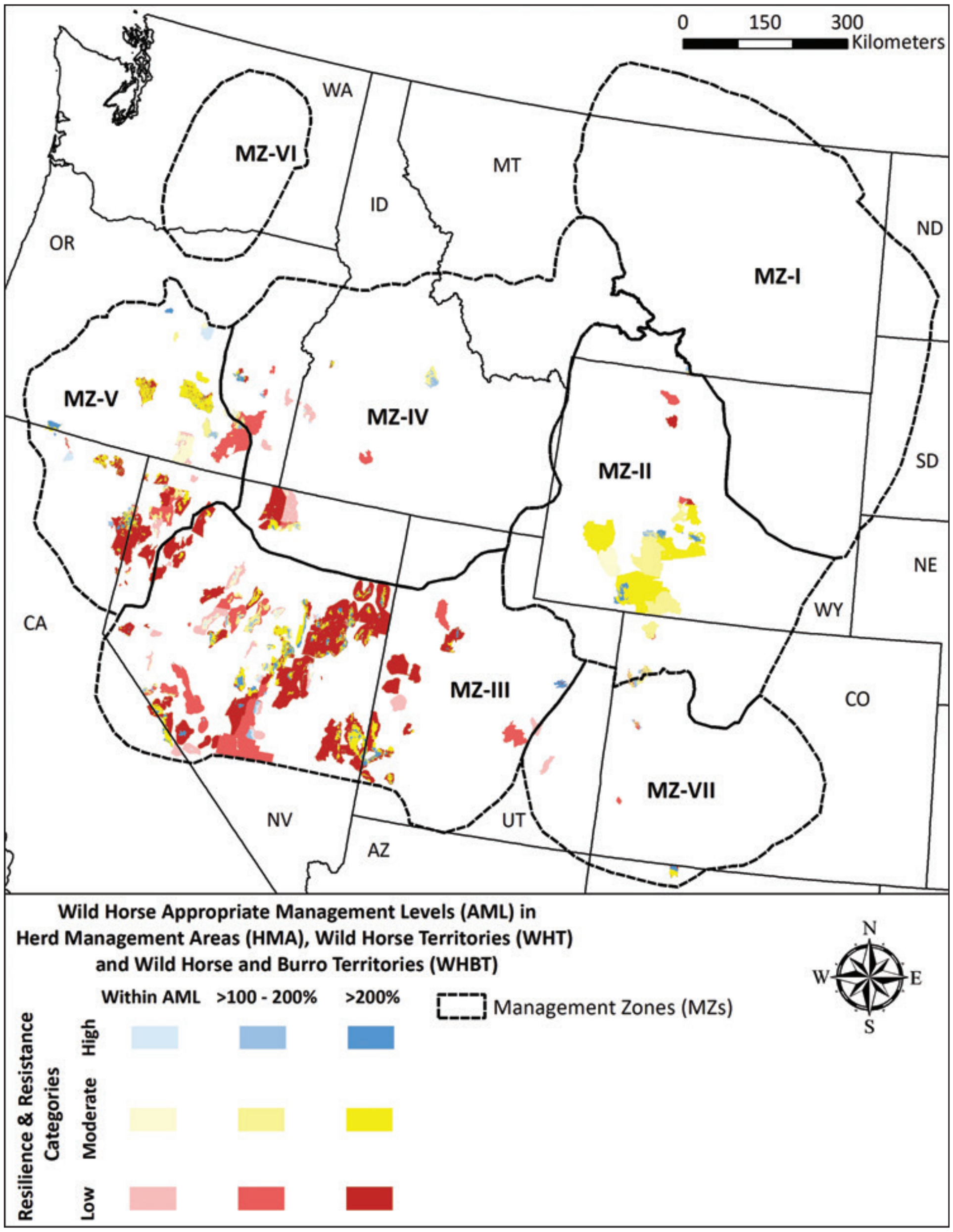

Figure 8.2—Categories of estimated wild horse abundance as of March 1, 2017 relative to Appropriate Management Level (AML), overlaid with the resilience and resistance classes within wild horse Herd Management Areas (HMAs) on BLM lands and Wild Horse Territories (WHTs) and Wild Horse and Burro Territories (WHBTs) on Forest Service lands. Most HMAs, WHTs, and WHBTs are in low to moderate resilience and resistance categories and exceed AML.

Table 8.1—The area and percentage of Herd Management Areas, Wild Horse Territories, and Wild Horse and Burro Territories for the Bureau of Land Management and Forest Service by wild horse Appropriate Management Level (AML) class and resilience and resistance class. Percentages within a Management Zone (MZ) add to 100.

Percent Horse AML class	Resilience and resistance: Low Acres	%	Moderate Acres	%	High Acres	%
MZ I						
<100	0	0	0	0	0	0
>100–200	0	0	4,326	57	3,200	43
>200	0	0	0	0	0	0
Total	0	0	4,326	57	3,200	43
MZ II						
<100	0	0	414,831	8	2,204	1
>100–200	182,045	4	1,578,883	31	68,236	1
>200	108,086	2	2,548,764	50	166,862	3
Total	290,131	6	4,542,478	89	237,302	5
MZ III						
<100	1,161,465	8	233,713	2	146,235	1
>100–200	2,965,677	19	368,132	2	168,363	1
>200	7,916,216	52	1,743,470	11	618,498	4
Total	12,043,358	79	2,345,315	15	933,096	6
MZ IV						
<100	560,601	27	67,981	3	19,771	1
>100–200	490,895	23	198,977	9	89,076	4
>200	560,706	27	90,401	4	49,144	2
Total	1,612,201	77	357,359	16	157,991	7
MZ V						
<100	193,058	4	426,958	8	186,252	4
>100–200	942,681	18	336,100	6	85,331	2
>200	1,618,840	31	1,119,312	22	276,522	5
Total	2,754,579		1,882,370		548,105	
MZ VII						
<100	130,987	38	0	0	0	0
>100–200	47,132	13	64,758	19	29,502	8
>200	8,427	2	40,236	12	27,286	8
Total	186,546	53	104,994	31	56,788	16
All MZs						
<100	2,046,111	7	1,143,483	4	354,462	1
>100–200	4,628,430	17	2,551,176	9	443,708	2
>200	10,212,274	36	5,542,187	20	1,138,311	4
Total	16,886,815	60	9,236,846	33	1,936,481	7

Differences in both resilience and resistance and the abundance categories exist among Management Zones for wild horses (fig. 8.2, table 8.1). In Management Zone III, where the majority of wild horses are found, lands managed for wild horses are primarily within low resilience and resistance areas (79%). In the area with low resilience and resistance, 52 percent has wild horse abundance in excess of 200 percent of the horse AML. In Management Zones IV and V, lands managed for wild horses also are primarily within low resilience and resistance areas: 77 percent and 53 percent, respectively. In both of these areas, most lands managed for wild horses have horse abundance greater than 100 to 200 percent of the horse AML.

For wild burro populations, most of the land area in HMAs, WBTs, and WHBTs included in this analysis is in low resilience and resistance areas (80 percent), followed by moderate resilience and resistance areas (18 percent) (fig. 8.3, table 8.2). Moreover, 73 percent of the lands managed for wild burros in this analysis have wild burro abundance in excess of 200 percent of the burro AML.

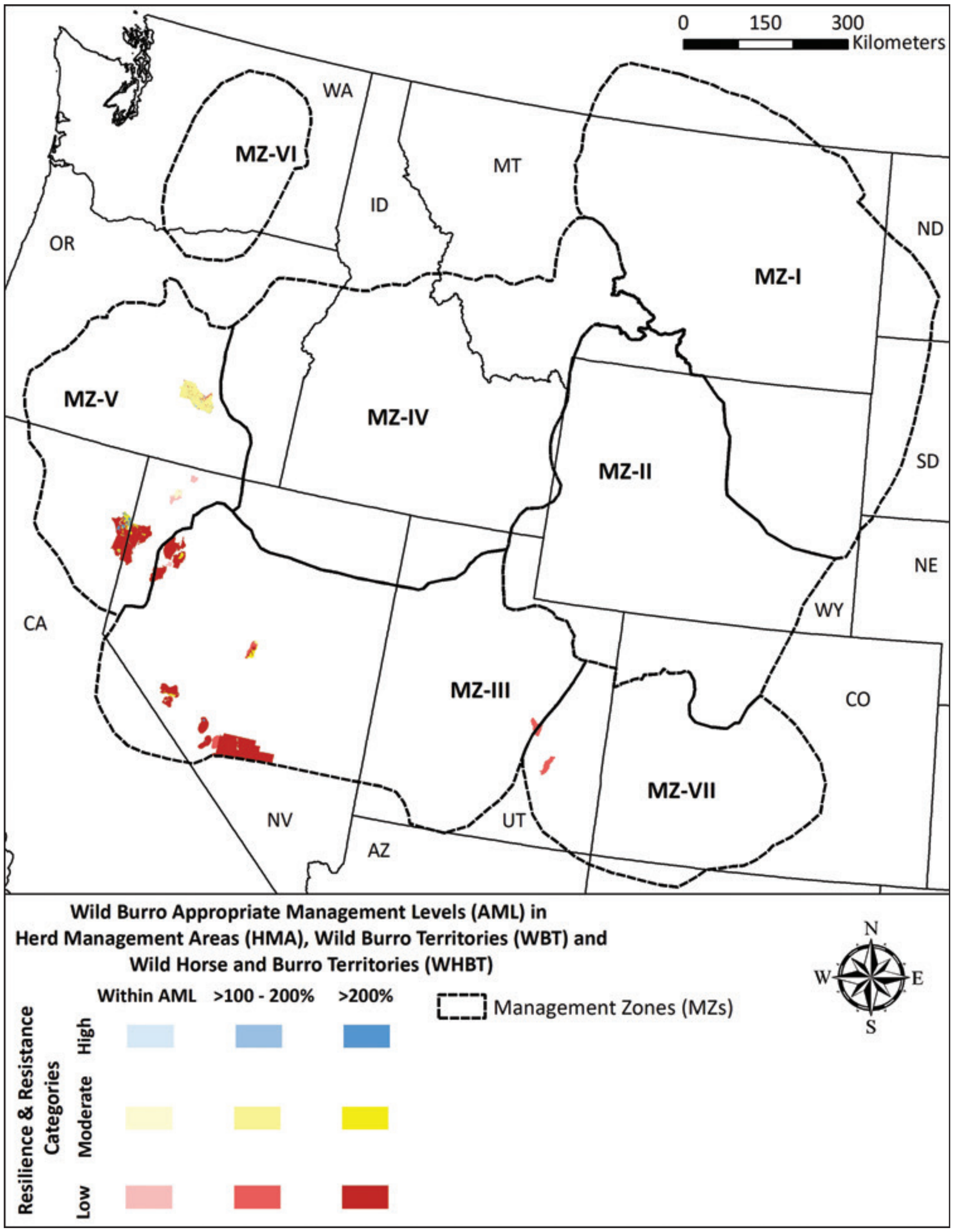

Figure 8.3—Categories of estimated wild burro abundance as of March 1, 2017 relative to Appropriate Management Level (AML), overlaid with the resilience and resistance classes within wild burro Herd Management Areas (HMAs) on BLM lands and Wild Burro Territories (WBTs) and Wild Horse and Burro Territories (WHBTs) on Forest Service lands. Estimated wild burro abundance exceeds AML in most HMAs, WHTs, and WHBTs.

Table 8.2—The area and percentage of Herd Management Areas, Wild Burro Territories, and Wild Horse and Burro Territories for the Bureau of Land Management and Forest Service by wild burro Appropriate Management Level (AML) class and resilience and resistance class. Percentages within a Management Zone (MZ) add to 100.

Percent Burro AML class	Resilience and resistance					
	Low		Moderate		High	
	Acres	%	Acres	%	Acres	%
MZ III						
<100	18,063	1	0	0	0	0
>100–200	162,160	8	9,563	1	0	0
>200	1,655,499	87	59,095	3	4,076	0
Total	1,835,722	96	68,658	4	4,076	0
MZ V						
<100	77,478	5	44,492	3	0	0
>100–200	30,008	2	442,165	29	20,651	1
>200	795,307	52	80,589	5	51,215	3
Total	902,793	59	567,246	37	71,865	4
MZ VII						
<100	0	0	0	0	0	0
>100–200	130,987	100	0	0	0	0
>200	0	0	0	0	0	0
Total	130,987	100	0	0	0	0
All MZs						
<100	95,541	3	44,492	1	0	0
>100–200	323,155	9	451,728	13	20,651	1
>200	2,450,806	68	108,351	4	55,290	1
Total	2,869,502	80	635,940	18	75,941	2

In Management Zones III and V the highest percentage of land is in low resilience and resistance areas with wild burro abundance more than 200 percent of the burro AML. Most of the burros managed by the BLM are located in Arizona and southern Nevada (USDOI 2017), which is outside of the sagebrush biome and the area of this analysis.

Overlaying the categories of wild horse abundance relative to AMLs with the sage-grouse breeding habitat probabilities shows that 42 percent of the lands managed for wild horses occur in the low, 40 percent in the moderate, and 18 percent in the high GRSG breeding habitat probability (fig. 8.4, table 8.3). In the high breeding habitat probability areas, which are the highest priority for protection, and in the moderate breeding habitat probability areas, which often provide opportunities for conservation actions, about two-thirds of the lands managed for wild horses have horse abundance in excess of 200 percent of the horse AML.

Analysis of the sage-grouse breeding habitat probabilities overlaid on categories of wild burro abundance relative to AML shows that 46 percent, 46 percent, and 8 percent of those GRSG breeding habitats managed for wild burros and included in this analysis occur in the low, moderate, and high breeding habitat probability areas, respectively (table 8.4). Within low, moderate, and high GRSG breeding habitat probability areas, 69 percent, 72 percent, and 38 percent, respectively, of the lands managed for wild burros have burro abundance greater than 200 percent of the burro AML. Management Zone V has a higher land area managed for wild burros with GRSG breeding habitat than Management Zone III, and a higher percentage of the wild burro population is in moderate and high GRSG breeding habitat probability areas.

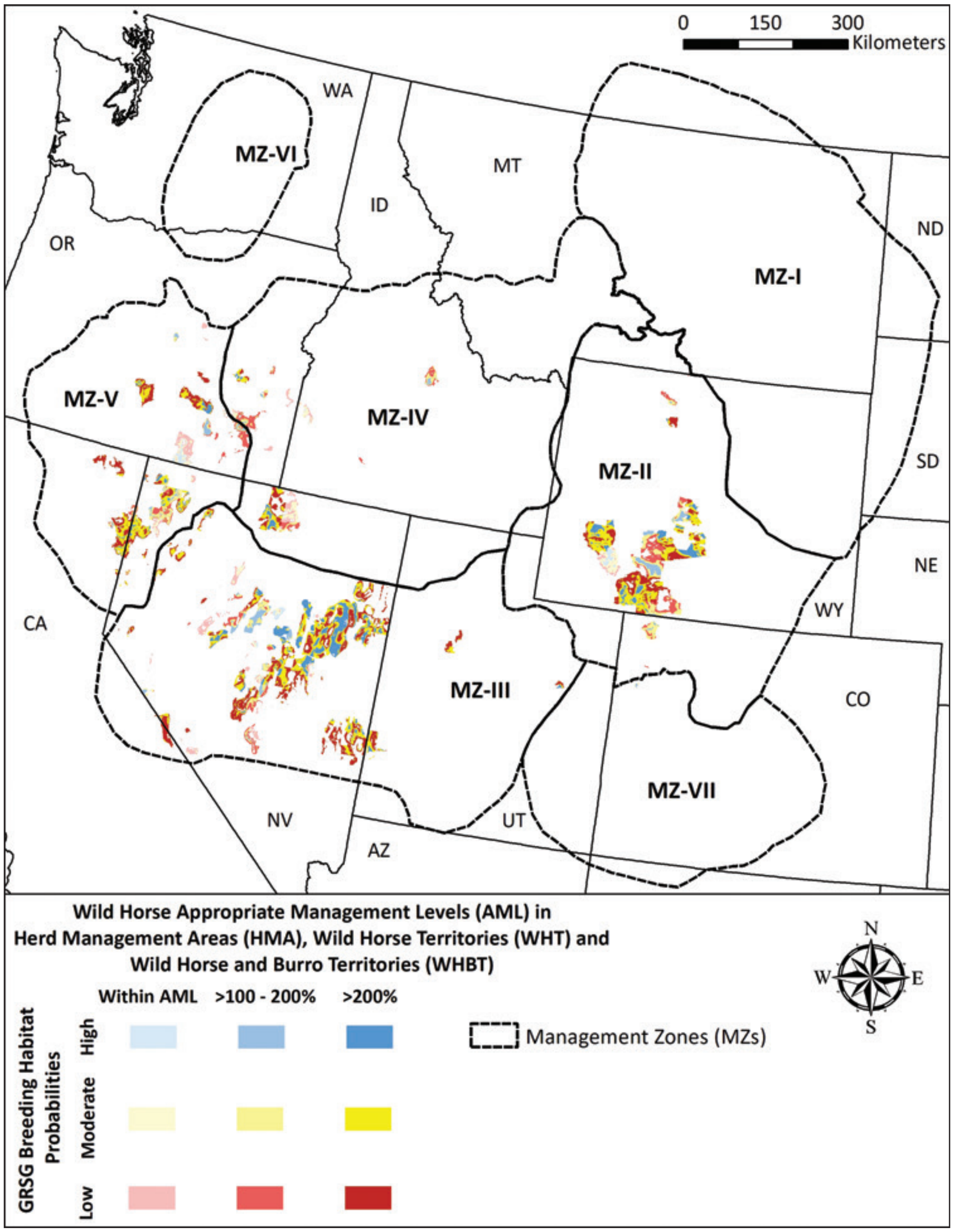

Figure 8.4—Categories of estimated wild horse abundance as of March 1, 2017 relative to Appropriate Management Level (AML), overlaid with the GRSG breeding habitat probabilities within wild horse Herd Management Areas (HMAs) on BLM lands and Wild Horse Territories (WHT) and Wild Horse and Burro Territories (WHBTs) on Forest Service lands. Estimated wild horse abundance exceeds AML in many areas with moderate to high GRSG breeding habitat probabilities.

Table 8.3—The area and percentage of Herd Management Areas, Wild Horse Territories, and Wild Horse and Burro Territories for the Bureau of Land Management and Forest Service by wild horse Appropriate Management Level (AML) class and Greater sage-grouse (GRSG) breeding habitat probability class. Percentages within a Management Zone (MZ) add to 100.

Percent Horse AML class	GRSG breeding habitat probability					
	Low		Moderate		High	
	Acres	%	Acres	%	Acres	%
MZ II						
<100	92,230	2	198,329	4	77,042	2
>100–200	573,836	13	557,183	13	255,275	6
>200	924,545	21	1,298,137	29	462,370	10
Total	1,590,610	36	2,053,649	46	794,686	18
MZ III						
<100	353,147	5	148,052	2	85,319	1
>100–200	312,594	4	319,359	5	273,905	4
>200	2,319,075	33	2,028,561	29	1,185,258	17
Total	2,984,816	42	2,495,972	36	1,544,482	22
MZ IV						
<100	234,091	16	208,371	14	10,955	1
>100–200	293,756	20	160,647	11	33,053	2
>200	212,954	14	224,679	15	95,330	7
Total	740,802	50	593,697	40	139,338	10
MZ V						
<100	281,312	9	161,838	5	94,638	3
>100–200	334,833	10	320,755	10	142,127	4
>200	867,460	27	832,302	26	178,115	6
Total	1,483,605	46	1,314,895	41	414,880	13
MZ VII						
<100	0	0	0	0	0	0
>100–200	252	3	2,494	29	5,748	68
>200	0	0	0	0	0	0
Total	252	3	2,494	29	5,748	68
All MZs						
<100	960,780	6	716,590	4	267,954	2
>100–200	1,515,271	9	1,360,438	8	710,108	4
>200	4,324,034	27	4,383,679	27	1,921,073	12
Total	6,800,085	42	6,460,707	40	2,899,135	18

Using the Science Framework to Inform Management Decisions

Primary considerations for wild horse and burro management from the Science Framework approach are presented next (see tables 1.3, 1.4).

- In general, areas that support medium to high sage-grouse breeding habitat probabilities or other important resources are high priorities for management (table 1.3: cells 2A, 2B, 2C, 3A, 3B, 3C), especially low resilience and resistance categories that lack the potential to recover from disturbances such as excessive wild horse and burro use without significant intervention (table 1.3: cells 2C, 3C). These areas could be considered priorities for wild horse and burro gathers and fertility control where horse and burro abundance exceeds target AMLs and the area is not highly degraded.
- Areas with moderate and, especially, high resilience and resistance often have the potential to recover through successional processes (table 1.3: cells 1B, 1C, 2B, 2C).

Table 8.4—The area and percentage of Herd Management Areas, Wild Burro Territories, and Wild Horse and Burro Territories for the Bureau of Land Management and Forest Service by wild burro Appropriate Management Level (AML) class and Greater sage-grouse (GRSG) breeding habitat probability class. Percentages within a Management Zone (MZ) add to 100.

Percent Burro AML class	GRSG breeding habitat probability					
	Low		Moderate		High	
	Acres	%	Acres	%	Acres	%
MZ III						
<100	107	1	0	0	0	0
>100–200	9,882	3	12,082	4	8,717	3
>200	168,963	58	86,373	30	2,943	1
Total	178,952	62	98,455	34	11,660	4
MZ V						
<100	23,217	2	68,662	7	18,022	2
>100–200	147,908	14	91,557	8	50,412	5
>200	263,516	24	364,745	34	44,423	4
Total	434,640	40	524,964	49	112,857	11
All MZs						
<100	23,217	2	68,662	5	18,022	1
>100–200	157,790	12	103,638	8	59,130	4
>200	432,479	32	451,118	33	47,366	3
Total	613,486	46	623,418	46	124,518	8

- ◦ These areas represent significant opportunities to improve habitat and could also be considered priorities for wild horse and burro gathers and fertility control where horse and burro abundance exceeds target AMLs and removals are likely to result in habitat improvement.
- ◦ In areas where wild horses and burros exceed target AMLs (including occupied areas outside of HMAs, HAs, WHTs, WBTs, and WHBTs), managers should carefully consider the current spatial extent and growth potential of any nearby wild horse herds and their potential effects on management actions to improve habitat.

- New postfire rehabilitation areas and areas that provide sagebrush habitat connectivity for GRSG and other species at risk are conservation priorities and, thus, could be priorities for wild horse and burro gathers, where abundance exceeds AMLs.

Ecological type or ecological site descriptions and their associated state-and-transition models (STMs) can be used to help evaluate potential effects of wild horse and burro use and the likely success of conservation and restoration actions. In the Science Framework, generalized ecological types and STMs have been developed for the range of environmental conditions in the eastern and western portions of the sagebrush biome (see Part 1, Appendices 5 and 6). The ecological types and STMs are characterized according to their resilience to disturbance and resistance to invasive annual grasses based on soil temperature and moisture regimes and other biophysical characteristics such as plant community composition. They provide information on the alternative states, ranges of variability within states, and processes that cause plant community shifts within states as well as transitions among states. These ecological types and STMs can be used to: (1) identify the different ecological types that exist within the HMA or Territory and determine their relative resilience to disturbance and resistance to invasive annual grasses; (2) evaluate the current ecological dynamics of the ecological types or ecological sites and, where possible, their restoration pathways; (3) increase understanding of the potential effects of wild horse and burro use; and (4) determine the likelihood of conservation and restoration actions succeeding given ongoing wild horse and burro use (Part 1, section 9).

Section 7 uses these STMs to illustrate potential livestock management strategies for ecological types that support GRSG populations and that may benefit from improved livestock grazing management. Information on how to use these resilience-based ecological types and STMs for managing ecosystem threats across the sagebrush biome is in Part 1, section 9.2. Information on how to use resilience-based ecological types and STMs for selecting appropriate treatments for assessing postwildfire recovery and restoration decisions in sagebrush and juniper-piñon ecosystems in the Great Basin is in Miller et al. (2014, 2015) and Pyke et al. (2017), respectively.

Management Considerations at the Project Scale

An assessment of the ecological sites in the project area and their relative resilience to disturbance and resistance to invasive annual grasses can help determine the potential for conservation and restoration treatments to succeed. More detailed information can be obtained from ecological site descriptions for those areas where they have been developed (see http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/). Ecological type and ecological site descriptions provide basic information on the climate and soil characteristics of an area and the potential of the area to support a dynamic set of plant communities. The associated STMs provide information on the current states and the potential transitions among them due to disturbances and other drivers such as wild horse and burro use as well as management treatments. Assessing the states and the plant communities within the states based on STMs provides information on both the disturbances and the drivers that have led to the current state and the potential restoration pathways. For example, plant communities within the reference state or within states that have feasible restoration pathways may respond favorably to conservation and restoration actions if the wild horse population can be managed at or below AML. However, plant communities in other states, such as an invaded state or annual state (see figs. 7.2, 7.6) may not respond favorably to conservation and restoration actions if the wild horse population cannot be managed at or below AML. Ecological types or ecological sites with relatively low resilience and resistance to invasive annual grasses often require more than one intervention for restoration efforts to succeed and wild horse and burro use can have significant effects on project success.

Effects of wild horses and burros on project success depend on the number of wild horses and burros that can reach the site. If the project site is located within an HMA, WHT, WBT, or WHBT, then grazing and trampling pressure from wild horses should be expected in most cases. Even if the project area is outside any HMA, WHT, WBT, and WHBT, managers should carefully consider the current spatial extent, and growth potential, of any nearby wild horse population. Higher population sizes tend to lead to an expanded spatial area used by the wild horse population. If the number of wild horses is at AML, and there are measures in place to limit the population's growth rate, then wild horse use across the landscape may be distributed enough that a conservation or restoration project could achieve habitat quality goals. Thus, managers should carefully evaluate the likelihood of success of planned conservation and restoration activities if a local or adjacent wild horse population cannot be kept at AML.

Project success is also likely to be influenced by distance to the nearest drinking water source for wild horses. The greater the distance, the lower the grazing pressure that can be expected. Horses require access to large amounts of water; an individual can drink an average of 7.4 gallons [28.0 liters] of water per day (Groenendyk et al. 1988). Despite a general preference for habitats near water (e.g., Crane et al. 1997), wild horses will routinely commute long distances (e.g., 10+ miles [16 kilometers] per day) between water sources and palatable vegetation (Hampson et al. 2010). Managers should expect that any restoration project less than 5 miles [8 kilometers] from water will be subject to use by wild horses in the area. Riparian and wildlife habitat improvement projects that intend to increase the availability of grasses, forbs, riparian habitats, and water are likely to attract and be subject to heavy grazing and trampling by wild horses that live near the project.

Managers need to understand and consider the potential effects of wild horses and burros on conservation and restoration projects and plan accordingly. For certain habitat restoration projects, managers may want to consider installing fencing to discourage use by wild horses, particularly around riparian areas. On BLM and Forest Service lands, temporary fencing for habitat rehabilitation is generally acceptable on HMAs, HAs, WHTs, WBTs, and WHBTs. But permanent fencing often requires a more in-depth environmental assessment or land use plan revision, and should be designed in a way that allows for wild horse and burro movement throughout the rest of the HMA or Territory. The Forest Service also requires National Environmental Policy Act analysis for fence installation. Fencing that excludes wild horses and burros from riparian areas or water development projects that are designed to disperse both riparian and upland use by wild horses and burros are important management tools to protect riparian habitat. Fencing riparian areas to exclude wild horses and burros is generally acceptable as long as water from the area continues to be available to them, and solid pipe fencing is used that can withstand pressure from wild horses and burros. Continued monitoring to assess changes in plant communities and wild horse and burro abundance should be part of any conservation or restoration project where these animals are found.

If AML cannot be achieved, it may be more reasonable to forego a habitat restoration project entirely instead of spending time and resources on projects with a low probability of success. Managers deciding about any project that is near a wild horse or burro population should consider population sizes of wild horses and burros relative to the AML, including explicit schedules for wild horse and burro removals or population growth suppression treatments that are adequate to limit population growth. Unfortunately, high populations of wild horses or burros can substantially affect the ability of land managers to implement conservation measures in some areas. A potential project area with high current wild horse or burro population sizes may become suitable for restoration if the manager can influence priorities and policies such that wild horse and burro populations in the project area are reduced to and maintained at or below high AML.

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9. INTEGRATION AND TRADEOFFS

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Introduction

Managing for sagebrush ecosystems that are resilient to disturbance and resistant to invasive plants often requires managers to make tough decisions in the face of considerable complexity and uncertainty. The decisionmaking environment is often characterized by multiple management objectives, limited management authority and capabilities, dynamic ecosystems and plant communities, and uncertain responses to management actions. Resource decisionmakers must be able to determine appropriate objectives based on desired management outcomes and sort through the different management considerations involved in obtaining those desired outcomes. Decisionmakers must also be able to evaluate the tradeoffs associated with diverse and often competing management considerations and determine the long-term positive or negative effects of particular management actions on the resource.

Management decisions are most effective when developed and implemented in an adaptive management framework. Adaptive management promotes flexible decisionmaking and allows adjustments in management as part of an iterative learning process (fig. 2.1) (Goldstein et al. 2013; USDOI 2009). This “decisionmaking process” emphasizes: (1) using the best available information to inform decisions, (2) learning from the results of management decisions and actions, and (3) adjusting management as outcomes from management actions and prior uncertainties become better understood. Adaptive management recognizes the importance of changing ecological and socioeconomic conditions in contributing to ecological resilience to disturbance and resistance to nonnative invasive plants. Rigorous monitoring of management outcomes related to clearly defined objectives provides the scientific basis for adjusting policies or management actions in response to dynamic conditions. Adaptive management is a means for making more effective decisions over time that when properly implemented can help to meet ecological, social, and economic goals, increase scientific knowledge, and reduce tensions among stakeholders.

Decisionmaking in an adaptive management context requires a collaborative process where tradeoffs among resources and management objectives are carefully considered. A structured approach to decisionmaking in natural resources can increase both accountability and specificity (Goldstein et al. 2013; USDOI 2009). Greater attention to key elements (text box 9.1) in the decisionmaking process can help decisionmakers focus on what, why, where, and how actions will be taken.

Top left: Sagebrush ecosystem (photo: Tom Koerner, USDOI Fish and Wildlife Service). Top right: Fire suppression in a cheatgrass dominated site (photo: USDOI Bureau of Land Management). 2nd left: Hand removal of piñon pine with a chainsaw (photo: SageSTEP.org). 2nd right: Pinyon jay, a juniper and piñon obligate species (photo: Richard Crossley from Wikimedia Commons). 3rd left: Deep gas drill rig outside of Pinedale, Wyoming (photo: Tomas J. Christensen, retired, Wyoming Game and Fish Department). 3rd right: Conversion of a sagebrush ecosystem in the West-Central Prairies to agricultural land (photo: John Carlson, USDOI, Bureau of Land Management). Bottom left: Greater sage-grouse at a lek site (photo: USDOI Fish and Wildlife Service). Bottom right: Santa Rosa Mountains and cattle (photo by Nolan Preece, used with permission).

Managers need to take into account many different factors when developing management objectives and deciding on alternative actions aimed at maintaining or increasing resilience to disturbance and resistance to nonnative invasive plants.

Spatial and Temporal Scale. In the Science Framework a multi-scale approach is used to inform different aspects of planning and implementation: (1) the sagebrush biome scale, where consistent data for the range of sagebrush and Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) can inform budget prioritization; (2) the mid-scale (ecoregion or Management Zone), where assessments are typically conducted to inform budget prioritization and develop priority planning areas; and (3) the local scale, where local data and expertise are used to select project sites and determine appropriate management strategies and treatments within priority planning areas (table 1.2, fig. 1.1). In the decisionmaking process it is necessary to ask whether decisions made at one scale will affect the ability to obtain objectives at other scales. For example, will management decisions at the local scale regarding the locations of fuel treatments or restoration activities have net positive, negative, or neutral effects on landscape connectivity, GRSG, and other species at risk at larger scales? It also is important to ask what the effects of decisions made today will be in 10 or 20 years. For example, will seeding an introduced species in an area that may recover on its own or where restoration of native species may eventually be needed have a net positive, negative, or neutral effect on agency budgets and ecological conditions?

Nontarget Resources. Another important question to ask in the decisionmaking process is: How will decisions to either leave current management practices in place or change management practices affect the resource being managed and nontarget resources over time? For example, will maintaining current grazing practices have net positive, negative, or neutral effects on forage production and habitat quality for GRSG and other species at risk? What will be the longer-term consequences on rangeland health of failure to manage wild horses and burros at Appropriate Management Levels (AMLs)?

Data Availability and Quality. Resource management increasingly involves the use of geospatial data, models, and maps to identify optimal management strategies. The quality and availability of data affect the information available

Text Box 9.1—Activities in a Structured Decisionmaking Approach (Based on USDOI 2009)

- Engage the relevant experts and stakeholders in the decision making process;
- Identify the problem to be addressed;
- Specify objectives and tradeoffs that capture the effects on the ecosystem and the values of stakeholders;
- Obtain the best available information on potential management outcomes and identify the range of decision alternatives from which actions are to be selected;
- Specify assumptions about resource structures and functions and the effects of management outcomes;
- Project the consequences of alternative actions;
- Identify key uncertainties;
- Evaluate risk tolerance for potential consequences of decisions;
- Account for future impacts of present decisions; and
- Account for legal guidelines and constraints.

for making decisions, the management actions that are implemented, and the outcomes of those actions. Consequently, it is necessary to stay informed about new data layers and decision-support systems and their relative strengths and weaknesses (text box 9.2). It also is important to consider both the source and quality of the science that is being used and ensure that it has been published in the peer-reviewed literature (text box 9.2).

Text Box 9.2—Data Considerations for the Science Framework

The models, maps, and data layers used throughout the Science Framework (Chambers et al. 2017; Crist et al. this volume) represent the best scientific information available at the time these documents were written. This information is the result of cutting-edge techniques in remote-sensing of plant communities (e.g., Boyte and Wylie 2017; Xian et al. 2013), combination of data from different spatial scales (Maestas et al. 2016), and new analytical techniques for combining complex datasets (Doherty et al. 2016). This information may be updated as we advance our understanding of these complex ecosystems and develop new and improved data layers and decision-support tools. In addition, new data may arise from interpretation of existing information or application of improved techniques for measuring and modeling dynamic and variable systems across space and time. Updates on the models, maps, and data layers used in the Science Framework are intended to be provided as new science information and geospatial data become available.

When selecting information to inform a decision or updating data layers, practitioners need data that are appropriate to the scale of interest. Technological advances in remote sensing and analysis are providing data with increasingly finer temporal, thematic, and spatial resolution. Although this provides tremendous opportunities for understanding and targeting actions, users must ensure that they have selected the best data to meet project objectives or answer the management questions. For example, most of the species distribution modeling literature uses landscape cover metrics derived from remotely sensed land cover maps that characterize ecological communities (i.e., LANDFIRE). Recently, remote-sensing products have been developed that provide continuous vegetation component values that are more equivalent to ground-based vegetation surveys (Xian et al. 2013). These two types of data are not directly interchangeable and it will be necessary to evaluate which data type is better for the intended application.

Users should critically evaluate uncertainty, measurement error, and model assumptions to understand potential limits to application and inference whenever selecting data for analyses. The original scientific publications should be consulted for information on the types of error, degree of uncertainty, and underlying assumptions. This is particularly important for modeling that integrates multiple spatial datasets, because the degree of error and uncertainty can vary across different datasets and can be compounded when data are combined to create new models or decision-support tools. However, integrative models and spatial products still offer very useful ways of understanding and visualizing complex information when the potential errors and uncertainties are understood and specified. These models and spatial products can guide practitioners to places on the landscape that can be verified by field surveys and local knowledge.

Finally, practitioners should consider the source and quality of the science they are using, because new geospatial layers, tools, and applications are being developed rapidly. They should use data that have been published in the peer-reviewed literature. The rigors of the peer review process necessary for publication in respected sources result in quality control and assurance that nonpeer-reviewed literature may or may not have acquired. Although new maps, data, or tools may appear to provide exciting new opportunities for analysis and decisionmaking, caution should be used in applying this information before adequate documentation is available and peer-review of methods and assumptions has been completed.

Dealing with uncertainty is one of the greatest challenges in decisionmaking. Changes in administrative priorities, policies, and economic resources can all cause uncertainty in the types of decisions that should be made as well as the outcomes of those decisions. In addition, there are several well-recognized sources of uncertainty specific to making natural resource decisions (Conroy et al. 2011; USDOI 2009; Williams et al. 2002). **First**, environmental uncertainty, or uncertainty in ecosystem and species responses to factors such as disturbances, weather events, climate change, and management actions, is a well-known source of uncertainty that characterizes all natural systems and requires little explanation. **Second**, partial observability, or the need to estimate and model the relevant "quantities" that characterize natural systems because of our inability to directly observe nature, often limits our ability to accurately determine the resource "quantities" that are the targets of management. For example, the amount of forage production on an allotment is often estimated from sampling a small number of plots and estimating values; the acres of habitat to support a particular species is often estimated from limited research on habitat requirements, often in a different location. **Third**, partial controllability is the frequent inability to apply management actions directly and with high precision. An example is aerial seeding of postfire reclamation species. **Fourth**, structural uncertainty is the uncertainty in the models that predict system responses to specific management actions. Structural uncertainty is often represented by alternative models of system dynamics, each with associated measures of relative credibility. Reducing this type of uncertainty is a key objective of adaptive management (Walters 1986; Williams et al. 2002). Dealing with uncertainty in decisionmaking requires recognizing its existence, establishing rules whereby an optimal decision can be made in the face of uncertainty, and reducing uncertainty where possible (Conroy et al. 2011).

Application to Management

This section is intended to facilitate the decisionmaking process by integrating the management considerations for each of the management topics addressed in this volume and identifying the tradeoffs involved in managing for the different objectives and resources associated with each management topic. On October 17–19, 2017, management and science experts from different agencies and organizations met in Boise, Idaho, to evaluate the management considerations and tradeoffs for the different topics. Specific objectives were to: (1) identify and discuss how to integrate project objectives and evaluate the tradeoffs that need to be considered across scales in decisions about land management activities in sagebrush ecosystems, and (2) develop scenarios that identify and discuss how tradeoffs influence priorities for managing dominant threats in the western and eastern portions of the sagebrush biome. As a result of this meeting and subsequent work by the editorial team, "management scenarios" were developed that focus on the management considerations and tradeoffs involved in managing (1) invasive annual grasses and uncharacteristic wildland fire, (2) juniper (*Juniperus* spp.) and piñon pine (*Pinus* spp.) expansion, and (3) land use and development (e.g., cropland conversion and associated invasion of nonnative species). In addition, an "integration table" was developed that includes all paired combinations of the topics addressed in this volume and identifies the desired outcome, management considerations, and tradeoffs for each paired combination. The integration table also includes any critical information needs and policy needs that were identified at the meeting.

The scenarios and integration table were not developed for a particular management agency and thus do not consider the different policies of individual agencies. Instead, collective management considerations are provided for all managing entities. Managers can incorporate other management considerations and tradeoffs important for their particular agency, geographic region, or program.

Management Scenarios

The management scenarios illustrate how different management considerations and tradeoffs (table 9.1) are taken into account when developing management actions and making management decisions about potential actions. Supporting information is found in Part 1 of the Science Framework (Chambers et al. 2017a; hereafter, Part 1). An overview of persistent ecosystem threats is in Part 1, section 5. These threats include nonnative invasive plant species, altered fire regimes, conifer expansion, and climate change, as well as land use and development threats including cropland conversion, energy development, mining, roads and other infrastructure, urban and exurban development, recreation, wild horse and burro use, and improper livestock grazing. Geospatial analyses with overlays of key data layers can help (1) evaluate the type, presence, and level of threat to ecological types and vegetation communities; (2) target areas for adaptive management; and (3) determine the most appropriate types of management actions. Part 1, section 8 presents data and analytical methods for identifying priority areas for management within ecoregions or Management Zones and evaluating both persistent ecosystem and land use and development threats. The use of higher resolution spatial data, combined with local information and knowledge, helps managers and stakeholders refine project areas and determine the most appropriate management strategies and is detailed in Part 1, section 9. Management strategies for persistent ecosystem threats, climate change, and land use and development threats are identified in table 1.4 (this volume), and recommendations for prioritizing and targeting strategies are in table 1.3 (this volume).

Invasive Annual Grasses and Uncharacteristic Wildfire

This scenario addresses the ongoing spread of invasive annual grasses and resulting uncharacteristic wildfires. The desired outcome is to reduce the occurrence and spread of invasive annual grasses in these landscapes and the loss of sagebrush habitat due to uncharacteristic wildland fire. The emphasis is on landscapes with low to moderate resilience and resistance, where these issues are most problematic and additional management focus is needed. Although the scenario was developed largely for the northern and central Great Basin and Columbia Plateau in the Cold Deserts, it also is applicable to the Western Cordillera (see fig. 1.1), where invasive annual grasses are spreading and uncharacteristic wildfires are occurring.

Three management approaches are provided to help address the threats of invasive annual grasses and wildfire in low to moderate resilience and resistance landscapes. These approaches are intended to work in tandem with the management considerations and tradeoffs described in the integration table (table 9.1) and build on the information provided in tables 5.1 and 5.2. These approaches are: (1) **prevention** of invasion of existing intact sagebrush habitat by nonnative invasive annual grasses, (2) **intervention** to help restore areas at risk of becoming dominated by invasive annual grasses and higher fire frequencies, and (3) **containment** of invasive annual grasses to decrease the effects and spread of the fire/invasive annual grass cycle in low to moderate resilience and resistance areas.

The use of the different management approaches depends on the extent and relative abundance of invasive annual grasses and associated wildfire occurrences. Multi-scale assessments that include geospatial datasets, monitoring data, and field surveys can help identify the most appropriate scale for applying the management approaches within a region. Geospatial datasets and methods are provided in text box 9.3 to help identify areas on the landscape where these management approaches apply. Areas managed for **prevention** are those where sagebrush communities are ecologically intact and have little to no cover of invasive annual grasses. Areas managed for **intervention** typically have lower cover of sagebrush or shrubs and perennial grasses and forbs, but a relatively low cover of invasive annual grasses. These areas may be at risk of invasive annual grass dominance and intervention may help them return to a more native species-dominated state. Areas managed for **containment** have moderate to high cover of invasive annual grasses and very low cover of shrubs and native grass and forbs. These areas are difficult to restore to a native species-dominated state due to invasive dominance. The three management approaches align with the five invasion states in tables 5.1 and 5.2. **Prevention** areas can be defined as "invasion free" and "trace"; **intervention** areas as "mild" to "moderate"; and **containment** areas as "invasion dominated."

Text Box 9.3—Mapping Prevention, Intervention, and Containment Areas for Managing Invasive Annual Grasses and Uncharacteristic Wildfire

A multi-scale spatial assessment can be used to identify and delineate where to apply **prevention, intervention,** and **containment** management approaches in landscapes with low to moderate resilience and resistance to invasive annual grasses. Geospatial data layers and a mapping framework for prioritizing areas for management at regional scales are in Part 1, section 8 and Appendix 8. The highest resolution data available for the assessment area should be used (text box 9.2). The categorization of an area for **prevention, intervention,** or **containment** should include characteristics such as: (1) the cover of native, intact sagebrush ecosystems; (2) the degree of connectivity among sagebrush habitats; and (3) priority resource values such as Greater sage-grouse (GRSG) habitat. Fire risk assessments should be used to identify areas with low to moderate resilience and resistance that have a higher probability of experiencing fire (Part 1, Appendix 10). Relevant data layers include ecological site types or vegetation cover types, resilience and resistance categories, and surface land management. Other information may include the potential of an area to provide native seed sources and reserves.

The proportion of the landscape dominated by sagebrush land cover provides information on the landscape context and potential habitat suitability for GRSG and for other sagebrush dependent species at risk (Chambers et al. 2017a,c; Knick et al. 2013). For example, sagebrush cover categories are based on the proportion of the landscape dominated by sagebrush (5-kilometer [3-mile] rolling window; low = 1–25 percent; moderate = 26–65 percent; high = >65 percent land cover). Data on topography, postfire recovery sites, rare species habitats, migratory pathways, and GRSG lek locations or population indices can refine the identification of these areas.

The use of Assessment, Inventory, and Monitoring (AIM) data, field survey data, and local expertise can be used for refining distinctions between the different areas. Tables 5.1 and 5.2 provide five invasion states that can further refine the delineation of **prevention**, **intervention**, and **containment** areas. **Prevention** areas can be defined as "invasion free" and "trace"; **intervention** areas as "mild" to "moderate"; and **containment** areas as "invasion dominated."

To implement the approaches, land management objectives of "**prevention**," "**intervention and restoration**," and "**containment and long-term rehabilitation**" are developed and assigned based on coordination among the science and resource specialists across a management jurisdiction. Strong partnerships and collaboration between State and Federal invasive programs are needed for targeted prevention, control, and eradication of invasive plants. In **prevention** areas, managers should minimize management activities known to spread invasive plants and implement a strong monitoring and eradication program, such as an Early Detection and Rapid Response program (EDRR) (USDOI 2016). Other prevention measures are in table 5.1. In **intervention** areas (previously burned or unburned), managers should emphasize restoring and maintaining resilience to wildfire and resistance to nonnative annual grass invasions. Primary intervention objectives include increasing the extent, connectivity, and ecological functioning of sagebrush ecosystems. These objectives are requisite to meeting other landscape objectives such as increasing the sustainability and resilience of habitat for different species of wildlife, forage for livestock, and other resources such as native seed reserves. Intervention measures include eradication, suppression, containment, and active restoration. Their use should be aligned with local environmental conditions to optimize success.

In **containment** areas, the management focus is on removal and containment of invasive plants to protect adjacent or nearby areas from invasion and address the higher frequency and larger extent of wildfire in these areas. The effectiveness of different herbicide treatments and seeding strategies can be tested through carefully designed treatments and long-term monitoring. This information can be shared among land management agencies. Monitoring of **containment** areas can provide information on changes in invasive annual grasses and other invasive plants and help identify new invaders. Monitoring along the interfaces of highly invaded sites and intact sagebrush communities can help provide information on where containment strategies have been successful and where adaptive management is needed. Once an area is designated as having a management objective of "containment," loss of ecological function may occur due to containment strategies. However, there may be opportunities for rehabilitation when methods become available in the future. In addition, surveys of potential **containment** areas for endangered, threatened, or sensitive species, species of concern, and known rare species can be used to determine whether these areas or portions of these areas should be reclassified as **intervention** areas to protect these resources. The development of evaluation criteria for restoration potential, along with an understanding of associated tradeoffs, will help inform the classification of these areas.

Climate Variability and Adaptation

Climate and climate variability have a strong influence on management considerations and tradeoffs and, thus, management approaches for low to moderate resilience and resistance areas. Identification of which invasive plants are likely to spread and of the areas susceptible to invasion coupled with EDRR monitoring can help managers decide where to implement **prevention, intervention,** and **containment** strategies to facilitate climate adaptation. Scenario planning also can assist with balancing the tradeoffs of different management approaches (e.g., assisted migration).

To help maintain or enhance the resilience and resistance of areas managed for **prevention** and **intervention**, native plant species distributions should be allowed to transition and adapt to changing climatic and environmental conditions. In areas managed as **intervention** and **containment**, resilience and resistance may be maintained or facilitated through vegetation treatments that help communities transition to new states or site types where appropriate. The use of carefully designed treatments and monitoring can help identify successful methods for assisted migration of native plant species (Bucharova 2017). Monitoring for appearance of novel invaders, changes in biodiversity and native species populations, and movement of key species can be used to evaluate how changing landscapes are responding to treatments in all three management approaches.

Land Uses, Development, and Rehabilitation

Anthropogenic land uses and developments that are known to serve as invasive and noxious weed vectors, such as roads, pipelines, fuel breaks, utility corridors, juxtaposed agricultural practices, grazing, and mining, should be addressed in all three management approaches. Land uses and developments that serve as vectors for invasive plants should be redirected around **prevention** areas or reduced in number, frequency, and extent to reduce impacts; minimized and monitored in **intervention** areas; and where resource values are not at risk, focused in **containment** areas. Management activities should use defined best management practices (BMPs) for preventing the spread of invasive plants. See tables 5.1 and 5.2 for other “on the ground” **prevention, intervention,** and **containment** strategies.

Grazing should be minimized in **protection** areas and potentially refocused to other areas that are more resilient to grazing to maintain no to low levels of invasive plants. For **intervention** areas, use of alternative grazing strategies (e.g., shifting the season of use, using outcome-based grazing, creating grass banks) can help contain spread of invasive plants. Where alternative grazing strategies may increase risk to the operator or permittee, outcome-based grazing and evaluating the degree of risk can help provide effective solutions. Identifying **containment** areas that may be used as grass banks or to extend grazing seasons may also address these tradeoffs. Grazing permits should include the season, duration, and amount of grazing that can sustain native grasses and forbs based on state-and-transition models for low and moderate resilience and resistance sites (section 7). They also should include plans for drought conditions and changing weather and climate patterns. Alternative grazing strategies such as changing season of use, targeted grazing, and grass banks could be focused in containment areas to reduce contiguous fuels throughout these areas. Grazing strategies developed for the three approaches will need to be adaptive and responsive to climate and weather patterns that result in changes in forage availability.

Control and removal of invasive plants through the use of adaptive management, EDRR strategies (USDOI 2016), and focused invasive plant removal treatments should become a primary management goal for all Federal and State management agencies. At the field office and district scale, spatial mapping, field surveys, and use of monitoring data can augment geospatial data to refine **prevention, intervention,** and **containment** areas (text box 9.3). The primary factors to consider are site conditions, relative abundance of residual grasses and forbs, relative abundance of the invader, and proximity and juxtaposition to invasive plant dispersal vectors. See tables 5.1 and 5.2 for “on the ground” **prevention, intervention,** and **containment** strategies.

In **prevention** areas EDRR is used to quickly remove new invasive plants. In **intervention** and **containment** areas strategies depend on the magnitude of the invasion, but can include a variety of treatments such as herbicides, seeding, and transplants, to reduce the cover and spread of invasive plants (section 5). In **intervention** areas, invasive plant control treatments should minimize soil surface disturbance and disturbance of biological soil crusts. Restoration should focus on seeding in areas that lack perennial grasses and forbs. Spatial mapping can be used to target restoration efforts between intact sagebrush patches to increase sagebrush habitat connectivity over the long term. Use of herbicides followed by seeding should be prioritized to control spread from **containment** areas, especially those located adjacent to **intervention** or **prevention** areas. Treatment success may be challenging and multiple interventions may be required, especially in **containment** areas. In general, long-term monitoring and adaptive management practices should be used to evaluate treatment successes, test other invasive plant removal strategies, identify challenging areas, and determine when **intervention** areas may need to be considered **containment** areas.

Following wildfire or other disturbances, tradeoffs to consider for invasive plant management in **prevention** areas include the potential negative effects of using herbicides and seeding on native species recovery versus allowing natural recovery. In **intervention** areas, herbicide application, seeding treatments, and other postfire or disturbance recovery efforts should be targeted. Management objectives for seeding in **prevention** and **intervention** areas should focus on reestablishing native species and ecological diversity rather than seeding specifically for livestock grazing benefits. Establishing restoration islands of diverse native forbs, bunchgrasses, and other shrubs can mimic natural recovery and succession after wildfire in sagebrush communities with depleted native herbaceous species.

The use of specific livestock grazing regimes for low to moderate resilience and resistance areas is essential for all restoration and postfire recovery efforts because grazing or use of seeded areas may inhibit recovery. Managers should consider structuring grazing regimes depending on the designated management approach—**prevention, intervention,** or **containment**. For example, spring and early summer grazing could be prioritized in **containment** areas before **intervention** and **prevention** areas. Focused monitoring and management of cattle grazing are needed to adapt grazing strategies where recovery goals are not met. Prioritizing management of wild horse and burro populations for population reductions where these populations exceed AML and are affecting ecological conditions will help protect treated and seeded areas (section 8). These types of strategies are applicable to other restoration activities for invasive plant control after disturbance.

Wildland Fire Management

Fire risk assessments are useful in determining priorities for wildfire management objectives for **prevention, intervention,** and **containment** areas. **Prevention** and **intervention** areas should receive higher priority for fire suppression efforts, especially if located next to a containment area. This juxtaposition increases the risk of wildfire and conversion to annual invasive grasses in **prevention** and **intervention** areas. Fuel treatments should be focused in **intervention** and **containment** areas. Tables 5.1 and 5.2 offer more specific management strategies. The following approaches, when integrated, can help reduce the occurrence of fire disturbances in lower resilience and resistance areas and mitigate potential natural resource tradeoffs in fuel treatments and wildfire management decisions.

First, a strong emphasis on wildland fire prevention strategies in wildland-human interface areas that focus on common causes of human ignitions such as powerlines, fireworks, campfires, target shooting, and vehicles parking on roadsides is needed to help reduce wildland fires in **prevention, intervention,** and **containment** areas. Across the western states, human-caused fires accounted for 31 percent to 97 percent of all wildfires (Balch et al. 2017). Strong partnerships and collaboration are needed between State and Federal wildfire prevention and mitigation programs to help reduce human-caused fires. Industries, land users, and recreationists need to be included in these partnerships.

Second, siting of fire suppression activities (e.g., firelines, burnouts) and equipment in containment areas where they occur adjacent to intervention and prevention areas can be used to minimize disturbance in intervention and prevention areas. Other strategies include training on invasive plant awareness, and incorporating invasive plant information and management into Fire Incident Action Plans.

Third, strategically placed and consistently maintained fuel treatments such as fuel breaks alongside roads within **intervention** and **containment** areas may help reduce substantial losses of sagebrush communities due to wildfire by aiding wildfire suppression efforts and reducing fire spread. The use of fuel breaks should be prioritized for areas of higher fire frequency to help protect wildland-urban interface areas, **prevention** areas, and **intervention** areas. The effectiveness of fuel breaks across large landscapes is unknown, and fuel breaks alone may not reduce the extent of uncharacteristic fire in sagebrush communities (Shinneman et al. 2018). However, different lengths and widths of fuel break networks can be tested using fire simulation modeling to identify strategic placement and design. Design and placement should take into account the fuels in the landscape, fire response, and operational efficiency. Monitoring and adaptive management will further inform their best use and placement over time.

Fuel breaks are for the sole purpose of wildland fire management and should not be used to achieve other management goals. Plant materials used in fuel breaks should have traits such as low stature to reduce flame lengths or resistance to invasive plant species. Native and nonnative species selected for seeding fuel breaks should not be managed as forage for wildlife or have traits that rely on grazing regimes to retain low biomass.

To help avoid unintended management consequences and ecological impacts, the design, placement, and long-term management of fuel breaks should be carefully evaluated before construction. Fuel breaks can become dominated by invasive annual grasses and serve as fire ignition points, especially when located next to wildland-urban interface areas or popular recreation sites. Therefore, consistent fuel break maintenance in perpetuity needs to be a high management priority to maintain their effectiveness for fire suppression efforts over time. To help mitigate unintended ecological impacts, managers should assess effects on wildlife habitat and adjacent ecosystems before deciding to construct a fuel break network (see Shinneman et al. 2018). Tradeoffs, such as habitat loss, fragmentation, and impeding wildlife species movements, may be mitigated by using wildlife habitat fragmentation thresholds and varying fuel break width, length, and placement across the landscape.

Several sections in this volume will be useful in evaluating management considerations and tradeoffs associated with fuel breaks (sections 4 through 6). Also see table 1.4.

In conclusion, this scenario provides a spatially integrated management approach that builds on many of the strategies in tables 5.1 and 5.2. There are many other factors to consider for applying **prevention, intervention,** and **containment** management approaches in low to moderate resilience and resistance areas, including:

- Special status wildlife and plant species
- Availability of seed
- Land use plan flexibility
- Stakeholders' willingness to engage and collaborate
- Unforeseen or unplanned disturbance
- Staff turnover—key personnel
- Topography and terrain access
- Availability of grass banks and grazing options
- Availability of useful monitoring data in and adjacent to site
- Emerging invasive species that pose a risk to these sites (early watch species)

Juniper and Piñon Pine Expansion

This scenario addresses the expansion of juniper and piñon pine trees into sagebrush ecosystems and the associated decline in sagebrush dependent species and resource values. The desired outcome is to reduce the loss of sagebrush resulting from juniper and piñon expansion, while maintaining a mosaic of sagebrush and juniper and piñon habitats needed for species dependent on these ecosystems. The focus is on moderate to high resilience and resistance areas at mid- to high elevations where juniper and piñon expansion is causing sagebrush habitat loss. This integrated management scenario discusses identifying juniper and piñon areas for targeted removals, addressing the threat of increasing invasive plants during site selection and treatment implementation, and using treatment methods that mimic natural disturbances which may help mitigate the negative effects on the species that depend on these expansion areas.

Identification of areas where juniper and piñon are expanding into currently occupied GRSG habitats or other threatened or at-risk species habitats is needed to locate the highest priority sites for tree removal treatments to maintain or restore sagebrush communities. The framework and geospatial datasets provided in Part 1, section 8 can be used to help select potential treatment sites. After identifying potential treatment sites, managers should coordinate with other science and resource specialists (State and Federal) to evaluate potential conflicts with other species' conservation needs and other resources to determine appropriate treatments. An approach for evaluating a site's relative resilience to disturbance and resistance to nonnative invasive plants and selecting appropriate treatment methods is in Miller et al. (2014).

Management objectives for juniper and piñon removals should incorporate potential changes in native juniper and piñon species distributions, fluctuations in populations, and adaptations to changing climatic and environmental conditions. Considering this information in site and treatment selection can help in managing for longer-term ecosystem resilience and multiple uses. When identifying juniper and piñon removal sites, practitioners should consider the presettlement distribution and history in relation to the number of acres (hectares) of juniper and piñon lost to disturbances, such as wildland fire, insects, and drought (see Board et al. 2018), as well as past removals over a specified period of time (past one to two decades), to help determine the appropriate number of acres for targeted removal. Continued monitoring of juniper and piñon as well as sagebrush habitats that are lost to disturbances such as wildland fire and drought over time can be used to identify where adjustments are needed in proposed removals and help adapt management strategies for local and regional areas. Recent increases in loss of juniper and piñon woodlands through natural disturbances may be contributing to removal goals, or these goals may have even been met in some areas. This type of information will improve understanding of how much targeted removal should occur across a geographic area and help to plan removals in the context of natural disturbances and climate change.

Areas should be prioritized for treatment where removals will not result in increases or dominance of invasive plants because of the disturbance caused by the removal treatment. Field-based surveys are needed to identify areas for removals that have sufficient cover of sagebrush and native grasses and forbs in the understory for site recovery (Miller et al. 2014). If expansion sites are relatively warm and dry, invasive annual grasses are present, and sagebrush or perennial grasses have low abundance, there is a strong possibility that the site will convert to invasive plant dominance after tree removal. Managers can consider treating the site with pre-emergent herbicides after tree removal and monitoring for recovery of perennial grasses and forbs (but see Pyke et al. 2014). However, seeding perennial native grasses and forbs may be required to facilitate recovery of these types of sites, and investments in tree removal will produce higher returns in areas that have the potential to recover without additional treatments.

Thresholds of native perennial grasses and forbs needed to ensure recovery of sagebrush ecosystems can be found in Davies (2008), Chambers et al. (2014d), and Miller et al. (2014). Recent research related to juniper and piñon treatments is in sections 4 and 5.

Removal of juniper and piñon in expansion areas may have negative consequences for species dependent on the different habitat conditions these areas provide (e.g., seed caching areas for pinyon jay [*Gymnorhinus cyanocephalus*] and winter habitat for mule deer [*Odocoileus hemionus*]). Expansion areas include edge and open transitional habitats important to a variety of species including some that are in sharp decline. Designing removals that mimic the patterns of natural disturbance such as wildland fire and drought will help ensure that the habitat needs of these species are taken into account and that objectives in land management plans for maintaining a mosaic of sagebrush and juniper and piñon habitats are achieved. To meet these needs, removal treatments can be designed to incorporate the following:

- Creation of transitional (feathered) and more convoluted-shaped edge habitats between sagebrush and juniper and piñon to avoid sharply contrasting and straight edges (e.g., dense juniper and piñon woodland adjacent to sagebrush)
- Creation of openings within juniper and piñon stands with high density and cover
- Leaving older piñon pine trees that produce pine nuts

During and after removals and associated treatments, there may be a need to temporarily change grazing management regimes. Shifting seasons of grazing use depending on climate and weather patterns can help encourage recovery of sagebrush habitats and deter invasive plants from spreading into treated sites. However, this can have economic effects on the grazing operator or permittee. Planning for the use of alternative grazing areas for the time needed to allow recovery after removal will help mitigate effects on the grazing operator. Where wild horse and burro management areas overlap or are adjacent to areas for targeted juniper and piñon removal, it may be necessary to reduce wild horse and burro populations to AML if the juniper and piñon removal treatments are to succeed (section 8).

Land Use and Development Threats

This scenario addresses two closely related issues. The first is type conversions such as those resulting from agricultural uses that degrade habitat quality or remove habitat through conversion to other land uses. The desired outcome is to prevent loss of sagebrush habitats and reduce fragmentation while maintaining or improving connectivity at multiple scales. The second issue is land uses that facilitate increases in invasive annual grasses and forbs. Here the desired outcome is to prevent new invasions and reduce expansion and spread of existing invasive plant threats that may be increased with surface-disturbing activities, such as energy development and conversion of sagebrush communities to cropland. The emphasis is on the eastern portion of the sagebrush biome, including the Northwestern Plains, Wyoming Basin, and Colorado Plateau, and Southern Rockies (see fig. 1.1), but management strategies are broadly applicable.

In the eastern portion of the sagebrush biome, land use impacts often represent a more immediate risk to high quality, intact, and connected GRSG habitat than wildland fire, invasive plant species, or the effects of a changing climate. For example, cropland conversion can pose a more immediate and lasting risk to GRSG habitat quantity or connectivity than is posed by invasive plant species or wildland fire. In the Conservation Objectives Team Report (USDOI FWS 2013), cropland conversion was ranked a widespread and persistent threat on more productive soils for 6 of 15 GRSG populations in the eastern range. The West-Central Semiarid Prairies (Management Zone I) has the highest percentage of private lands and highest amounts of filled cropland of the Management Zones (Doherty et al. 2016; Knick et al. 2011, table 12.1). GRSG extirpations have occurred in areas where cultivated crops exceeded 25 percent of landscape cover (Aldridge et al. 2008) and recent studies show that 96 percent of active leks are surrounded by less than 15 percent cropland in Management Zone I (SGI 2015; Smith et al. 2016). Loss of landscape cover of sagebrush associated with energy development has been well documented in recent analyses, especially for oil and gas. Oil and gas development affects 8 percent of sagebrush habitats, with the highest intensities occurring in Management Zone I and Management Zone II (Part 1, section 5.3.2). Mining is considered a persistent and widespread threat to 8 of 15 GRSG populations in the eastern range (USDOI FWS 2013) (Part 1, section 5.3.2).

Numerous studies have found invasive plant species associated with soils disturbed by development activities and have noted that restoration becomes much more difficult once these species are established (see Part 1, section 5.3.6). The cumulative effects of anthropogenic development and persistent ecosystem threats may be most evident for sites with relatively warm or dry soil temperature and moisture regimes that have relatively low resilience and resistance; these effects may intensify as the climate warms (Part 1, section 5.3.6). The most successful tool for maintaining sagebrush ecosystem resistance to nonnative plant invasions is generally to manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts to prevent the establishment or population growth of the invader (Chambers et al. 2014b,d).

Best management practices can reduce or prevent introductions of invasive plant species to new areas and can help maintain the resistance of the ecosystem to invasion. Monitoring (including EDRR) can be used to identify areas where preventive action can decrease the risk of reaching the levels of invasive annual grasses currently found in parts of the Great Basin. Monitoring can also provide the necessary information to quickly respond to reports of new sightings of invasive plant species. Although invasive annual grasses are arguably the most widespread ecosystem disrupters across the sagebrush biome, other plant life forms are also responsible for impacts to the sagebrush uplands and the riparian and wet meadow habitats. These invasive plant species should be included in EDRR efforts as well (see section 5 and Appendix 3). EDRR for these species can be enhanced through the use of standardized vegetation monitoring programs such as the Bureau of Land Management's Assessment Inventory and Monitoring (AIM) and Natural Resources Conservation Service's National Resources Inventory (NRI) efforts which, when combined with enhanced data tracking systems, can be used to locate and treat identified areas in the same year that they are discovered.

In much of the eastern part of the sagebrush biome, the culture, customs, and practices of landscape management have formed within a relatively resilient ecosystem. Failure to consider how land uses and impacts can degrade habitat and increase the likelihood for invasive plants may give a false sense of resilience and resistance. It is important to ask how decisions to either leave current management practices in place or change management practices will affect the resource being managed and nontarget resources over time. To fully address this question, it will be necessary to reexamine current assumptions about the effects of weather and climate on environmental responses and underlying assumptions about the expected results of management actions. Use of appropriate BMPs can help adapt management over time.

Type Conversions

Several management strategies can be used to prevent habitat loss from land uses that degrade habitat and conversion of sagebrush to cropland. These include conservation agreements (easements and Federal and private lands programs, such as the Conservation Reserve Program, Agricultural Conservation Easement Program, Environmental Quality Incentives Program, and Candidate Conservation Agreements with Assurances), land use regulations, and land acquisitions. Factors to consider are:

- Willingness of private landowners to utilize conservation programs
- Wildlife and habitat resource values
- Subsidies for conversion
- Benefits in terms of larger scale connectivity
- International agreements
- Cost of managing the land after acquisition or agreement
- Spatial strategy for acquiring lands or conservation easements (or both) to improve connectivity
- Positioning of existing conservation easements
- Subsurface mineral ownership issues potentially impacting durability and benefit of conservation actions used to address other primary threats
- Existing regulations that may limit the amount of disturbance allowed

There are tradeoffs to consider when easements or land purchases are used to meet conservation objectives. Easements may limit or restrict other land uses and result in a potential long-term economic loss to farmers or to the community. Acquisition of lands results in both short-term and long-term costs associated with managing the land to achieve desired conditions or management goals. Additionally, acquiring easements opportunistically based on the willingness of landowners may not be the most strategic approach to reaching desired outcomes, such as habitat connectivity, or may not occur in areas with the most important resource conditions (i.e., low versus high resilience and resistance and wildlife habitat values, such as GRSG population densities and seasonal habitats).

Land Uses that Facilitate Increases in Invasive Annual Grasses and Forbs

Preventing new nonnative plant invasions and reducing the expansion or spread of existing invasive plants begins by identifying uninvaded areas and areas at increased risk of invasion and prioritizing management responses. Once the size and impact of an invasion are determined, the recovery potential of the area is evaluated. Uninvaded areas, especially those with lower resilience and resistance, are often at risk and should be identified for prevention strategies to keep "clean areas clean."

Tables 5.1 and 5.2 provide many management strategies for prevention of invasive grasses and forbs. Integrated pest management techniques are used to prevent introductions and reduce or control invasive plant spread into sagebrush habitat. Increased EDRR monitoring for invasive annual grasses and forbs, such as cheatgrass (*Bromus tectorum*), medusahead (*Taeniatherum caput-medusae*), ventenata grass (*Ventenata dubia*), leafy spurge (*Euphorbia esula*), and Russian knapweed (*Acroptilon repens*), is used in high priority areas (i.e., high GRSG population density and GRSG breeding habitat) near areas with development potential (cropland conversion or oil and gas potential). Strong working partnerships with landowners and local governments are developed to treat invasive plant species across ownership boundaries. Where development will occur, Conditions of Approval are employed for regulated activities to reduce the invasion and spread of unwanted nonnative invasive plants. Examples are reducing or controlling invasive plants in an area before disturbance and during active development and production; power-washing construction equipment before transporting to the project area; reclaiming the site to meet objectives for resistance to invasive plants and other objectives, such as value to wildlife; and educating vehicle operators about the dangers of fire ignition resulting from sparks caused by drag chains, cigarettes, and other ignition sources.

Factors to consider are:

- Willingness of private landowners to treat invasive plants
- Adequacy of post-disturbance reclamation requirements, implementation, and outcomes
- Coordination of treatments across ownership boundaries
- Use of methods other than chemical treatment, such as targeted livestock grazing, to control invasive plants
- Durability of treatment efforts to ensure that treatments are maintained long enough to avoid reestablishment of invasive plants and the potential for other land uses (development, infrastructure, grazing [livestock, wild horse and burro, wildlife]) to undo the efforts being implemented

Several tradeoffs need to be considered when implementing these strategies, including: (1) costs of conducting monitoring and potential treatments necessary to control invasive plants versus not having influence on how sagebrush communities are managed, (2) fewer resources for monitoring elsewhere or for other resources, (3) possible increased use of herbicides (which may have unintended impacts to nontarget species), and (4) herbicide application without emphasis on increasing desirable native species (herbicide treatments may create voids in which new invasive plants may occur).

Integration Table

The integration table is a tool that can be used to help develop management objectives and make management decisions regarding potential actions (table 9.1). The table is designed to help identify the relevant management considerations and tradeoffs involved for the different management topics addressed in this volume. It can be used to cross-check the relevant topics for a particular objective or desired outcome to ensure that all of the relevant management considerations and tradeoffs have been taken into account.

Table 9.1—The desired outcomes, management considerations, and tradeoffs, as well as any critical information needs and policy needs, for each combination of the topics included in this volume. The information provided for the integrated topics can be used to help managers determine whether all of the relevant management considerations and tradeoffs have been taken into account when making decisions regarding potential management actions. The length of the table and the inclusion of some repetition reflects the need to ensure that the relevant management considerations and tradeoffs were included for each integrated topic. It is anticipated that only a subset of the integrated topics will need to be reviewed for any particular action.

MONITORING and CLIMATE ADAPTATION

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated by collecting monitoring data that can be used to understand where and how ecosystems are changing and to inform adaptive management.

Management Considerations:

(1) Identify monitoring questions, ecosystem attributes, and indicators needed to evaluate effects of climate change and incorporate them into monitoring programs.

> **Tradeoff**: Durability of conservation and restoration efforts may be impacted if projects do not incorporate climate change or transition zone information due to changes in resilience and resistance, soils, and other resource conditions.

(2) Incorporate climate change information into project planning and use it to prioritize monitoring efforts among resources and treatments. Then adapt management based on results.

> **Tradeoff:** Increased monitoring requires greater investment and other areas or resources may be monitored less intensively. If Assessment Inventory and Monitoring (AIM) sampling is increased, it may be difficult to maintain sampling rigor.

(3) Monitor areas projected to change rapidly and areas with strong environmental gradients (transitions). Focus on resources and species within these areas.

> **Tradeoff:** Additional climate and weather monitoring stations and downscaled climate projections will be needed for areas projected to undergo changes or transitions.

(4) Use vegetation metrics to evaluate relative changes and impacts on different resources and wildlife species if possible.

> **Tradeoff:** Interactions among climate variables, the metrics for evaluating change, and species will need to be evaluated carefully.

(5) Use local climate data and climate projections to help indicate possible wildfire activity, potential for reclamation, grazing impacts, limits to recreational activities, and impacts to habitats.

> **Tradeoffs:** (a) Some activities may be limited or prohibited due to climatic conditions for short (summer) or long (years) terms. (b) The current spatial mismatch between the location and coverage of climate monitoring and the location and scales where we are making management decisions makes it difficult to incorporate climate impacts into assessments of other impacts, and to understand the effectiveness of management actions. (c) A temporal mismatch between the climate information collected and weather data, especially drought and seasonal weather which can influence management decisions, limits our ability to predict how seasonal weather has impacted things like wildfire, drought, and seeding effectiveness.

(Continued)

Table 9.1—(Continued).

Critical Information Needs:

(1) Create a systematic approach to monitoring weather and climate, building on existing monitoring networks that provide compatible data across the environmental gradients in the sagebrush biome. Without an expanded weather network, weather and climate data for mid- and upper elevations will have larger error rates because of spatial mismatches between weather stations and areas where management decisions are being made.

(2) Assess the relationships among various land changes, management outcomes, and climate to determine potential longer-term effects of climate change and to inform monitoring and adaptive management.

MONITORING and WILDLAND FIRE AND VEGETATION MANAGEMENT

Desired Management Outcome:

The effectiveness of wildfire suppression and vegetation management on current uncharacteristic wildfire regimes in sagebrush systems and the capacity to maintain resilience and resistance are positively related to current policies and practices on the ground across scales and over time.

Management Considerations:

(1) Identify and refine monitoring metrics for successful wildfire suppression, vegetation management, and invasive plant control with a focus on effectiveness and outcomes (e.g., acres with invasive plants reduced) rather than outputs (e.g., acres treated) to facilitate adaptive management. Utilize project "failure" information from monitoring results and focus on what we can learn from challenging postfire restoration or reclamation projects.

> **Tradeoff:** Reporting to Congress on short-term actions versus long-term outcomes creates too much focus on implementation rather than the effectiveness of treatments and other management actions.

(2) Change current monitoring (e.g., Fuel Treatment Effectiveness Monitoring) from a binary yes and no response to focus on more meaningful and quantifiable information for adaptive management.

> **Tradeoff:** It may be difficult to obtain the resources needed to monitor adequately.

(3) Use existing monitoring protocols to track long-term dynamics in grass/fire cycles and grass/shrub ecosystems. Base monitoring on timeframes beyond those specified in current protocols that require short-time measurement intervals at small scales (e.g., seasonal versus annual data over multiple years).

> **Tradeoff:** Results will need to be analyzed in a consistent and timely manner so that the results are meaningful at multiple scales, and land management decisions and actions can be adapted quickly.

(4) Monitor the spread of annual invasive grasses and their effects on fire processes.

> **Tradeoff:** If annual invasive grasses are shown to have widespread effects on fire spread, changes in firefighting strategies may be needed.

(5) Monitor the rates of recovery of sagebrush ecosystems in terms of the effects on different wildlife species with varying habitat requirements.

> **Tradeoff:** Failure to consider and plan for a variety of wildlife species and resources in management decisions can have undesired outcomes. For example, postfire recovery efforts may have negative effects on certain wildlife species by changing the composition of plant communities.

(6) Monitor fuel breaks to determine the effectiveness for wildfire suppression activities and the consequences for ecosystems. Monitoring should include quantifying vegetation loss due to fuel break construction and maintenance.

> **Tradeoff:** Monitoring may show that fuel breaks may be installed and maintained that either do not fully meet project objectives to aid wildfire suppression efforts or provide protection for fire suppression personnel. Monitoring may also show that extensive implementation of fuel breaks may increase both fragmentation and the chance of nonnative plant invasions into sagebrush ecosystems as a result of increased disturbance or intentionally seeding potentially invasive introduced species such as forage kochia (see section 6).

(7) Allocate both staff time and funding to conduct effectiveness monitoring to increase the return on investment. Embed costs of monitoring within estimated project costs up front and indicate the monetary tradeoff for monitoring to document effectiveness (outcomes) compared to only implementation (outputs).

> **Tradeoff:** Resources are limited for conservation actions. Although funding for this activity will divert resources from action implementation (outputs), it will provide critical information on success of those actions (outcomes).

(8) Provide the necessary training for conducting monitoring and evaluating the data across scales.

> **Tradeoff:** Without training, the data collected may be less accurate and fail to provide the desired information.

(9) Monitor current exposure to threats. Use that information to evaluate potential future exposure to the threat and to plan conservation and restoration efforts.

(Continued)

Table 9.1—(Continued).

Tradeoff: It will be necessary to determine whether resources will be used to protect those areas most at risk due to threats such as wildfire and plant invasions, or to protect those areas at least risk to maintain current values.

MONITORING and INVASIVE PLANTS

Desired Management Outcome:

Information on resilience and resistance and the current distribution and abundance, vectors, pathways, and impacts of invasive plants is used to inform prioritization of treatment areas, target monitoring efforts, and evaluate treatment effectiveness across scales.

Management Considerations:

(1) Monitor for high priority invasive plants with Early Detection and Rapid Response (EDRR) (USDOI 2016) protocols to prevent additional management burden due to new invasions and to detect spread from existing invasions.

Tradeoff: Without adequate monitoring to locate new invasions, invasive plants may spread and increase in abundance, degrading sagebrush habitat and understory and increasing the risk of catastrophic wildfires. Existing invasions may require long-term efforts and monitoring to achieve and identify success. EDRR monitoring can reduce the management burden and costs through eradication of the invasive plant that can be measured with monitoring within a shorter timeframe.

(2) Link prevention and EDRR strategies to agencies' implementation responses to invasive plant species in the sagebrush biome.

Tradeoff: An agency needs funds and capacity to be able to respond quickly, validate new reports, and have decision rules for level of response.

(3) Use resilience and resistance classes to stratify areas to monitor for invasive plants, focusing on areas of lower resistance and areas of high resource value.

Tradeoff: Monitoring in low resilience and resistance areas can help prevent spread and reduce current risk. Monitoring in high resilience and resistance areas is necessary to prevent new invasions and reduce future risk.

(4) Monitor the effectiveness of treatment strategies for invasive plants across ecological site types to provide more local and regional information on treatments or other management actions that have higher likelihoods of controlling invasive plants and thus will save time and resources.

Tradeoff: Monitoring may take resources from short-term actions (outputs), but having longer-term information on success (outcomes) will improve overall cost-effectiveness of future actions.

(5) Conduct posttreatment effectiveness monitoring following Emergency Stabilization and Rehabilitation (ES&R) to determine invasive plant response and report results to common agency databases.

Tradeoff: ES&R efforts for invasive plant control often have limited monitoring timeframes and can identify short-term reductions in invasive plants. However, additional resources for longer-term monitoring are needed to identify invasive plant treatment needs for effective restoration. Forgoing this monitoring may appease sociopolitical needs or concerns, or partners' concerns if resources are instead used for actions; however, efforts to control or reduce invasive plants in areas that are important for GRSG or other sagebrush dependent species may fail.

(6) Incorporate data or information on invasive plant presence into project planning to better assess the risk of invasive plant spread from existing invasions and in response to disturbance, development, vectors, and pathways.

Tradeoff: Federal land management agencies have mandates for multiple land use, yet authorized uses may increase the spread of invasive plants. Without incorporating information on the existing distributions and abundances of invasive plants into planning efforts, the risk of invasion from disturbance, development, vectors, and pathways may be underrepresented.

(7) Use Citizen Science opportunities to assist with EDRR monitoring for presence of new invasive plants.

Tradeoff: Citizen Science may not collect all of the information needed to confirm or evaluate the presence or abundance of an invasive plant and may be opportunistic and inconsistent. However, it is an opportunity to engage the public and can help identify new invasions.

(8) Identify opportunities to participate in collaborative efforts that are evaluating which tools (e.g., managing for perennial native grasses, selective use of herbicides and targeted grazing) can effectively control annual grasses over large enough areas to reduce risks associated with invasive plant spread and wildfire.

Tradeoff: Unless these efforts are focused and well-conceived, time and resources may be lost for reducing the population while waiting for results.

(Continued)

Table 9.1—(Continued).

Critical Information Needs:

(1) Develop better spatial information related to presence and cover of invasive plants to better target monitoring.

(2) Determine the climatic suitability and risk of future invasion for priority invasive plants. Use this information to determine the relationship between invasive plants and the resilience and resistance categories.

(3) Conduct long-term monitoring across a variety of ecological and geographical areas on native vegetation response to invasive species management tools: cultural (grazing, fire), mechanical (cutting, mowing), pesticides, and biological (pests, pathogens, bacteria, fungi).

MONITORING and SEED STRATEGY

Desired Management Outcome:

Implementation and effectiveness monitoring is used to ensure that projects and seeding strategies increase resilience and resistance by remaining flexible and adaptive and by tracking seed sources, species performance, and the outcomes of different seeding methods.

Management Considerations:

(1) Use monitoring information to determine whether seeding is necessary based on factors such as disturbance history, relative abundances of native perennial plant species, proximity to intact habitat, potential for invasive plant species competition with seeded species, and likely seed sources. If seeding is necessary, select appropriate species based on management objectives and ecological site characteristics, such as precipitation and soil type.

> **Tradeoff:** Although additional investments are necessary, much of the information required for determining the need to seed and selecting the species to seed could be determined by coupling prior monitoring data with resilience and resistance information and local knowledge about past fires/treatment success (Miller et al. 2015). For example, the response of postfire treatments in loamy, 8- to 12-inch [20–30 centimeter] ecological site types with Wyoming big sagebrush and bluebunch wheatgrass can be determined largely based on vegetation composition and cover prior to the wildfire, intensities of past burns, and past and current site-disturbance legacies, such as spring versus fall livestock grazing, or multiple livestock classes using the same allotment.

(2) Use effectiveness monitoring to assess the need for follow-up seeding, the addition of other species, and other management actions due to the effects of disturbances such as improper livestock grazing.

> **Tradeoff:** Monitoring the appropriate information for a sufficient period of time to determine the need for follow-up actions requires additional resources, but can help ensure longer-term treatment success.

(3) Record seed sources, pure live seed (PLS), and seeding methods. Monitor the germination and establishment of the different seed sources in a consistent manner.

> **Tradeoff:** With only anecdotal data, project managers can draw or perpetuate erroneous conclusions about the effectiveness of seeding outcomes. They may not be able to identify the cause of a seeding failure and prevent the failure from being repeated in the future.

(4) Develop monitoring protocols for managers and practitioners that are simple and infer results quickly in order to adaptively manage seeding strategies (e.g., Wirth and Pyke 2009).

> **Tradeoff:** More simplistic monitoring protocols may not capture long-term successes and failures. Implementation of nonstandardized protocols does not allow for comparisons of results among sites or the ability to analyze data at broad scales to identify trends that may affect seeding strategies across large areas.

Critical Information Needs:

(1) Better understand environmental cues that trigger germination in species we predominantly use or want to use in restoration, such as forbs, to determine why species perform poorly or seedings fail.

(2) Further develop climate tools to time seeding treatments to the most appropriate climate window(s). Effective use of these tools would require a new way to get and keep restoration funding to use when those windows are open (Hardegree et al. 2017).

(3) Develop equipment that ensures that native species seed is placed at the right depth in the seedbed.

(Continued)

Table 9.1—(Continued).

MONITORING and LIVESTOCK GRAZING MANAGEMENT

Desired Management Outcome:

Resilience and resistance of lands grazed by livestock are maintained or improved by using monitoring information to evaluate how and to what extent livestock grazing is influencing an area's rangeland health, effects on wildlife habitat, and forage production and to adaptively manage the timing, intensity, and frequency of livestock use.

Management Considerations:

(1) Collect monitoring data and analyze the results to evaluate the effectiveness of grazing strategies. Revise grazing permits and leases where rangeland health standards are not being achieved because of current livestock grazing management.

> **Tradeoff:** Monitoring of grazing effects is at the local level and is the primary monitoring activity for most field offices. Although data collection is generally occurring, failure to analyze the data and revise permits and leases as needed can result in declines in rangeland health and forage production.

(2) Identify expectations should monitoring data show that a grazing management change is warranted. Communicate these expectations to grazing permittees and lessees.

> **Tradeoff:** Monitoring data can indicate improper grazing of public lands, which can strain relationships with grazing permittees and lessees. These may be the same grazing permittees and lessees with whom managers would like to work to implement GRSG habitat improvements.

(3) Assess grazing utilization earlier than at the end of the grazing season to have the opportunity to make management changes (e.g., move livestock) before reaching utilization levels that can cause negative vegetation impacts.

> **Tradeoff:** Without this type of monitoring information and proactive management, rangeland health may decline over time.

(4) Use monitoring to determine how long to defer the onset of grazing after restoration or postfire rehabilitation to allow seeded species to establish and gain the vigor needed to withstand grazing pressures.

> **Tradeoffs:** Native grass species have not been selected to produce large amounts of aboveground biomass, are more susceptible to spring grazing, and are generally more palatable than nonnative species, leading to preferential grazing by livestock. (a) It may be necessary to defer the onset of grazing longer in areas where local native seed is used for restoration. (b) Producers may need other grazing options during the deferment in order to provide the treated or seeded area with the necessary time for recovery. Expected outcomes and estimated yields or treatment effectiveness may help achieve buy-in on deferments.

MONITORING and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Resilience and resistance are maintained by determining the effects of wild horses and burros (WHBs) on sagebrush ecosystems and whether Appropriate Management Levels (AMLs) for WHBs are appropriately set into the future.

Management Considerations:

(1) Continue aerial surveys using defensible methods to evaluate WHB distribution and abundance.

> **Tradeoff:** Increased conflict regarding WHB management could arise without rigorous measures of WHB distribution and abundance.

(2) Conduct utilization monitoring, keeping livestock grazing numbers and WHB abundance measures as covariates in the analyses. An assessment of range condition before livestock grazing and after grazing has ended in a particular year may help identify which impacts are from livestock and which are from WHBs.

> **Tradeoff:** Determining the effects of livestock versus WHB grazing is challenging, and this approach may not accurately portray WHB effects. However, by not monitoring WHB utilization and managing to AML, certain allotments may not be able to withstand the grazing pressure from both livestock and WHBs.

(3) Implement a monitoring program that includes measures of WHB impacts at or near water sources because WHBs are known to impair soil penetration, water quality, and flow at spring sites, especially when WHBs are at high densities.

> **Tradeoff:** Other areas may need to be less intensively monitored due to budget constraints.

(4) Include measures of WHB herd size (i.e., densities relative to AML) in the analysis of status and trends monitoring datasets that can be aggregated over the landscape based on data from multiple monitoring sites.

> **Tradeoff:** The spatial scale of project sites and vegetation monitoring may be very small compared to the scale of a local wild horse herd.

(Continued)

Table 9.1—(Continued).

(5) Consider including specific levels of WHB population, relative to AML as soft or hard triggers requiring a WHB gather in herd management area plans.

> **Tradeoff:** These adaptive management triggers and responses have a high likelihood of ending up in litigation, which is also a management consideration.

(6) Consider distance to water as an important covariate in monitoring program design (site selection) in areas with high populations of WHBs.

> **Tradeoff:** By not incorporating this information, monitoring could underestimate population densities and ecosystem impacts.

(7) Use adaptive management with WHBs and vegetation monitoring (validation monitoring) to answer the question: "Will habitats recover if WHBs are kept at AML?"

> **Tradeoff:** If monitoring data show that WHBs are causing damage or negative impacts, policy changes may be needed to address management needs and actions. These adaptive management triggers and responses have a high likelihood of ending up in litigation, which is also a management consideration.

CLIMATE ADAPTATION and WILDLAND FIRE AND VEGETATION MANAGEMENT

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated through effective prioritization and implementation of vegetation management treatments and other wildland fire management activities as wildfire regimes continue to change and additional conservation priorities arise.

Management Considerations:

(1) Use regional climate information to better predict high fire years.

> **Tradeoff:** This requires additional investment but can assist with fire preparedness.

(2) Expect that increases in fire potential will lead to increases in fire staff and the need for greater coordination of emergency services at the local level.

> **Tradeoffs:** Project implementation may be postponed until conditions improve, and budget priorities may shift to emergency services. Fire restrictions could impact recreational and other land uses.

(3) Clearly identify objectives when prioritizing habitats or species for protection and determining vegetation management strategies.

> **Tradeoff:** Managing for connectivity will facilitate dispersal and adaptation of species. However, assisted migration of native plant species may introduce species into new environments where they are not adapted or alter ecosystem processes (Bucharova 2017). Resources may be wasted if low priority habitats are selected for protection and management.

(4) Consider the climate vulnerability of species when prioritizing habitats or species for protection.

> **Tradeoff:** Protecting habitats or species in their current location that is not expected to support them in the future may preclude protecting another location that may be viable for them in the future.

Critical Information Needs:

(1) Determine how climate change is likely to alter vegetation across the landscape to guide management decisions.

(2) Evaluate how climate change will influence wildfire frequency and size across the sagebrush biome to allow for repositioning suppressive resources (e.g., local fire personnel and equipment) and potentially for locating fuel breaks or green strips.

(3) Research how climate change will affect landscape scale connectivity, species' vulnerability to climate change, and their projected distributions.

CLIMATE ADAPTATION and INVASIVE PLANTS

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated by identifying new plant invasions; effectively treating, suppressing, containing, and where possible eradicating existing invasions; and identifying die-offs and restoration opportunities.

(Continued)

Table 9.1—(Continued).

Management Considerations:

(1) Increase EDDR efforts to detect new invasive plants and monitor for die-offs with a focus along climatic transition zones.

Tradeoff: This may result in other areas being monitored less intensively.

(2) Use permanent monitoring plots in Areas of Critical Environmental Concern and Research Natural Areas that are generally not grazed by livestock and WHBs, or in ungrazed national wildlife refuges, to detect emerging invasive plant species.

Tradeoff: Emerging invasive plants may be detected, but not necessarily in systems where new invasions are most likely.

(3) Use all permanent plots (e.g., AIM, possibly National Resources Inventory) to track changes in invasive plants over time.

Tradeoff: Taking advantage of existing systems is cost-effective.

(4) Identify refugia for climate change that include redundancy and a range of values for stepping stones (linkages) for native species movements.

Tradeoff: Identification of refugia that maintain representative native ecosystems and prevent extinctions will require substantial investment. Refugia would need to be intensively monitored for invasive plant species.

(5) Use resilience and resistance (soil temperature and moisture regimes) to help evaluate potential nonnative plant invasions.

Tradeoff: This provides a good first filter, especially for invasive annual grasses, but additional information and investment are required to relate soil temperature and moisture regimes to the distributions of many other invasive plants. Changes in climate may modify the distribution of soil temperature and moisture regimes on the landscape (i.e., change the distribution of resilience and resistance on the landscape).

(6) Use information about resilience and resistance to determine the types of actions for addressing plant invasions. In areas with high resilience and resistance, the priority may be to maintain intact, uninvaded ecosystems. In areas with low resilience and resistance, the priority may be to prevent degradation due to soil erosion, protect groundwater, and manage fire risk.

Tradeoff: Caution is needed to prevent areas with low resilience and resistance from being managed solely for livestock forage and wildfire prevention. Intact areas with low resilience and resistance need to be identified and protected.

(7) Determine whether programmatic environmental assessments or environmental impact statements are needed to address invasive plant impacts that affect all programs.

Tradeoff: Budgets for inventory of invasive plants and control treatments are expensive and long-term costs usually fall to one program (e.g., range in the Bureau of Land Management [BLM]).

Critical Information Needs:

(1) Improve capacity to map the extent of all major invasive annual grasses, not just cheatgrass.

(2) Obtain information on the climate suitability of all major invasive plants (including biennial and perennial forbs) that can be used to understand and map the probability of invasion of these species.

(3) Increase understanding of how changes in climate are likely to influence the resilience and resistance of sagebrush and juniper and piñon ecosystems.

Policy Need:

(1) State laws for reclamation and restoration standards are needed to address invasive plant species. If no standards are set (or met), then an increase in spread is likely to be followed by a failure to meet habitat needs. Private companies doing business on public land may push back if stricter reclamation standards are applied. However, if the companies are not responsible or not held accountable, then the land management agency must pay for the long-term invasive control or the problem of invasion will continue to spread.

CLIMATE ADAPTATION and SEED STRATEGY

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated by selecting adapted seed sources, using effective restoration methods, monitoring outcomes, and adapting management. Seeding creates plant communities that are adapted to current climate conditions and can adapt to future conditions. Species should be able to move, adapt, and establish in their future climate zones.

(Continued)

Table 9.1—(Continued).

Management Considerations:

(1) Prioritize where to invest in restoration and seed based on resilience and resistance considerations—what to collect, what to produce, and what to put on the ground.

> **Tradeoff:** It may be necessary to choose between doing nothing, using native species with the best available information and seed sources, and using introduced species (mid- or local scale).

(2) Use seed sources that are adapted to site conditions and that maintain genetic diversity.

> **Tradeoff:** Broad- and mid-scale shifts in vegetation species will directly impact local seed collections and needs. Areas exhibiting climate change may no longer support certain native species, including sagebrush (see Chambers et al. 2017a, section 5.2). Information to facilitate transitions is just now being developed and assisted migration is controversial.

(3) Develop maps that pre-specify seed mixes and treatments before wildfires based on ecological types and ecosystem conditions.

> **Tradeoff:** This requires additional upfront resources, but may substantially increase success.

(4) Use a continuum in restoration—seed sources, implementation, monitoring, and adaptive management—and recognize differences among stabilization, rehabilitation, and restoration. Also consider incorporating concepts and tools from the Society for Ecological Restoration's International Standards for the Practice of Ecological Restoration (McDonald et al. 2016).

> **Tradeoff:** Funding additional education of staff is likely to be well worth the investment.

(5) Use adaptive management and monitoring to identify changes with climate in considering the best places for assisted migration. Accidental assisted migration is already occurring but may not have the desired outcome where the environmental requirements of the cultivated species used in restoration do not match the environmental conditions in which they are planted (Bucharova 2017).

> **Tradeoff:** Without information on species adaptations to the new site or how the new species will affect the communities where they are introduced, the results may not be as desired.

(6) Consider species' current and future distributions and seed zone boundaries to select populations for inclusion in restoration projects that will reduce the risk of future maladaptation and to identify potential bottlenecks to species movement.

> **Tradeoff:** Development of climate shift models is time consuming and will require active planning and coordination to target species populations for collection and growth in order to increase availability in the market (5+ years per seed collection). It is difficult to respond quickly to new information on shifting climates.

Critical Information Needs:

(1) Continue to develop seed zones for more local restoration species—forbs, grasses, and shrubs.

(2) Set aside areas to be used for common garden studies across Management Zones.

(3) Develop and evaluate models of how seed zones may shift as climate changes.

(4) Develop seeding and monitoring strategies that incorporate and test assisted migration.

(5) Identify genotypes for focal restoration species that are widely adapted and will lend themselves to facilitated migration as the climate changes.

(6) Ensure that seed zone development captures seed sources across a species range. Evaluate and develop models on how seed zones may shift as climate changes.

CLIMATE ADAPTATION and LIVESTOCK GRAZING MANAGEMENT

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated by adjusting grazing permits and leases as rangeland ecological condition, forage production, and the level of animal stress change.

Management Considerations:

(1) Revise ecological site descriptions and grazing management to permit adaptation to changing climate conditions.

> **Tradeoff:** This will require information on projected changes in plant species composition and productivity. Changes in long-term habitat objectives, allotment management plans, and grazing permits and leases may be needed.

(2) Change both the locations and timing of livestock use.

(Continued)

Table 9.1—(Continued).

Tradeoff: Analysis of permittee and lessee flexibility will be needed; some will have capacity to move and some will not. Land use plan amendments may be needed.

(3) Create regional networks of grass banks to increase flexibility.

Tradeoff: This may require adjusting other land uses such as WHB AMLs and may have unintended effects on species at risk.

(4) Allow managers to manage for performance (i.e., maintaining or improving resilience and resistance).

Tradeoff: This may increase capacity to manage for resilience and resistance, but would require developing the correct metrics for monitoring.

(5) Develop the capacity to support outcome-based grazing management under a changing climate by adjusting livestock grazing based on current conditions to allow for corrections to occur as climate gradually changes.

Tradeoff: The method for determining animal unit months (AUMs) may need to be modified so that future projections of site productivity and site capacity for livestock grazing take into account the influence of climate change.

(6) Develop drought plans that identify thresholds and list responses. Ideally such plans would be coordinated with drought planning for the permittee's base property.

Tradeoff: Additional management investment and proactive coordination that considers impacts to economies and way of life as well as ecological damage or desertification will be required.

(7) Evaluate changes in wildfire risk due to a warming environment and increases in invasive annual grasses in the context of allotments and the potential mitigation of wildfire effects by grazing, including fuels and the probability of ignition.

Tradeoff: Identifying short-term objectives and the correct metrics will be required. Prioritizing protection of habitats over other resources may be a hard sell at local, mid-, and broad scales.

(8) Evaluate potential changes in native ungulate distributions attributable to changing climate and their interaction with livestock grazing.

Tradeoff: This requires an understanding of potential changes in native ungulate populations and distributions and likely impacts on vegetation communities, soil erosion, and disease transmission.

Critical Information Need:

(1) Identify how and where vegetation composition and productivity and thus AUMs will change in response to climate change.

Policy Need:

(1) Evaluate the policy changes needed to allow grazing management to adapt to climate change.

CLIMATE ADAPTATION and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Resilience and resistance are maintained and transitions to desirable new states or site types are facilitated by managing WHB populations at AMLs that will sustain ecosystems in the face of reduced water and forage availability and increased competition for these resources by livestock and native ungulates.

Management Considerations:

(1) Reevaluate AML to account for warming and drying conditions. This will require reevaluating site productivity and capacity to support WHBs during drought.

Tradeoff: Failure to adjust AML as climate changes will decrease water and forage for livestock and native ungulates, and place other plant and animal species at greater risk. It may also increase stress on individual WHBs in overpopulated areas. Evaluating and monitoring WHB populations and their use of the landscape will require additional resources that could be spent elsewhere.

(2) Increase understanding of how WHBs use the landscape. This will provide information on how natural water resources may be altered, which in turn can inform management decisions relative to livestock and native ungulate grazing.

Tradeoff: Failure to understand how WHBs use water sources (seeps, springs, riparian systems) will accelerate degradation. Evaluating and monitoring WHB populations and their use of the landscape will require additional resources that could be spent elsewhere.

(3) Adjust public expectations.

Tradeoff: Failure to effectively educate the public will result in increased conflict when and if AMLs are adjusted and gathers are increased.

(Continued)

Table 9.1—(Continued).

WILDLAND FIRE AND VEGETATION MANAGEMENT and INVASIVE PLANTS

Desired Management Outcome:

Allocations for fuel treatments and postfire rehabilitation in agency budgets are prioritized for invasive plant management to decrease the invasive grass/fire cycle that causes large losses of sagebrush habitats. Agency staffs and the public are knowledgeable about the negative effects of the spread of invasive plants on public lands and are supportive of rapid response and eradication efforts.

Management Considerations:

(1) Curtail or change management practices (e.g., some grazing practices) that promote spread of annual invasive grasses and in turn increase fire occurrence and spread.

> **Tradeoff:** Such practices require proactive management by local staff and may not always be agreeable to permittees and lessees.

(2) Change vegetation management priorities and budget allocations to protect postfire recovery efforts and address invasive plants adjacent to postfire recovery areas so that they do not spread into rehabilitated areas.

> **Tradeoff:** Allocation of funds to invasive plant management may decrease funds for other management activities.

(3) Use integrated modeling of resilience and resistance, fire risk, and resource values to determine configuration and placement of fuel treatments in conjunction with district-wide, programmatic National Environmental Planning Act (NEPA) analyses to address invasive annual grass/wildfire concerns.

> **Tradeoff:** Certain assumptions may be required regarding effects of fuel treatments on fire risk. Additional resources will be required to complete the necessary models and NEPA documents.

(4) Design and locate fuel treatments and fuel breaks based on ignition sources and accessibility for firefighters and maintenance activities.

> **Tradeoff:** Fuel breaks may increase wildlife habitat fragmentation and loss, and function as a vector for invasive plants into high quality sagebrush habitats.

(5) Monitor and remove invasive plants in vegetation or fuel treatments and fuel breaks and remove any nonnatives planted in fuel breaks that have spread outside of fuel breaks to ensure that they do not act as a vector for invasion.

> **Tradeoff:** It will be necessary to recognize that although fuel breaks may have a single management objective and result in an ecological type conversion, they should still be managed to prevent plant invasions.

(6) Consider designing prescribed burns that result in a mosaic of burned and unburned patches to maintain seed sources and habitat connectivity rather than designing larger, more extensive burns.

> **Tradeoff:** Additional planning and careful execution is needed to create mosaics that will enhance connectivity.

(7) Use resilience and resistance classes to prioritize areas for postwildfire recovery efforts to increase cost:benefit ratios.

> **Tradeoff:** This approach requires additional staff training to implement and monitoring to evaluate effectiveness.

(8) Continue partnerships, such as the multi-jurisdictional Cooperative Weed Management Area (CWMA) partnership, for invasive plant management.

> **Tradeoff:** Prioritizing for the largest invasion or for protection of more intact uninvaded sagebrush systems, especially at low resilience and resistance, will require partner engagement. Determining which agency programs should cover the cost of treatment is challenging.

(9) Focus eradications and rapid response efforts on areas that act as invasive plant vectors (e.g., along roadsides).

> **Tradeoff:** This requires proactive collaboration with and education of State or county agencies responsible for road maintenance and of grazing lessees who may not treat invasive plants on private lands because of the cost.

(10) Keep annual invasive patches small and focus efforts on proactively treating these before they expand.

> **Tradeoff:** Budgets are limited and treating invasive plants, which includes initial and follow-up treatments and monitoring, is expensive.

(11) Train field specialists, staff, and the public (including permittees) to recognize local weeds and invasive plants and their negative effects on public lands.

> **Tradeoff:** This takes additional resources initially, but can yield large benefits.

(12) Incorporate monitoring of any new “invasions” into existing vegetation monitoring efforts.

> **Tradeoff:** Funding and staffing will be needed, as will time to develop collaborative partnerships across jurisdictional and private property boundaries.

(Continued)

Table 9.1—(Continued).

Critical Information Needs:

(1) Determine how to best address invasive plants in low resilience and resistance areas at a large scale.

(2) Evaluate the use of a variety of plant species, including native species, for fuel breaks.

(3) Develop an understanding of how many plants per square foot or how much cover of perennial grasses is needed following wildfires and prescribed fires to promote recovery and effectively keep annual grasses under control. (This is likely to vary by ecological site type.)

(4) Develop better metrics for measuring perennial grass mortality following both wildfires and prescribed burns and for determining the need to seed.

WILDLAND FIRE AND VEGETATION MANAGEMENT and SEED STRATEGY

Desired Management Outcome:

Resilience and resistance of sagebrush ecosystems are maintained and transitions to desirable new states or site types are facilitated through stabilization, rehabilitation, and restoration treatments following wildfire.

Management Considerations:

(1) Capitalize on natural recovery following wildfires by evaluating the burned areas' environmental conditions and identifying where native plant species will recover on their own and where native plant species should be planted, seeded, or both.

> **Tradeoff:** Additional effort is required to assess postfire areas to determine the ecological site types and their resilience and resistance after wildfire (see Miller et al. 2015). If bunchgrasses are not adequate for natural succession and site recovery, seeding is likely to be necessary.

(2) Use genetically appropriate seed sources identified by seed transfer zones, rather than nonnative species or native cultivars, to avoid introducing species that are invasive or overly competitive with native species.

> **Tradeoffs:** Seeding with nonnatives represents an ecological tradeoff because they have the potential to invade, compete with native species, or spread beyond a project boundary. Seeding with native cultivars represents a genetic tradeoff because of potential adverse impacts to local population genetics through hybridization that may affect overall species fitness. However, seed choices may be limited until more source-identified germplasm is developed by seed zone for native forbs, grasses, and shrubs.

(3) Better match local site conditions with seeded species (right seed, right place, right time) to minimize ecological impacts and increase treatment success (e.g., avoid seeding low sagebrush sites with big sagebrush species).

> **Tradeoff:** More effort and resources are needed to adequately assess sites, determine the appropriate species, and obtain the needed seed sources. Many native species are not readily available and require time for cultivation practices to be developed and for larger-scale seed increase to occur.

(4) Increase sources of sagebrush by developing seed orchards through the private sector for the different ecoregions in the sagebrush biome.

> **Tradeoff:** Seed sources must be carefully chosen and trusted contractors located.

(5) Evaluate several approaches for seeding on harsh sites, such as encapsulating seed.

> **Tradeoff:** Successfully implementing more effective seeding approaches may increase expense and will necessitate monitoring outcomes.

(6) Follow seedings over time using effectiveness monitoring to determine whether and when retreatment is needed or whether the treatment was successful.

> **Tradeoff:** Monitoring resources must be allocated to determine treatment effectiveness.

(7) Carefully evaluate whether and when herbicide application is needed for postfire reclamation of areas with invasive plants.

> **Tradeoff:** Application of pre-emergent herbicides with active ingredients like Imazapic prior to seeding may be appropriate for burned areas with high risk of invasive annual grass or sites where release of native species would be enhanced by reducing annual grass invasion risk. However, depending on application rates, surviving native species and seedbanks may be affected for several years post-application.

(8) Carefully evaluate the use of drill seeding and aerial seeding treatments.

> **Tradeoff:** Aerial application of seed after wildfires has been shown to be largely ineffective, except on moister sites (Knutson et al. 2014). However, drill seeding may not be possible in some areas due to terrain conditions. Seeded species may interfere with native species recovery (section 6) and before deciding whether a site even requires seeding, it is necessary to first determine whether there are sufficient native species for recovery. On sites where seeding would be beneficial, but aerial seeding is unlikely to be successful and drill access is limited, it may be necessary to allow recovery without seeding and manage some risk of an invasive plant species component.

(Continued)

Table 9.1—(Continued).

(9) Test species known to be tolerant of fire and to increase resistance to invasion in fuel breaks.

Tradeoff: Seeding of native species that are not preferred by cattle in fuel breaks could help reduce the spread of cheatgrass in fuel breaks. However, managers and practitioners are not always comfortable using species that they are unfamiliar with or have not used previously.

WILDLAND FIRE AND VEGETATION MANAGEMENT and LIVESTOCK GRAZING MANAGEMENT

Desired Management Outcome:

Grazing management is flexible enough to allow livestock to be moved as needed to maintain the resilience and resistance of sagebrush ecosystems and to provide for grazing deferment following postfire restoration.

Management Considerations:

(1) Train field personnel in how to manage grazing pre-fire to minimize fire risk in fire susceptible areas and post-fire to promote site recovery.

Tradeoff: This type of training needs to balance the needs to reduce fuels, while maintaining or increasing perennial native grasses to promote postfire recovery. If grazing is not carefully managed, it can decrease resistance to invasive annual grasses and increase fire risk.

(2) Consider all available options for managing grazing (e.g., season of use, number of animals, type of livestock), and determine whether those options are sufficient to achieve objectives or whether new options need to be explored.

Tradeoff: The grazing permit states the number of livestock (AUMs and season of use) and it is legally binding for grazing on public lands. Permits may need to be adjusted to maintain resilience and resistance and provide for grazing deferment following postfire restoration.

(3) Minimize grazing use, or adjust the timing or levels of grazing use that are currently promoting spread of annual invasive grasses, which in turn increase fire occurrence and spread.

Tradeoff: Permittees or lessees may not have sufficient flexibility or be receptive to these types of changes even though failure to change may increase fire risk.

(4) Manage for threatened and endangered (T&E) species' habitats, riparian areas, and restoration and postfire rehabilitation areas that may need a reduction in livestock grazing impacts.

Tradeoff: Managers may be pressured to allow livestock grazing to take precedence over other resources.

(5) Work with permittees or lessees in an adaptive management setting to defer the onset of grazing to allow for successful postfire restoration projects.

Tradeoff: Grazing is addressed at the local level with each ranch being its own unit. Postfire grazing deferments may depend on the size of the fire, the resources at risk, and impacts to the grazing permittee or lessee. Permittee or lessee willingness to move livestock in relation to seeding and grazing tolerance may vary by geographic area.

(6) Strategically place targeted grazing in areas where it will be the most effective for fuel reduction and managing fuel breaks.

Tradeoffs: Targeted grazing practices may not always work for permittees or lessees because of the time and management practices required to implement it effectively (e.g., it is expensive for permittees or lessees, or permittees or lessees may not want to participate). If not properly executed, targeted grazing may increase invasion by nonnative annual grasses and fire risk.

Critical Information Needs:

(1) Determine the effectiveness of grazing to maintain fuel breaks along roadsides or other linear features at operational scales.

(2) Evaluate the effects of targeted grazing to control invasive annual grasses on establishing and maintaining native grasses.

WILDLAND FIRE AND VEGETATION MANAGEMENT and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Wild horses and burros are maintained at AML, which are intended to be population levels that provide for resilience and resistance of rangeland ecosystems and are consistent with other land uses and resources. WHBs are limited to designated management areas: Herd Management Areas (HMAs) and Herd Areas (HAs) on BLM lands; and Wild Horse Territories (WHTs), Wild Burro Territories (WBTs), and Wild Horse and Burro Territories (WHBTs) on Forest Service lands.

(Continued)

Table 9.1—(Continued).

Management Considerations:

(1) Monitor vegetation and fuel loads to determine the effects of WHBs on wildfire and the fire/invasive annual grass cycle and ecosystem resilience and resistance.

Tradeoff: WHBs may decrease fuel loads and the potential for wildfire, but may also reduce perennial grasses and forbs, decrease forage for livestock, and compete with wildlife.

(2) When WHB management areas experience large fires and large-scale WHB removals are not possible, plan for lands to be grazed or browsed by WHBs.

Tradeoff: During wildland or prescribed fires, burned fences can lead to WHB movement outside of established pastures. If WHBs are above AML, they may decrease postfire recovery and increase the risk of nonnative invasive plant spread.

(3) Explore and fund options for effective exclusion of WHBs in areas of postfire vegetation recovery.

Tradeoffs: Given that horses can routinely move 10 miles (16 kilometers) between water and available forage (Hampson et al. 2010), any seeding area, as well as newly revegetated areas after burns, can be attractive forage to WHBs if the areas have palatable forage. WHB presence in postfire recovery areas is likely to decrease seeding success, especially if WHBs are above AML.

(4) For prescribed fires, consult with the local WHB specialist or other appropriate agency staff about which gates should be left open to allow WHBs to escape burn areas.

Tradeoff: WHBs have the potential to impact adjacent areas.

(5) Temporarily remove most WHBs from a landscape (with an emergency gather, holding in BLM facility) to facilitate postfire rehabilitation.

Tradeoff: The efficacy of such options should be weighed against expense and effects on livestock grazing movements. Emergency gathers require agency approval, and may require NEPA analysis.

Critical Information Needs:

(1) Determine the conditions under which WHBs spread invasive annual grasses and affect invasive plant species distributions, which in turn influence fire processes.

(2) Determine the effects of WHBs on fuels and wildfire probabilities and evaluate the tradeoffs between reducing fuels and ecological resilience and resistance.

INVASIVE PLANTS and SEED STRATEGY

Desired Management Outcome:

Management practices are modified to maintain or increase resilience and resistance by protecting native seed sources, providing sufficient native seed for restoration or rehabilitation projects, and establishing mixes of species that can compete effectively with invasive plant species.

Management Considerations:

(1) Ensure that permitting for native seed collection is not resulting in overcollection of native populations by not allowing seed collection in the same areas every year.

Tradeoff: Native seed collections may require additional oversight to ensure permit compliance and cost more.

(2) Diversify seed mixes to include a variety of life forms (shrubs, grasses, and forbs) that increase ecosystem function and provide the range of plant phenologies and rooting depths necessary for long-term resilience to disturbance and resistance to invasive annual grasses.

Tradeoff: Until the availability of genetically appropriate native plant material increases, it may be difficult to develop more diverse seed mixes.

(3) Use restoration and rehabilitation practices that will help ensure establishment and persistence of diverse mixtures of seeded species.

Tradeoff: Diverse seed mixes may require adjusting seeding methods, such as seeding depth, based on seed size and germination requirements of the individual species.

(4) Evaluate site conditions on low resilience and resistance areas to determine whether ecological thresholds have been crossed that may influence the choice of seeded species.

Tradeoffs: Use of nonnative species and native cultivars on highly disturbed or invaded sites that have crossed ecological thresholds may meet objectives for site stabilization or fuel breaks. However, it is necessary to acknowledge that these types of seedings are not designed to meet wildlife habitat objectives.

(Continued)

Table 9.1—(Continued).

(5) Use postfire vegetation monitoring and reporting to evaluate the competitive ability of both native plant species and mixtures, including forbs, with invasive annual grasses.

> **Tradeoff:** Seed mixes need to match site conditions well in order to effectively evaluate their competitive ability.

Policy Need:

(1) Change current seed laws to increase consistency in not allowing cheatgrass seed in commercial seed sources, because it is difficult and expensive to remove from purchased seed and seeded sites. This requires evaluation. If seed law required cheatgrass-free seed, then there could be economic impacts and less native seed availability if it is cost-prohibitive or operationally impossible to provide cheatgrass-free seed.

INVASIVE PLANTS and LIVESTOCK GRAZING MANAGEMENT

Desired Management Outcome:

Grazing management maintains or increases resilience and resistance by decreasing or minimizing dispersal and growth of invasive plant populations and does not increase invasive plants when used as a tool for reducing fuels.

Management Considerations:

(1) Evaluate the different vectors (dispersers) of nonnative invasive plants, including livestock grazing, WHBs, and wildlife, to determine the relative effects of the different vectors.

> **Tradeoff:** Vehicle and livestock movement among parcels can transport and assist dispersal of invasive plant seed, increasing invasive plant species spread and necessitating early detection and treatment based on vector management. If movement among parcels is prevented, then additional areas may be needed for grazing. If invasive plant species spread is not addressed through vector management and hence restriction of the invasion to the original location, a much larger invasive plant species management problem may develop.

(2) Consider both the state of invasion and resilience and resistance when developing or modifying grazing management practices in areas with invasive annual grasses.

> **Tradeoff:** There are general management strategies for cheatgrass and other nonnative invasive annual grasses based on resilience and resistance and the invasion state (tables 5.1, 5.2) that can be used to help evaluate whether grazing management is appropriate for the site conditions and degree of invasion. Monitoring to ensure that grazing management decreases the degree of invasion or at a minimum does not increase it can be used to develop more effective grazing strategies, but may require additional investment.

(3) Consider the state and condition of the areas being evaluated for targeted grazing, including relative resilience and resistance, the degree of invasion by nonnative annual grasses, and proximity to invaded areas.

> **Tradeoff:** Targeted grazing may help reduce the biomass of nonnative invasive annual grasses and thus fuels once these grasses are dominant, but in uninvaded or low invasion areas improper grazing may increase invasive plant species. Appropriate use will depend on the degree of invasion.

(4) Conduct coordinated research and management trials to evaluate the effectiveness of targeted grazing for setting up fuel breaks or fuel reduction. This effort should be limited. Managers should evaluate the amount of time and infrastructure required and strategize as to where to try targeted grazing.

> **Tradeoff:** Targeted grazing to establish effective fuel breaks requires intense livestock management during a short time period. It may be difficult or expensive for permittees or lessees to implement and require close monitoring of contractors. Annual maintenance would be required; species other than cattle, such as sheep and goats, may have less impact, but carry disease risk if bighorn sheep (Ovis canadensis) are in the area. Targeted grazing may increase invasive annual plants, facilitate new invasions attributable to livestock movement, or reduce vigor of extant native plants.

(5) Evaluate the need to move livestock grazing operations outside of the allotment or into different pastures within an allotment after a treatment or disturbance until the desired outcomes are obtained.

> **Tradeoff:** The producer has to keep livestock off the allotment or off certain pastures within an allotment for a set number of years depending on resilience and resistance and current level of invasion by nonnative annual grasses. But policy or landowner agreements limit the flexibility to change implementation guidelines. Returning livestock to the allotment earlier than guidelines suggest may decrease overall sustainability of ecological conditions and forage sources.

(6) Require the use of weed-free hay for supplemental feeding of livestock following wildfire.

> **Tradeoff:** Requiring weed-free hay is expensive in the short term, but can reduce long-term costs of managing invasive plants.

(Continued)

Table 9.1—(Continued).

(7) Consider creating grass banks where livestock can be moved during the period required for areas to recover after restoration or rehabilitation activities.

Tradeoff: Nonnative plant species could be seeded to provide for grazing in certain areas, such as those with low resilience and resistance, rather than seeding with native plant species, but this may have negative ecological effects in the long term.

(8) Use a holistic approach when evaluating effects of livestock grazing on invasive plants that considers: (a) the management objectives; (b) current ecological state, resilience and resistance, and geographic area; (c) wildlife resources; (d) distance to water to prevent concentration of impacts from grazers; (e) different management needs for managing different kinds of livestock (cattle, sheep, goat, horse); and (f) control of livestock for utilization and ability for timing and frequency of movement of the herd.

Tradeoff: Clear information on appropriate grazing management (timing of grazing, number of livestock) based on the ecological site type and kind of livestock is needed for this type of approach but is often lacking.

INVASIVE PLANTS and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Wild horses and burros are maintained at AML, which is intended to be population levels that allow for the resilience and resistance of rangeland ecosystems and are consistent with other land uses and resources. WHBs are limited to designated management areas: HMAs on BLM lands; and WHTs, WBTs, and WHBTs on Forest Service lands.

Management Considerations:

(1) Evaluate the degree to which WHBs versus livestock are acting as vectors (dispersers) of invasive plants.

Tradeoff: If movement of WHBs among parcels is prevented to manage weed invasions, then additional areas for grazing, or gathers, may be needed. If invasive plant species spread is not addressed through this type of vector management and thus restriction of the invasion to the original location, a much larger invasive plant species management problem may develop.

(2) Consider both the state of invasion of invasive annual grasses and resilience and resistance of the area when evaluating the effects of WHBs and the need for gathers.

Tradeoff: There are general management strategies for cheatgrass and other invasive plants based on resilience and resistance and the invasion state (tables 5.1, 5.2) that can be used to help evaluate site conditions and the degree of invasion within management areas. Monitoring to ensure that WHBs grazing does not increase the state of invasion by nonnative annual grasses can be used to evaluate the need for gathers, but may require additional investment.

(3) Identify areas without WHBs present that may be higher priority for conservation and restoration. Consult with local WHB specialists or agency staff to identify areas beyond HMA or WHT, WBT, or WHBT boundaries that WHBs occupy.

Tradeoff: Areas with valuable resources that have WHBs above AML may fail to receive restoration or conservation actions.

(4) Consider how water sources influence WHB movement patterns when developing invasive plant management plans. (WHBs will congregate around water sources and move up to 10 miles each way from forage to water [Hampson et al. 2010], increasing the likelihood of spreading invasive plants.)

Tradeoff: This requires an extra step in developing invasive plant management plans but may have large benefits.

SEED STRATEGY and GRAZING MANAGEMENT

Desired Management Outcome:

Livestock grazing is managed to maintain or increase the resilience and resistance of restored or rehabilitated native plant communities.

Management Considerations:

(1) Consider creating grass banks where livestock can be moved during the period required for areas to recover after restoration or rehabilitation activities.

Tradeoff: Areas already seeded with nonnative plant species could be used as grass banks. Nonnative plant species could also be seeded to provide for grazing in certain areas, such as those with low resilience and resistance, rather than seeding with native plant species, but this may have negative ecological effects in the long term.

(Continued)

Table 9.1—(Continued).

(2) Consider using ecological site descriptions and state-and-transition models within the project area to evaluate the relative resilience and resistance of the area to be seeded.

Tradeoff: Ecological types and ecological sites with relatively low resilience and resistance often require more than one intervention for restoration efforts to succeed. Livestock use can have negative effects on project success.

(3) Evaluate the distance to the nearest drinking water source for livestock during project planning.

Tradeoff: The shorter the distance, the greater the grazing pressure that can be expected, potentially decreasing the likelihood of success.

(4) Consider installing fencing to prevent use by livestock on certain habitat restoration projects, particularly those associated with riparian areas.

Tradeoff: Temporary fencing for habitat rehabilitation is generally acceptable, but permanent fencing often requires a more in-depth environmental assessment or land use plan revision, and should be designed in a way that allows livestock to reach drinking water and move throughout the rest of the allotment.

(5) Consider forgoing a habitat restoration project entirely instead of spending time and resources on projects where spring, summer, and fall season of use occurs or where permittees do not have the flexibility or desire to change grazing system or season of use.

Tradeoff: Areas in need of active restoration may not be treated unless grazing permits are revised.

SEED STRATEGY and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Wild horse and burro populations are managed at AML to protect sagebrush ecosystems from overgrazing and maintain resilience and resistance in areas where native seedings have been conducted.

Management Considerations:

(1) Consider using ecological site descriptions and state-and-transition models within the HMA to evaluate the relative resilience to disturbance and resistance to invasive annual grasses of the area to be seeded.

Tradeoff: Ecological types or ecological sites with relatively low resilience and resistance often require more than one intervention for restoration efforts to succeed. WHBs use can have negative effects on project success.

(2) Assess the current spatial extent and population size of any nearby WHB population during project planning.

Tradeoff: Effects of WHBs on seedings depend on the number of WHBs that can enter the site, and high numbers can limit project success.

(3) Evaluate the distance to the nearest drinking water source for wild horses during project planning.

Tradeoff: The shorter the distance, the greater the grazing pressure that can be expected, potentially decreasing the likelihood of success. Horses can travel long distances (10 or more miles per day) from water to forage in arid to semi-arid environments (Hampson et al. 2010).

(4) Consider installing fencing to discourage use by WHBs on certain habitat restoration projects, particularly those associated with riparian areas.

Tradeoff: Temporary fencing for habitat rehabilitation is generally acceptable, but permanent fencing often requires a more in-depth environmental assessment or land use plan revision. Permanent fencing should be designed in a way that lets WHBs reach drinking water, and allows their movement throughout the rest of the HMA.

(5) Consider forgoing a habitat restoration project entirely instead of spending time and resources on projects in areas with wild horse populations above AMLs.

Tradeoff: Areas in need of active restoration may not be treated until WHB populations have been reduced.

GRAZING MANAGEMENT and WILD HORSE AND BURRO CONSIDERATIONS

Desired Management Outcome:

Wild horses and burros are maintained at AML, which is intended to be population levels that provide for resilience and resistance and allow for other land uses and resources (including livestock grazing). WHBs are limited to designated management areas: HMAs on BLM lands; and WHTs, WBTs, and WHBTs on Forest Service lands.

Management Considerations:

(1) Maintain WHBs at AML because overpopulated WHB numbers along with management actions for grazing may have effects that are counter to rangeland health objectives.

(Continued)

Table 9.1—(Continued).

Tradeoff: Local economies may be impacted in the form of reduced grazing opportunities, reduced wildlife populations, and other multiple uses if WHBs are not maintained at AML.

(2) Reduce WHBs to AML in order to stabilize rangeland conditions.

Tradeoffs: (a) Periodic deferment or movement of domestic livestock and adjustments of livestock allotments do not reduce WHB grazing impacts, especially where WHB densities are well above AML. (b) Livestock producers may not have the flexibility to move and adjust in response to WHBs and their impacts.

(3) Once WHB populations are maintained at AML, monitor to determine whether land health standards are being achieved.

Tradeoff: If land health standards are not being achieved, and WHBs are causing the non-achievement, it is necessary to consider a reduction in AML in land use plans.

(4) Where WHB numbers are above AML, consider using other available livestock management tools to minimize overlap with areas that have high WHB densities.

Tradeoff: Use of such tools presents challenges and costs to livestock producers. Livestock numbers may need to be decreased, but livestock grazing must be considered as a legally protected multiple use of the rangeland resource.

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Appendix 1—Definitions of Terms Used in This Document

Adaptive management—A structured, iterative process of robust decisionmaking in the face of uncertainty, with the aim of reducing uncertainty over time via system monitoring.

At-risk community phase—A community phase that can be designated within the reference state and also in alternative states. This community phase is the most vulnerable to transition to an alternative state (Caudle et al. 2013).

Biological control—The use of natural enemies—predators, parasites, pathogens, and competitors—to control invasive plants over multiple years. Invasive plants have many natural enemies including insects and plant pathogens.

Biopesticide—A pesticide derived from such natural materials as animals, plants, bacteria, and certain minerals. Fungal pathogens and bacterial agents are potential biopesticides for cheatgrass.

Change agents—Disturbances and management actions that influence resource conditions (or status) and trends and subsequent outcomes of conservation and restoration actions.

Community phase—A unique assemblage of plants and associated soil properties that can occur within a state (Caudle et al. 2013).

Cool season/warm season grasses—Cool season or C3 grasses grow during cooler times of the year, typically when temperatures are 40 to 75 °F [4–24 °C], and include wheatgrasses, needle grasses, brome grasses, and blue grasses. Warm season or C4 grasses grow during warmer periods when temperatures are 70 to 95 °F [21–35 °C] and include blue grama, buffalograss, and bluestems. Warm season grasses use soil moisture more efficiently than cool season species and often can withstand drought conditions. For a detailed explanation, see OSU 2017.

Deferred livestock grazing—The dropping of an allotment from the normal scheduled use or rotation for use at a later time.

Early Detection and Rapid Response (EDRR)—A management approach to minimize the establishment and spread of new invasive plant species through a coordinated framework of public and private partners and a process that includes detection and reporting, identification and vouchering, rapid assessment, planning, and rapid response. An overview of the National Framework for Early Detection and Rapid Response (USDOI 2016) is available on the National Invasive Species Council website (https://www.doi.gov/invasivespecies/edrr).

Ecological niche—A species' ecological niche is a function of the environmental conditions under which the species can establish and persist. It depends on the species' physiological and life history requirements for establishment, growth, and reproduction, and its interactions with the native perennial plant community including interspecific competition and response to herbivory and pathogens.

Ecological site (ES)—A conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geology, and climate characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its ability to respond similarly to management actions and natural disturbances (Caudle et al. 2013).

Ecological site description (ESD)—Documentation of the characteristics of an ecological site. The documentation includes the data used to define the distinctive properties and characteristics of the ecological site, the abiotic and biotic characteristics that differentiate the site (i.e., climate, physiographic characteristics, soil characteristics, plant communities), and the ecological dynamics of the site that describes how changes in disturbance processes and management can affect the site. An ESD also provides interpretations about the land uses and ecosystem services that a particular ecological site can support and management alternatives for achieving land management goals (Caudle et al. 2013).

Ecological type—A category of land with a distinctive (i.e., mappable) combination of landscape elements. The elements making up an ecological type are climate, geology, geomorphology, soils, and potential natural vegetation. Ecological types differ from each other in their ability to produce vegetation and respond to management and natural disturbances (Winthers et al. 2005). In the Science Framework, ecological type is used in a broad sense and refers to ecological type or ecological site groups as described in Chambers et al. 2017: Appendix 3.

Ecosystem services—The direct and indirect contributions of ecosystems to human well-being.

Fire regime—The patterns of fire seasonality, frequency, size, spatial continuity, intensity, type (crown fire, surface fire, or ground fire), and severity in a particular area or ecosystem (Agee 1994; Heinselman 1973; Sugihara et al. 2006). A fire regime is a generalization based on the characteristics of fires that have occurred over a long period. Fire regimes are often described as cycles or rotations because some parts of the fire histories usually get repeated, and the repetitions can be counted and measured.

Focal species—Sagebrush obligate, near-obligate, dependent, or associated species identified as having one or more of the following characteristics: (1) at-risk, (2) influencing management actions and regional economies, (3) potentially being negatively influenced by management actions, or (4) serving as indicators of habitat quality or habitat niches such as riparian areas in sagebrush ecosystems.

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 (NWCG 2018).

Greater sage-grouse habitat designations

- Priority Areas of Conservation—Key habitat areas identified and delineated in the sage-grouse conservation plans for each State or through other sage-grouse conservation efforts (USDOI FWS 2013).
- Priority Habitat Management Areas—A Federal habitat designation that includes areas identified as having the highest habitat value for maintaining sustainable GRSG populations including breeding, late brood-rearing, and winter concentration areas.
- General Habitat Management Areas—A Federal habitat designation that identifies areas that are occupied seasonally or year-round and are outside of Priority Habitat Management Areas.
- Important Habitat Management Areas (Idaho only)—Areas in Idaho that provide a management buffer for and that connect patches of Priority Habitat Management Areas. Important Habitat Management Areas encompass areas that are generally moderate to high conservation value habitat or populations but that are not as important as Priority Habitat Management Areas.

- Other Habitat Management Areas (Nevada and northeastern California only)—Areas in Nevada and northeastern California identified as unmapped habitat in the Proposed Resource Management Plan or Final Environmental Impact Statement that are within the Planning Area and contain seasonal or connectivity habitat areas.

Green stripping—The practice of establishing or using patterns of fire tolerant vegetation or other material to reduce wildfire occurrence and size (St. John and Ogle 2009; USDOI BLM 1987). A green strip can be a fuel break as defined by the National Wildfire Coordinating Group (NWCG 2018).

Habitat connectivity—The degree to which the landscape facilitates animal movement and other ecological flows.

Improper livestock grazing—Grazing that impedes progress toward or maintenance of ecological processes and the desired plant community composition and structure within a given set of site conditions and the natural range of variability, including climatic variability and natural disturbance regimes, expected within a management planning time horizon.

Invasive plant species—An invasive species is (1) nonnative (or alien) to the ecosystem under consideration, and (2) its introduction causes or is likely to cause economic or environmental harm or harm to human health (Presidential Executive Order 13112, 1999).

Local adaptation—A population is locally adapted if organisms in that population have differentially evolved as compared to other populations within their species in response to selective pressures imposed by some aspect of their local environment. Locally adapted restoration species or seed collections are likely to perform better than species or collections from outside the local environment.

Major Land Resource Area—A geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of agriculture.

Management strategies—Coordinated management activities conducted at mid- to local scales to achieve vegetation and habitat objectives (e.g., strategically locating firefighting resources to protect habitat, coordinating Early Detection and Rapid Response activities for invasive plant species, positioning treatments to increase connectivity).

Metapopulation—A group of populations that are separated by space but consist of the same species. These spatially separated populations interact as individual members move from one population to another.

Monitoring attributes—Ecosystem attributes, such as soil stability and health, hydrologic function, water flow and quality, and biotic integrity, monitored to determine ecosystem status at local, mid-, and broad scales.

Monitoring benchmarks—Indicator values, or ranges of values, that establish desired conditions and are meaningful for management.

Monitoring indicators—Indicators of ecosystem attributes that can be measured and can account for changes in the resource within a realistic timeframe and budget given the site potential and spatial scale of the area being managed. For example, bare ground, vegetation composition, and soil aggregate stability are indicators of hydrologic function.

Monitoring triggers—Levels of environmental conditions that can provide an early warning of possible thresholds and of management changes that may be necessary to maintain the desired environmental conditions (Briske et al. 2008; Goldstein et al. 2013).

Persistent ecosystem threats—Threats that include invasion of nonnative invasive plant species, altered fire regimes, and conifer expansion; are difficult to regulate; and are managed using ecologically based approaches (Evans et al. 2013; Boyd et al. 2014).

Prescribed fire—Any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific objectives (NWCG 2018). A prescribed fire is also sometimes called a "controlled burn" or "prescribed burn." Prescribed fires consider the safety of the public and fire staff, weather, and probability of meeting the burn objectives (see also Wildfire, Wildland Fire).

Projects—Projects consist of multiple land treatments (see also Treatments).

Reference state—Ecological potential and natural or historical range of variability of the ecological site.

Resilience—Capacity of an ecosystem to reorganize and regain its fundamental structure, processes, and functioning when altered by stressors such as invasive plant species and disturbances such as improper livestock grazing and altered fire regimes (based on Angeler and Allen 2016; Holling 1973).

Resistance—Capacity of an ecosystem to retain its fundamental structure, processes, and functioning (or remain largely unchanged) despite stresses, disturbances, or invasive species (Angeler and Allen 2016; Folke et al. 2004).

Resistance to invasion—Abiotic and biotic attributes and ecological processes of an ecosystem that limit the population growth of an invading species (D'Antonio and Thomsen 2004).

Restoration pathways—A description of the environmental conditions and practices that are required to recover a state that has undergone a transition (Caudle et al. 2013).

Seed zone—An area of relative climatic similarity within which plant materials can be transferred with little risk of being poorly adapted to their new location.

State—A suite of community phases and their inherent soil properties that interact with the abiotic and biotic environment to produce persistent functional and structural attributes associated with a characteristic range of variability (adapted from Briske et al. 2008).

State-and-transition model—A method to organize and communicate complex information about the relationships among vegetation, soil, animals, hydrology, disturbances (fire, lack of fire, herbivory, drought, unusually wet periods, insects and disease), and management actions on an ecological site (Caudle et al. 2013).

Targeted grazing—Application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals (Launchbaugh and Walker 2006).

Thresholds—Conditions sufficient to modify ecosystem structure and function beyond the limits of ecological resilience and result in transitions to alternative states (Briske et al. 2008).

Transition—Transitions describe the biotic or abiotic variables or events, acting independently or in combination, that contribute directly to loss of state resilience and result in shifts between states. Transitions are often triggered by disturbances, including natural events (climatic events or fire) and management actions (grazing, prescribed fire, fire suppression). They can occur quickly as in the case of catastrophic events like fire or flood, or over a long period of time as in the case of a gradual shift in climate patterns or repeated stresses like frequent fires (Caudle et al. 2013).

Treatments—Local scale management actions that directly manipulate vegetation to achieve a vegetation or habitat objective (e.g., conifer removals, invasive annual grass controls, fuel treatments, or revegetation).

Wildfire—An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out (NWCG 2018). See also Prescribed Fire, Wildland Fire.

Wildland fire—Any non-structure fire that occurs in vegetation or natural fuels. Wildland fire includes prescribed fire and wildfire (NWCG 2018). See also Prescribed Fire, Wildfire.

Wildland-Urban Interface—The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels (NWCG 2017, 2018). Describes an area within or adjacent to private and public property where mitigation actions can prevent damage or loss from wildfire.

Woodland (juniper and piñon) phase I, II, III—In phase I trees are present, but shrubs and herbs are the dominant vegetation influencing ecological processes on the site; in phase II trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes; in phase III trees are the dominant vegetation on the site and the primary plant layer influencing ecological processes on the site (Miller et al. 2005, 2014).

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Appendix 2—Websites and Resources for Climate Adaptation and Mitigation

Websites

Climate Change Resources Center (CCRC)

The CCRC is a USDA Forest Service sponsored portal. It is a web-based, nationwide resource that connects land managers and decisionmakers with usable science to address climate change in planning and application. The website contains links to numerous reports, papers, tools, and data for assessing climate change and climate change impacts. Website: http://www.fs.usda.gov/ccrc/home.

Conservation in a Changing Climate

This website is sponsored by the USDOI Fish and Wildlife Service (FWS) and provides information on climate change and the impacts of climate change on wildlife within each FWS region. The website provides information on the FWS response to climate change, including the U.S. Department of the Interior's Strategy for addressing climate change and the FWS Strategic Plan for managing in a time of uncertainty. In addition, ways that individuals can help mitigate the effects of climate change and support wildlife conservation are available. Website: https://www.fws.gov/home/climatechange/.

Climate Data and Analysis Tools

Historical and projected climate and climate change impacts data are available through a wide variety of sources and at different scales, although data at the mid-scale are the most common. In some cases, data may be limited to part of the sagebrush biome.

Climate Impacts Group (CIG)

Hosted by the University of Washington, the CIG provides climate data and analyses of potential climate change impacts at a variety of scales, ranging from local communities to the western United States. Most of the work to date is focused on the Pacific Northwest. Website: https://cig.uw.edu/.

Climate Adaptation Science Centers (CASCs)

The CASCs comprise eight regional CASCs covering the continental United States, Alaska, Hawaii, and U.S. Affiliated Pacific Islands. Each CASC is based at a host university in its region. Most are composed of multi-institution consortia, which include university and non-university partners. The CASCs provide scientific information, decision-support tools, and techniques needed to effectively manage natural and cultural resources and build resilient communities. The website allows individuals to search for climate science research and topics in the region of interest and provides a variety of resources including funding opportunities, webinars, and available education and training. Website: https://nccwsc.usgs.gov/.

Conservation Biology Institute (CBI) Integrated Climate Scenarios

The CBI provides projected climate change scenarios for climate, hydrology, and vegetation in the Northwest (Oregon, Washington, Idaho, western Montana) using downscaled climate projections based on multivariate adapted constructed analogs (MACA) in combination with the MC2 dynamic vegetation model. Model results are available for the entire area or by ecoregion. The site provides guidance and answers to frequently asked questions to assist users. Website: http://consbio.webfactional.com/integratedscenarios/.

Multivariate Adapted Constructed Analogs (MACA)

The MACA site is hosted by the University of Idaho and provides statistically downscaled climate projections for the continental United States using the most current emissions scenarios, several global climate models, and multi-model means. The website provides a number of options for viewing and downloading the data. Website: http://maca.northwestknowledge.net/.

PRISM Historical Climate Data

PRISM uses weather and climate observations from a wide range of monitoring networks to create wall-to-wall spatial climate datasets from 1895 to the present. PRISM datasets are widely used in a variety of climate and natural resource studies to describe historical climate. Website: http://www.prism.oregonstate.edu/.

State Climate Offices

Nearly every State has a climate office that provides access to State and local climate data from a variety of weather stations such as the Community Collaborative Rain, Hail and Snow Network, or CoCoRaHS (https://www.cocorahs.org/), and the Agricultural Meteorological Network (AgMet).

WestMap Climate Analysis Toolbox

WestMap delivers PRISM historical climate data at a variety of spatial scales ranging from Westwide to a single pixel, including user created polygons, and a variety of temporal scales. Climate data provided are precipitation, mean temperature, maximum temperature, and minimum temperature. Website: http://www.cefa.dri.edu/Westmap/westmappass.php.

Western Regional Climate Center (WRCC)

The WRCC provides access to climate and weather data across the western United States from several weather sources, include the NOAA co-op network, remote automated weather stations (RAWS), the Snotel network, and the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS). Website: http://www.wrcc.dri.edu/.

Weather and Climate Tools for Sagebrush Managers

This website was developed by the Conservation Biology Institute to deliver the types of weather and climate data that land managers in sagebrush ecosystems of the northern Great Basin identified as desirable. The website provides graphics and descriptions of historical climate and weather data, including temperature, seasonal precipitation, aridity, and potential evapotranspiration. Also provided are near-term and short-term forecasts for use in planning projects such as postfire seeding and on projected climate change for 2016 to 2045 and 2046 to 2075 based on the MC2 model. The data and information cover the sagebrush biome, but are intended for use at the local scale. Website: http://climateconsole.org/sagebrush.

Great Basin Weather Applications for Rangeland Restoration

The Great Basin Weather Applications website was developed by the Agricultural Research Service in cooperation with the University of Idaho, U.S. Geological Survey, Utah State University, and the Great Basin Fire Science Exchange. This website provides access to restoration-specific weather and microclimatic information that can be used for (1) analyzing historical planting data, (2) expanding inferences derived from short-term field studies, and (3) developing long-term contingency-based adaptive management plans for rangeland restoration. This site provides historical time-series of site-specific weather and seedbed microclimatic information, rankings of year and seasonal weather effects, and detailed assessments of year-specific seasonal favorability for seedling establishment. Educational modules are being developed in collaboration with Brigham Young University for training restoration professionals in the use of weather and climate information for field planning and management. Additional future applications include using seasonal forecasts for real-time management planning and developing probabilistic future weather scenarios for determining adaptation and mitigation strategies under potential future climate regimes. Website: http://greatbasinweatherapplications.org/.

Carbon Storage Tools

Because of the emphasis on forest management in climate change programs, and the fact that most research and information on carbon storage focus on the mid- to biome scale, field personnel in semiarid lands generally lack the baseline information and impact estimation tools they need to conduct either quantitative or qualitative analyses. The U.S. Geological Survey, through its LandCarbon website (https://www2.usgs.gov/climate_landuse/land_carbon/), and Natural Resources Conservation Survey, through its CarbonScapes website (http://carbonscapes.org/), attempt to provide baseline carbon storage information. The LandCarbon site attempts to project how carbon storage may change by mid-century under different greenhouse gas emissions scenarios. Limitations are that the scales of the data provided by LandCarbon and CarbonScapes are too coarse for land use plan and project scales, and data provided by LandCarbon are outdated (2005 vintage). Further, data provided by CarbonScapes use only Forest Service Forest Inventory and Analysis (FIA) data for aboveground carbon, and watershed-scale data in CarbonScapes are not universally available due to lack of completed soil surveys.

The Fire and Fuels Tools (http://www.fs.fed.us/pnw/fera/fft/index.shtml) and First Order Fire Effects Model (FOFEM) (https://www.firelab.org/project/fofem) provide estimates of aboveground carbon by carbon pool for standardized fuel beds and community types. Users can adjust the estimated fuel loadings manually based on local information or plot data. Both tools predict changes in aboveground carbon storage and greenhouse gas emissions from burning. However, these tools are designed to operate at the treatment block scale and cover only fire. Batch processing is theoretically possible with Fire and Fuels Tools, but can be difficult to conduct.

Appendix 3—Invasive Plants to Include in Early Detection and Rapid Response Programs in Sagebrush Ecosystems

Nonnative invasive plants in sagebrush ecosystems listed from highly invasive to weakly invasive (modified from Ielmini et al. 2015: tables 2 and 4), followed by the States where there is still only no, patchy, or limited presence of the species in sagebrush habitat, and then the habitat characteristics and impacts of the invasive plant (based on Sheley and Petroff 1999 and DiTomaso et al. 2013). If a State is not listed, then the species is already established in sagebrush habitat, but there still may be potential for Early Detection and Rapid Response (EDRR) (USDOI 2016) in limited regional and local EDRR areas. For example, Idaho has significant populations of yellow starthistle, but there are still regional areas and land management units that are uninvaded and suitable for local EDRR strategies. Assistance in developing the list was provided by State Weed Coordinators from State Departments of Agriculture.

Certain problem species were noted but not included. For example, perennial pepperweed or tall whitetop (*Lepidium latifolium*) is a major concern in sagebrush ecosystems in California. This species prefers pastures and areas with greater water availability than typically occurs in sagebrush ecosystems, but significant sagebrush areas are on the margins of riparian or wetland zones that are being heavily invaded by perennial pepperweed. There are similar concerns about saltcedar (*Tamarix* spp.). North Dakota did not include any of the listed species because of the small amount of sagebrush habitat in the State.

Plant	Scientific name	EDRR potential in sagebrush habitat	Habitat	Negative impacts
Medusahead	*Taeniatherum caput-medusae*	CA, CO, MT, UT, WY, ID, NV, WA, SD	Occurs in sagebrush-grass or bunchgrass communities that receive at least 9–12 inches [23–30 centimeters] precipitation. Often invades after disturbance. Does well in clay soils that shrink, swell, and crack and openings in chaparral vegetation types.	Low palatability for livestock due to high silica content, which confers competitive advantage over native plants. Awns can injure eyes and mouths of animals. Dense, long-lasting litter layer creates fire risk and reduces seed germination of other species.
Cheatgrass	*Bromus tectorum*	Local and regional EDRR potential	Wide ecological amplitude from salt desert in the Great Basin to coniferous forests in the Rocky Mountains. Areas in which most precipitation arrives in late winter or early spring are most susceptible. Often occurs in disturbed areas and areas with dry sandy soils with little competition.	Increases fine fuels and fire risk. Can outcompete many perennial native plant species and replace many annual species. Reduces production of perennial grasses for livestock forage, but can be grazed in winter or spring. Sharp seeds may cause eye injuries.
North African wiregrass	*Ventenata dubia*	CA, MT, CO, ID, UT, WY, NV, WA, SD	Occurs in bunchgrass, sagebrush, and meadow communities.	Can outcompete perennial bunchgrasses. Low palatability for livestock due to high silica content. Matures early in the season and is likely to pose fire risks.

(Continued)

Plant	Scientific name	EDRR potential in sagebrush habitat	Habitat	Negative impacts
Spotted knapweed	*Centaurea maculosa*	CA, UT, NV, WA, SD, OR*	Occurs over a wide range of elevation and annual precipitation. Does well in forest-grassland interface on deep, well-developed soils, with dense stands occurring in moist areas on well-drained soils including fields, roadsides, and disturbed and degraded rangeland.	Very competitive and can form dense stands that result in higher surface water runoff and soil erosion. Excludes desirable vegetation, thereby reducing livestock and wildlife forage.
Yellow starthistle	*Centaurea solstitialis*	CA, CO, MT, UT, WY, NV, SD, OR*	Occurs on deep, loamy soils and south-facing slopes with 12–25 inches [30–64 centimeters] precipitation. Found in open disturbed sites, rangeland, roadsides, and open woodlands.	Highly competitive and develops dense, impenetrable stands. Reduces forage production for livestock and wildlife. Can be grazed before spine development, but poisonous to horses.
Iberian starthistle	*Centaurea iberica*	CA, CO, ID, MT, UT, WY, NV, WA, SD, OR	Occurs on riverine banks, along watercourses, and in other moist areas.	Unpalatable—spines restrict access to the plant and deter grazing.
Purple starthistle	*Centaurea calcitrapa*	CA, CO, ID, MT, UT, WY, NV, WA, SD, OR	Can inhabit a wide range of conditions, including fertile alluvial soils, pasture, range, open forest, and riparian areas.	Unpalatable—spines restrict access to the plant and deter grazing.
Diffuse knapweed	*Centaurea diffusa*	CA, UT, NV, SD, OR*	Wide ecological amplitude for elevation, aspect, slope, and soil properties. Maximum invasiveness is in shrub steppe, rangelands, and forested benchlands. Often occurs on well-drained soils.	Increases soil erosion and surface runoff. Replaces wildlife and livestock forage, but has some forage value through the bolting stage. Dispersal similar to tumbleweeds.
Leafy spurge	*Euphorbia esula*	CA, UT, NV, WA, OR*	Found in disturbed sites, roadsides, rangelands, and riparian areas with semiarid to mesic conditions. It has wide ecological amplitude and occurs on many soil types. High genetic variability allows it to easily adapt to local growing conditions.	Highly competitive and can form dense clones that suppress native plants and reduce forage. Milky sap is toxic and can irritate skin, eyes, and digestive tracts of humans and other animals. Sheep and goats graze it and can tolerate the toxins.
Rush skeletonweed	*Chondrilla juncea*	CA, CO, MT, WY, NV, SD	Found in rangelands and pastures and along roadsides. Occurs in very dry to very wet environments on disturbed soils and well-drained, sandy-textured, or rocky soils.	Can form dense monocultures and displace native plants, reduce livestock forage, and spread from rangeland to adjacent cropland. Wiry stems can interfere with harvest machinery.
Dalmatian toadflax	*Linaria dalmatica*	CA, NV, WA, SD	Tolerates many soil types and is found on well-drained, coarse-textured soils and sandy loams, as well as heavier soils. Does best in cool, semiarid climates on dry, coarse soils with neutral to slightly alkaline pH and south- to southeast-facing slopes. Occurs in rangelands, disturbed areas, roadsides, and forest clearings. Can move into undisturbed prairies and riparian habitats.	Aggressive invader capable of forming dense colonies and outcompeting native grasses and other perennials. Decreases forage for livestock and wildlife. If sufficient quantities are ingested, quinazoline alkaloids can pose toxicity problems to livestock, but goats and sheep are tolerant. Can increase soil erosion, surface runoff, and sediment yield in invaded bunchgrass communities.

(Continued)

Plant	Scientific name	EDRR potential in sagebrush habitat	Habitat	Negative impacts
Sulphur cinquefoil	*Potentilla recta*	CA, UT, ID, WY, NV, WA, SD	Wide ecological amplitude. Found in conifer, grassland, shrubland, and seasonal wetland ecosystems. Occurs along roadsides and in other disturbed sites, but also will invade low-disturbance sites.	Low palatability for grazing animals, possibly due to phenolic tannins in leaves and stems. Can become a dominant component of plant communities.
Russian knapweed	*Acroptilon repens*	NV, WA, OR*	Found in pastures, in rangelands, and along streambanks and roadsides. Will invade croplands. Occurs on many soil types, but prefers moist soils that are not excessively wet.	Allelopathic and very competitive, forming dense stands. Reduces forage for livestock; low palatability for livestock and toxic to horses.
Squarrose knapweed	*Centaurea virgata*	CA, CO, ID, MT, WY, NV, WA, SD, OR	Found in fields, roadsides, disturbed sites, grasslands, and big sagebrush bunchgrass- and juniper-dominated rangelands. Extends into salt desert shrub, particularly in sandy or gravelly washes, and on dry, rocky, south-facing slopes. Will invade fairly pristine mountain brush types and juniper-Idaho fescue rangeland. Also will invade abandoned dry wheat fields, crested wheatgrass seedings, burned areas, and improperly grazed areas.	Highly competitive. Can endure drought at either temperature extreme, is fire tolerant, and has excellent seed dispersal and rapid response to soil resources released by fire. Rosettes grow slowly for years before flowering, creating basically a vegetative seedbank. Similar palatability and nutritive value to diffuse or spotted knapweed. Sheep and cattle may graze it when other annual forage is sparse. Dense stands can exclude desirable vegetation and wildlife in natural areas.
Whitetop, hoary cress	*Cardaria* spp.	Not listed as an EDRR species by any of the States	Found in disturbed open sites, on ditch banks, and along roadsides. Well-adapted to moist habitats, especially sub-irrigated rangeland, pastures, wetlands, and riparian areas. Tolerates a wide range of soil types and moisture conditions; often found in disturbed areas with other invasive species.	Can form dense monocultures, and is difficult to control due to large and deep roots and rhizomes. Can dramatically reduce biodiversity and forage production and can invade cropland and reduce yields. Plants contain glucosinolates, which can form toxic compounds. Unpalatable to livestock.
Yellow toadflax	*Linaria vulgaris*	CA, UT, SD	Found in riparian areas, rangeland, disturbed areas, roadsides, and forest clearings. Often occurs on moister sites. Tolerates many soil types varying from coarse gravels to sandy loams, but is also found in heavier soils. Can move into undisturbed prairies and riparian habitats.	Highly competitive for soil moisture with winter annuals and shallow-rooted perennials. Aggressive invader capable of forming dense colonies and outcompeting native grasses and perennials. Decreases forage for livestock and wildlife. If sufficient quantities are ingested, quinazoline alkaloids can pose toxicity problems to livestock, but goats and sheep are tolerant.
Dyer's woad	*Isatis tinctoria*	CO, MT, UT, WY, NV, WA, SD	Occurs in disturbed sites, roadsides, pastures, forests, and rangeland often on dry, rocky, or sandy soils. Invades undisturbed natural areas as well as alfalfa and small grain fields. Also found along waterways. Adapted to the arid climate and alkaline soils of the West.	Palatable to cattle only before bolting; grazing can be done before flowering to minimize seed production. Can spread at an annual rate of 14% and reduce grazing capacity by an average of 38%. Capable of invading and increasing density on well-vegetated range sites even in the absence of grazing or disturbance.

(Continued)

Plant	Scientific name	EDRR potential in sagebrush habitat	Habitat	Negative impacts
Mediterranean sage	*Salvia aethiopis*	CO, ID, MT, UT, WY, NV, WA	Found in degraded big sagebrush communities, rangeland, openings in ponderosa pine, and disturbed sites, including roadsides. Also occurs in floodplain and riparian areas following overgrazing, excessive trampling, and soil erosion. Often inhabits moderate to deeper soils with good drainage. Often associated with sites dominated by annual grasses.	Unpalatable to grazing animals, and although not considered toxic, reduces forage production on rangeland and pastures. Tumbleweed-mobility facilitates rapid spread in degraded communities. May attain understory dominance in sagebrush/cheatgrass communities.
Scotch thistle	*Onopordum acanthium*	CA, WA	Found in disturbed areas, rangeland, forest clearings, abandoned cropland, areas of high rodent activity, and along river and stream corridors and roadsides. Best suited to areas with high soil moisture during germination. Often associated with cheatgrass.	Can form dense stands over large acreages and decrease desirable forage. Sharp spines deter livestock and wildlife from grazing. Dense stands can prevent movement by livestock, wildlife, and humans. Grazing of young plants may occur in early stages of infestation, but overgrazing promotes scotch thistle.
Halogeton	*Halogeton glomeratus*	CA, NV, WA, SD	Occurs in dry, arid regions, and is adapted primarily to alkaline and saline soils.	Foliage contains soluble sodium oxalates and can be toxic to livestock, especially sheep, when large quantities are ingested.
Musk thistle	*Carduus nutans*	CA, WA	Found in disturbed open sites, roadsides, pastures, and annual grasslands. Occurs over a wide range of environmental conditions, ranging from saline soils in low elevation valleys to acidic soils in high elevations. Potentially intolerant of shading from neighboring plants.	Can form dense stands over large areas and decrease desirable forage. Sharp spines deter livestock and wildlife from grazing. Dense stands can prevent movement by livestock, wildlife, and humans. Allelopathy can reduce growth of desirable pasture species in an area much greater in diameter than the musk thistles themselves. May take 15 years of treatment to decrease germination.
Common crupina	*Crupina vulgaris*	CA, CO, ID, MT, UT, WY, NV, WA, SD	Occurs in grasslands, pastures, rangeland, canyons, disturbed riparian areas, and gravel pits. Adapted to many temperature and moisture regimes and soil types. Infests sites with cheatgrass.	Highly competitive for limited soil moisture. Dense populations reduce and displace desirable forage species for livestock and wildlife and can contaminate hay. Seeds can survive ingestion by animals and remain viable in soil up to 3 years. Most livestock avoid grazing it. Can displace perennial bunchgrasses and lead to soil erosion because of less effective soil stabilization.

Note.—*Oregon species that is a State-listed B-Noxious Weed and is established in some areas. However, in areas that are currently known to lack the listed invader, it is considered and EDRR species.

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