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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 1. Science Basis and Applications

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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 actions in the sagebrush biome. The Science Framework provides a multiscale approach for prioritizing areas for management and determining effective management strategies within the sagebrush biome. The emphasis is on sagebrush (*Artemisia* spp.) ecosystems and Greater sage-grouse (*Centrocercus urophasianus*). The approach provided in the Science Framework links sagebrush ecosystem resilience to disturbance and resistance to nonnative, invasive plant species to species habitat information based on the distribution and abundance of focal species. A geospatial process is presented that overlays information on ecosystem resilience and resistance, species habitats, and predominant threats and that can be used at the mid-scale to prioritize areas for management. A resilience and resistance habitat matrix is provided that can help decisionmakers evaluate risks and determine appropriate management strategies. Prioritized areas and management strategies can be refined by managers and stakeholders at the local scale based on higher resolution data and local knowledge. Decision tools are discussed for determining appropriate management actions for areas that are prioritized for management. Geospatial data, maps, and models are provided through the U.S. Geological Survey (USGS) ScienceBase and Bureau of Land Management (BLM) 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, persistent ecosystem threats, land use and development threats, climate change, management prioritization, resilience, resistance, conservation, protection, restoration

Front cover photo. Spring bloom in sagebrush country in the Bodie Hills overlooking Mono Lake near the Nevada-California State line. Photo by Bob Wick.

Inside cover photos. Natural recovery of native forbs and grasses in the Soda Fire rehabilitation area in southwestern Idaho with native lupine in the upper right (photos by Francis Kilkenny) and a mature mountain big sagebrush and bluebunch wheatgrass community in the upper left (photo by Kirk Davies).

Rear cover photo. Spring bloom in a Wyoming big sagebrush community near Pilot Butte in southwestern Wyoming. Photo by Corey Kallstrom.

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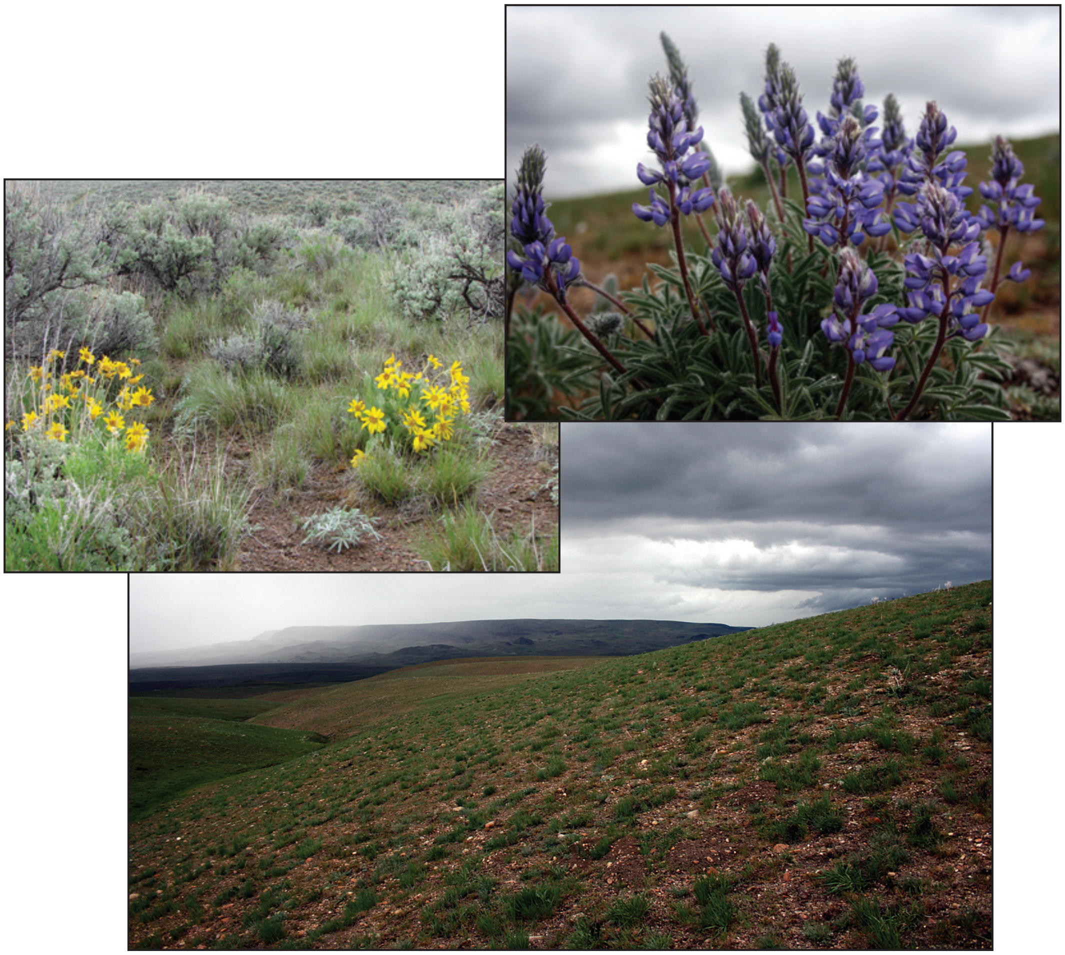


1. Executive Summary

In May 2015 the Department of the Interior released "An Integrated Rangeland Fire Management Strategy: Final Report to the Secretary of the Interior," (IRFMS; USDOI 2015b). The IRFMS outlined longer-term actions needed to implement policies and strategies for preventing and suppressing rangeland fire and restoring rangeland landscapes affected by fire in the Western United States (USDOI 2015a). Priority was placed on protecting, conserving, and restoring Great Basin sagebrush (*Artemisia* spp.) ecosystems and, in particular, Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) habitat. Eighty-three individual actions were identified and a provision was included for developing a multi-scale Conservation and Restoration Strategy (C and R Strategy) for sagebrush ecosystems.

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" (Science Framework) focuses on the *science basis and applications* for the C and R Strategy. Scientific information and decision-support tools are provided that are intended 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.

Part 2 of the Science Framework focuses on *management considerations* for the C and R Strategy and will be available in 2017. The following topics are planned for inclusion in Part 2: (1) nonnative invasive plant species management, (2) wildfire and fuels management, (3) livestock grazing management, (4) wild horse and burro considerations, (5) seed zone considerations, (6) monitoring to inform adaptive management, and (7) integration of the Science Framework with other actions initiated in response to the IRFMS.

The Science Framework builds on a strategic, multi-scale approach developed by two regional Western Association of Fish and Wildlife Agencies (WAFWA) working groups to address persistent ecosystem threats, including invasive plant species, uncharacteristic wildfire, conifer expansion, climate change, and land use and development threats. The approach developed by these groups has been published in two U.S. Department of Agriculture (USDA), Forest Service, Rocky Mountain Research Station, General Technical Reports (Chambers et al. 2014b, 2016a), and was used by the Bureau of Land Management to develop a multi-year program of work for the Great Basin (BLM 2014). The Science Framework provides a unifying approach that includes and updates the two previous efforts and incorporates areas that were not addressed earlier, such as the Columbia Plateau.

The Science Framework focuses on the sagebrush biome and GRSG, but provides information and tools to allow managers to address other resource values and at-risk species as geospatial data for those values and species become available. A crosswalk is provided between Environmental Protection Agency ecoregions (EPA 2016) and sage-grouse Management Zones (Stiver et al. 2006). This approach aligns with the Sage-grouse Habitat Assessment Framework (Johnson 1980; Stiver et al. 2015). Three scales are included to inform different aspects of the planning process: (1) the sagebrush biome scale where consistent, rangewide data can inform budget prioritization; (2) the mid-scale (individual or multiple ecoregions/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.

An overview of the dominant threats to sagebrush ecosystems and GRSG is provided and spatially explicit data and maps are presented for the threats. The threats included are those identified in the Sage-Grouse Conservation Objectives Team Final Report (COT Report; FWS 2013). 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 States and reducing the need for future listings under the Endangered Species Act. In addition to these previously identified threats, climate change is addressed in the Science Framework and climate projections are included for key climate variables (e.g., mean annual temperature and mean annual precipitation) (Appendix 3) and for the most common sagebrush species, Wyoming big sagebrush (Still and Richardson 2015).

The Science Framework uses an approach for prioritizing areas for management and determining effective management strategies that is based on ecosystem resilience to disturbance and resistance to invasive species. Resilient ecosystems have the capacity to ***reorganize and regain*** their basic characteristics when altered by stressors such as invasive plant species and disturbances such as improper livestock grazing and altered fire regimes (Holling 1973). Ecosystems that are resistant to invasion by nonnative plants have attributes that limit the establishment and expansion of the invader (D'Antonio and Thomsen 2004). Management focused on ecosystem resilience and resistance can help sustain local communities by ensuring that ecosystem services, such as water for consumer and agricultural use, forage for livestock, and recreational opportunities are maintained or improved over time. The resilience of socio-economic systems, threats to those systems, and current capacities to implement management actions to address those threats is a separate aspect of developing an approach for conservation and restoration of the sagebrush biome that will be addressed in other venues.

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 and/or management actions (i.e., resilience to disturbance and resistance to invasion by nonnative plants), (2) the capacity of an area to support target species and/or resources, and (3) the predominant threats. It uses a mid-scale approach and has six steps.

1. 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 recently 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.
2. Develop an understanding of ecosystem resilience and resistance for the assessment area. At landscape scales, the resilience and resistance of sagebrush

ecological types are closely linked to soil temperature and moisture regimes (Chambers et al. 2014a,b), and soil temperature and moisture regimes are used to quantify and map resilience and resistance (Appendix 2; Maestas et al. 2016a). More detailed information on soil characteristics and ecological site descriptions assist managers to step-down generalized vegetation dynamics, including resilience and resistance concepts, to local scales.

3. Integrate ecosystem resilience and resistance 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.
4. Assess the key threats in the assessment area using geospatial data and maps.
5. 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 and resistance, and the key threats.
6. Determine the most appropriate management strategies for areas prioritized for management based on its habitat characteristics, relative resilience and resistance, and predominant threats. The management strategies are developed in collaboration with stakeholders and are reconciled with socio-economic and budgetary considerations.

These six steps help identify priority areas for management and overarching management strategies for the assessment area. To step down ecoregion/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. The Science Framework provides methods and decision tools for determining the suitability of an area for management actions as well as the most appropriate action. Examples of the approach in the Science Framework are provided for three areas that support GRSG populations but differ in relative resilience and resistance and the dominant habitat threat: (1) east-central Montana, which is exhibiting cropland conversion, (2) southwestern Wyoming, which has wide-spread oil and gas development, and (3) northeastern Nevada, which is exhibiting cheatgrass (*Bromus tectorum*) invasion and spread at low- to mid-elevations, localized conifer expansion, and large wildfires.

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 resources and focal species become available. The Western Association of Fish and Wildlife Agencies and U.S. Fish and Wildlife Service (FWS) have developed the Sagebrush Science Initiative, which has identified and prioritized science needs for conservation of sagebrush dependent species and allocated funding to address them. As information and data are compiled for these species, they will be used to inform the Science Framework. Future updates to the Science Framework can be further informed by the outcomes of the research conducted as part of implementation of the Actionable Science Plan (ASPT 2016). The State Wildlife Action Plan provides a resource for more detailed information for the Science Framework at the State level, while the Science Framework provides a resource for the State plan revisions.

The Sagebrush Science Initiative, with additional support from the Department of the Interior and the Bureau of Land Management (BLM), is developing a collaborative strategy to conserve sagebrush, sagebrush dependent species, and human uses of the sagebrush system that adopts the use of resistance and resilience concepts, threat assessments, and habitat prioritization methods described in the Science Framework. This strategy will identify sagebrush dependent species and associated habitat and vegetation types for the sagebrush biome as a whole.

To support use of the Science Framework, geospatial data, maps, and models are provided through the U.S. Geological Survey (USGS) ScienceBase (https://www.sciencebase.gov/catalog/item/576bf69ce4b07657d1a26ea2) and BLM Landscape Approach Data Portal (https://landscape.blm.gov/geoportal/catalog/main/home.page).

2. Use of This Document

This document is divided into four topic areas that can be used by the reader to gain an understanding of: (1) the background and structure of the Science Framework, (2) the biophysical characteristics of sagebrush ecosystems and the threats to sagebrush ecosystems and GRSG, (3) the key concepts and approach used in the Science Framework to prioritize areas for management and develop effective management strategies, and (4) the information used for determining appropriate management treatments.

Users of the document will find the background for the Science Framework as well as the approach, scope, and scales in Section 3. Individuals who are unfamiliar with the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems and GRSG can access that information in Sections 4 and 5, respectively. Those who are familiar with sagebrush ecosystems and their threats, but lack an understanding of resilience to disturbance and resistance to invasive annual grasses can obtain that information in Section 6. The key elements of the approach used in the Science Framework are in Sections 7 and 8 and will be of interest to all users. Section 7 combines information on resilience and resistance with species habitat requirements to develop a spatially explicit sage-grouse habitat matrix that can be linked directly to management strategies for maintaining or increasing sagebrush habitat. Section 8 provides the data sources and geospatial process for delineating priority areas for management at the biome, ecoregional/Management Zone, and local scale. Section 9, the final section, provides information and examples for determining appropriate management treatments at the local scale and will be of general interest.

In addition to this technical document, geospatial tools and training are being developed to assist managers in implementing the resilience-based approach described here. Also, handbooks and guides for implementing this approach are available for the western portion of the sagebrush biome and may be adapted to the eastern portion of the sagebrush biome (Miller et al. 2014, 2015; Pyke et al. 2015a,b).

3. Overview of The Science Framework

3.1 Background

Sagebrush ecosystems are among the largest and most imperiled ecosystems in North America (Noss et al. 1995). Sage-grouse and more than 350 other vertebrate species rely on sagebrush ecosystems (Suring et al. 2005a). These ecosystems now comprise only about 59 percent of their historical area and the primary patterns, processes, and many components of these systems have been significantly altered since Euro-American settlement in the mid-1800s (Knick et al. 2011; Miller et al. 2011a). In 2010, the FWS determined that GRSG, a sagebrush obligate species, was warranted for listing under the Endangered Species Act, but listing was precluded by higher priority actions (FWS 2010). The concern over sagebrush habitats and the potential for listing resulted in major changes to Federal and State land management plans and new management direction and actions to address current threats to sagebrush ecosystems and GRSG (FWS 2015). In September 2015, the FWS determined that GRSG did not warrant protection under the Endangered Species Act due to ongoing conservation and restoration efforts, but that its status would be reevaluated in 2020 (FWS 2015).

Two types of threats impact sagebrush ecosystems and sagebrush obligate species. Persistent ecosystem threats include the spread of nonnative invasive plant species, altered fire regimes, conifer expansion, and climate change (Knick et al. 2011; Miller et al. 2011a). (See Appendix 1 for definitions used in this report.) These types of threats are difficult to regulate and are managed using ecologically based approaches (Boyd et al. 2014a; Evans et al. 2013). In contrast, threats due to land uses and development include cropland conversion, energy development, mining, roads and other infrastructure, urban and exurban development, recreation, wild horse and wild burro use, and improper livestock grazing (FWS 2013). These types of threats can be regulated but because of human population growth and increasing resource demands will likely continue to affect sagebrush ecosystems.

The two types of threats often interact with each other. For example, oil and gas development can increase the spread of invasive annual grasses and potential for wildfire, and invasive annual grasses can increase the difficulty of restoring sites impacted by oil and gas development (Mealor et al. 2013). Many of the threats from land uses and development have been the subject of detailed assessments or reviews in recent years (see Hanser et al. 2011; Knick and Connelly 2011; Knick et al. 2011; Manier et al. 2011; Wisdom et al. 2005). The Science Framework focuses on persistent ecosystem threats and the secondary effects of land use and development threats on ecosystems such as reduced ecosystem functioning and landscape connectivity. Importantly, the same types of ecologically based approaches used to manage the detrimental effects of persistent ecosystem threats can be used to promote avoidance, minimize impacts, guide mitigation, and increase restoration effectiveness of habitats affected by land use and development.

Spatially explicit knowledge of how ecosystem resilience and resistance vary across large landscapes can provide the basis for managing threats (Chambers et al. 2014b, 2016a, 2017; Wisdom and Chambers 2009). Resilient ecosystems have the capacity to ***reorganize and regain*** their 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 (Holling 1973). Resistant ecosystems have the capacity to ***retain*** their fundamental structure, processes, and functioning when exposed to stressors or disturbances (Folke 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**)**. By identifying key indicators of the capacity of ecosystems and species to recover from disturbance and resist stressors, like nonnative invasive plant species, it is possible to assess and predict how native ecosystems and species will respond to management actions designed to mitigate persistent threats.

3.2 Approach

The Science Framework uses a strategic, multi-step approach (see table 1) that builds on those developed by two WAFWA working groups (Chambers et al. 2014b, 2016a). The first group focused on persistent ecosystem threats, specifically invasive annual grasses, uncharacteristic wildfire, and conifer expansion in the western range of sagebrush and GRSG (MZs III, IV and V; Chambers et al. 2014b). The second addressed both persistent ecosystem threats and land use and development threats to sagebrush ecosystems, Gunnison sage-grouse (*C. minimus*; GUSG), and GRSG in the eastern portion of its range (MZs I, II, and VII; Chambers et al. 2016a). The approach developed for the western portion of the range was subsequently incorporated into the "Greater Sage-Grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment" (BLM 2014), which served as the basis for a multi-year program of work by the BLM in the Great Basin. The Science Framework updates the two previous efforts and incorporates areas that were not previously addressed, such as the Columbia Plateau (MZ VI). To support future assessments related to the Science Framework, geospatial data, maps, and models are provided through the USGS ScienceBase (https://www.sciencebase.gov/catalog/item/576bf69ce4b07657d1a26ea2) and BLM Landscape Approach Data Portal (https://landscape.blm.gov/geoportal/catalog/main/home.page).

3.3 Scope and Scales

The Science Framework focuses on sagebrush ecosystems and GRSG. Updates to the Science Framework will include additional species and values as biome-wide and other data become more available. For example, the WAFWA-coordinated Sagebrush Science Initiative will identify sagebrush dependent species and associated habitat or vegetation types for the sagebrush biome as a whole. Information and data compiled for these species will be used to inform the Science Framework.

The Science Framework provides a cross-walk between EPA ecoregions (EPA 2016) and sage-grouse Management Zones (Stiver et al. 2006) (fig. 1). The sagebrush biome encompasses four Level II and thirteen Level III ecoregions (fig. 1; EPA 2016). The seven Management Zones are based largely on ecoregional differences and provide a common basis for GRSG management within the sagebrush biome (fig. 1). Distinct differences in the type and extent of sagebrush habitat, persistent ecosystem threats, resilience to disturbance, and resistance to invasive plant species exist across the sagebrush biome and are reflected in the different ecoregions. These differences influence management strategies both within and among ecoregions.

This Science Framework uses a multi-scale approach that includes the sagebrush biome, ecoregions and Management Zones, and local land planning areas (table 2).

Table 1—Components of a strategic, multi-scale approach for managing threats to sagebrush ecosystems, sage-grouse, and other sagebrush obligate species.

Process steps	Description
1.0 Identify focal species and key habitat indicators	
1.1 Identify focal species	Native species whose spatial, compositional, and functional requirements are representative of the needs of a larger set of species
1.2 Determine the habitat characteristics needed to support persistent populations	Landscape-scale indicators of habitat suitability such as climate, landform, vegetation, and degree of disturbance
2.0 Develop an understanding of ecosystem resilience and resistance for the planning area	
2.1 Determine biophysical indicators of ecosystem processes	Landscape-scale indicators of potential ecosystem response to stress and disturbance and to invasive plants such as temperature and moisture regimes and ecosystem productivity
3.0 Integrate resilience and resistance with species habitat requirements	
3.1 Develop a habitat matrix that links resilience and resistance with species habitat characteristics	A matrix that can be used to spatially link ecosystem response to stress and disturbance, species habitats, and management actions
3.2. Determine appropriate management strategies and link the strategies to matrix cells	Management strategies that are related to different levels of ecosystem resilience and resistance and habitat probabilities
3.3. Evaluate the spatial relationships between resilience and resistance and species habitat characteristics	Maps and geospatial data that illustrate and quantify the relationships between resilience and resistance indicators and species habitat characteristics
4.0 Assess dominant threats	
4.1 Incorporate dominant stressors and disturbances	Maps and data that illustrate and quantify stressors and disturbances such as land use and development, invasive species, wildfire, and conifer expansion
5.0 Prioritize areas for management	
5.1 Use available species data or models to help identify habitats for targeted management within ecoregions/ management zones	Information on focal species, such as distribution and abundance, that can be used to identify stronghold or connectivity areas needed to support persistent populations
5.2 Prioritize areas for targeted management based on species information, relative resilience and resistance, and threats	Maps and data that overlay species information with information on resilience and resistance to dominant threats to assess risks and target efforts
6.0 Determine the most appropriate management strategies and treatments	
6.1. Managers and stakeholders select appropriate management strategies for priority areas at mid- to local scales based on species information and resilience to threats	Management strategies that consist of coordinated management activities conducted at mid- to local scales to achieve landscape-scale vegetation and habitat objectives, such as strategically locating firefighting resources
6.2. Managers and stakeholders select project areas and treatments at the local scale for priority areas based on species information, resilience and resistance, and threats	Treatments or management actions conducted at local scales that directly manipulate vegetation to achieve a vegetation or habitat objective
6.3. Implement monitoring to evaluate and adapt management actions	Monitoring data for both ecosystem and species responses to threats and management actions that can be used in an adaptive management framework

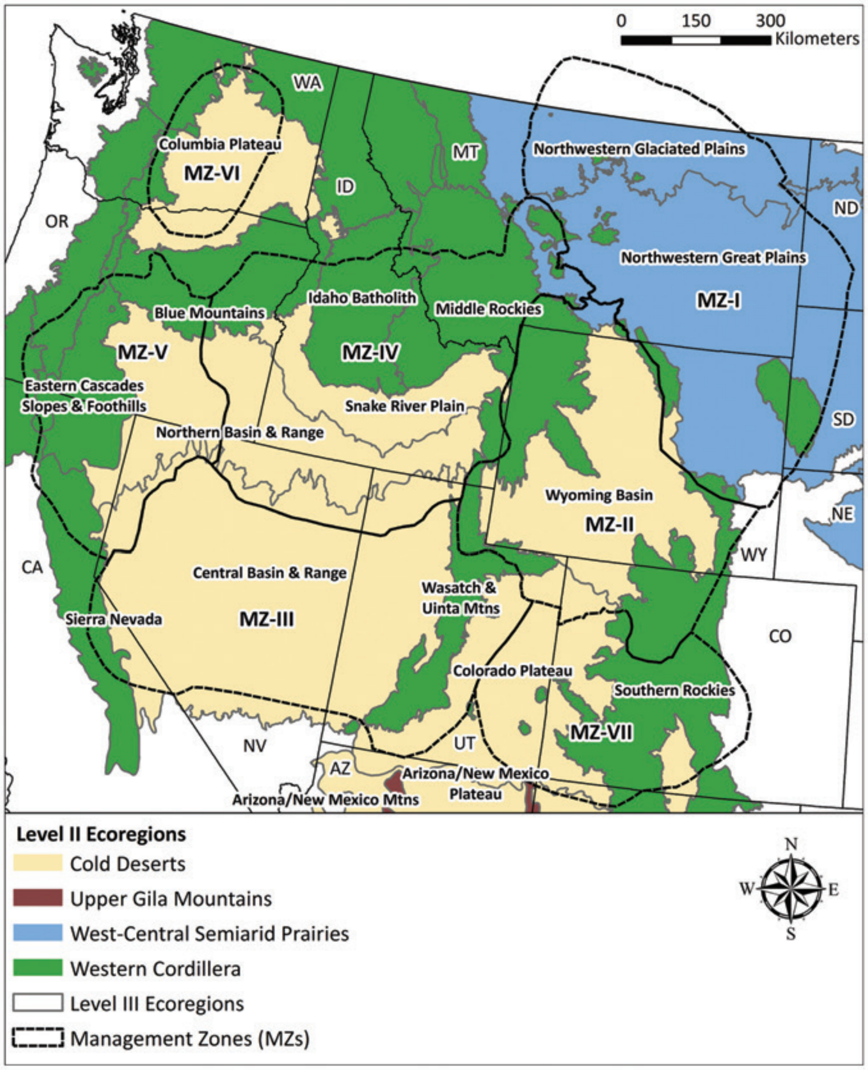


Figure 1—A cross-walk between Level II and Level III Ecoregions (EPA 2016) and sage-grouse Management Zones (MZs; Stiver et al. 2006).

This approach aligns with the Sage-Grouse Habitat Assessment Framework (Stiver et al. 2015) and Johnson's (1980) orders of habitat selection. The sagebrush biome approximates GRSG species range (1st order), ecoregions and Management Zones provide population relevant information (2nd order), and local planning areas inform decisions regarding seasonal habitats (3rd and 4th order). Data, models, and tools from a variety of partners (e.g., U.S. Forest Service [USFS], Natural Resources Conservation Service [NRCS], WAFWA, non-governmental organizations [NGOs], States, and USDOI bureaus including USGS, BLM, and FWS) are available for use at each scale. The data, models, and tools are specific to the different scales, but are additive from the sagebrush biome scale to the local land planning area scale. For example, habitat data available at the biome scale, such as landscape cover of sagebrush, is also relevant at the ecoregion and Management Zone scale, but higher resolution or more detailed data may further inform ecoregional assessments. Similarly, data from ecoregional scales are relevant at local planning area scales, but higher resolution or more detailed data may be available from planning area assessments or monitoring.

Table 2—Scales and areas included in the strategic approach for managing threats to sagebrush ecosystems, sage-grouse, and other sagebrush obligate species and 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	Broad	West-wide	Habitat Soils Population data and models Priority resource data Fire and other threat data Climate change projections	Budget prioritization within DOI for rangewide consistency
Sage-grouse Management Zones and ecoregions	Mid	State or National Forest	Above, plus Assessments and planning docs Regional data and models Regional tools	Assessments at ecoregion/MZ scales 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

The three scales inform different aspects of the planning process (table 2). Prioritizations of areas for management actions are typically conducted at the mid-scale (individual or multiple ecoregions and Management Zones) because of similarities in environmental characteristics, ecosystem threats, and management strategies. At the sagebrush biome scale, such ecoregional and Management Zone assessments are used to inform budget prioritization within USDOI and help ensure rangewide consistency in allocating funds. At the local scale, local data and expertise are used to select project sites and determine appropriate management strategies and treatments within areas prioritized for management. In this document, management strategies are 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 (EDRR) activities for invasive plant species, or positioning treatments to increase habitat connectivity). Treatments are local scale management actions that directly manipulate vegetation to achieve a vegetation or habitat objective (e.g., conifer removal, invasive annual grass control, fuel treatment, or seeding efforts).

4. Climatic Regimes and Vegetation Types in the Sagebrush Biome

In the Science Framework, level II and level III EPA ecoregions are used as the basis for describing the differences in climatic regimes, dominant landforms and elevation ranges, and soil temperature and moisture regimes among ecoregions and Management zones (fig. 1; table 3). An understanding of these differences can help inform biome to mid-scale prioritizations and management strategies.

The ecoregions are characterized by distinct temperature and precipitation regimes (fig. 2) and differ in the amount of precipitation received in winter versus summer (fig. 3). In the western portion of the sagebrush biome most precipitation arrives as winter snow and rain. In contrast, in the eastern portion of the biome as much as 30 to 50 percent of the annual precipitation arrives during the summer months of July, August, and September (fig. 3). These differences, especially when coupled with total amount of precipitation, influence both plant functional type dominance (Lauenroth et al. 2014; Sala et al. 1997) and competitive interactions with invasive species such as cheatgrass (*Bromus tectorum*) and field brome (*B. arvensis*, formerly *B. japonicus*) (Bradford and Lauenroth 2006).

The amount of precipitation that is received during the period when temperature, and thus potential evapotranspiration, is low influences the amount of water stored in deep soil layers and therefore the balance between woody and herbaceous species (Lauenroth et al. 2014; Sala et al. 1997). Areas that receive more winter and spring precipitation typically have greater deep soil water storage and are dominated by woody species, such as sagebrush, which are more effective at using deep soil water (figs. 4a,b). In contrast, areas that receive predominantly summer precipitation are typically dominated by grasses. Also, seasonality of precipitation during the period when temperatures are favorable for plant growth is an important control on the balance between C3 and C4 species (cool and warm season with different photosynthetic pathways). C3 species such as wheatgrasses (e.g., *Pascopyrum*, *Pseudoroegnaria*, and *Elymus* spp.) dominate in areas with cool, wet springs and C4 species such as grama grasses (*Bouteloua* spp.) dominate in areas with warm, wet summers (Paruelo and Lauenroth 1996; Sala et al. 1997). These differences are reflected in the landscape cover of sagebrush. Most of the western portion of the sagebrush biome is characterized by sagebrush-dominated systems, while the West-central Semiarid Prairies are characterized by grass-dominated systems with sagebrush components (fig. 5).

Resistance to *Bromus* species and many other cool-season invaders generally increases as summer precipitation and amount of precipitation increase (fig. 4c) as a function of higher perennial grass productivity and dominance. This appears to be due to less favorable conditions for establishment of annual species like cheatgrass and strong competition from perennial native grass species that dominate under this precipitation regime (Bradford and Lauenroth 2006; Bradley 2009). However, even in this competitive environment, disturbances that remove perennial native grass cover often facilitate establishment of invasive annual grasses and other invasive plant species, especially when productivity is low (fig. 4c; Bradford and Lauenroth 2006; Knight et al. 2014; Lauenroth et al. 2014).

Table 3—Environmental characteristics of the Level III Ecoregions based on Griffith (2010).

	Temperature range (°F)	Frost-free days	Precipitation range (in)	Dominant landforms	Elevation range (ft)	Soil temperature regime	Soil moisture regime
Cold Deserts							
Columbia Plateau	45 to 54	70 to 190	6 to 24	Tableland, plateaus, hills	197 to 4,921	–	–
Northern Basin and Range	41 to 48	30 to 140	6 to 39	Tableland, mountains, basins, valleys	2,625 to 9,845	Frigid, Mesic	Xeric, Aridic
Snake River Plain	42 to 50	50 to 170	4 to 26	Mountains, basins, valleys	2,100 to 6,450	Mesic	Xeric, Aridic
Central Basin and Range	36 to 57	15 to 200	4 to 39	Mountains, basins, valleys	3,346 to 13,120	Frigid, Mesic	Xeric, Aridic
Wyoming Basins	32 to 46	30 to 130	5 to 20	Intermontane basins	4,000 to 9,450	Frigid, Mesic	Aridic-ustic
Colorado Plateau	41 to 59	50 to 220	5 to 32	Tableland	2,950 to 9,840	Frigid, Mesic	Aridic-ustic
Western Cordillera							
E. Cascades Slopes and Foothills	36 to 52	10 to 140	20 to 138	Mountains, plateaus	984 to 8,202	Cryic to Mesic	Mostly Xeric
Idaho Batholith	28 to 46	30 to 140	8 to 60	Mountainous plateau	–	Cryic, Frigid	Udic, Xeric
Blue Mountains	30 to 50	30 to 160	9 to 80	Mountains and foothills	1,000 to 9,843	Cryic to Mesic	Udic, Xeric
Wasatch and Uintah Mtns	28 to 46	40 to 200	6 to 55	Mountains, plateaus	4,790 to 13,527	Cryic to Mesic	Udic, Xeric, Aridic
Middle Rockies	23 to 46	25 to 140	12 to 98	High mountains and foothills	–	Cryic, Frigid	Udic, Ustic
Southern Rockies	25 to 52	25 to 150	10 to 69	High mountains and foothills	5,085 to 14,403	Cryic, Frigid	Udic, Ustic
Northwestern Great Plains							
West-Central Semiarid Prairies	37 to 47	–	10 to 21	Plains	–	Frigid	Ustic
Northwestern Glaciated Plains	37 to 45	95 to 170	10 to 22	Plains	–	Frigid, Mesic	Ustic, Aridic

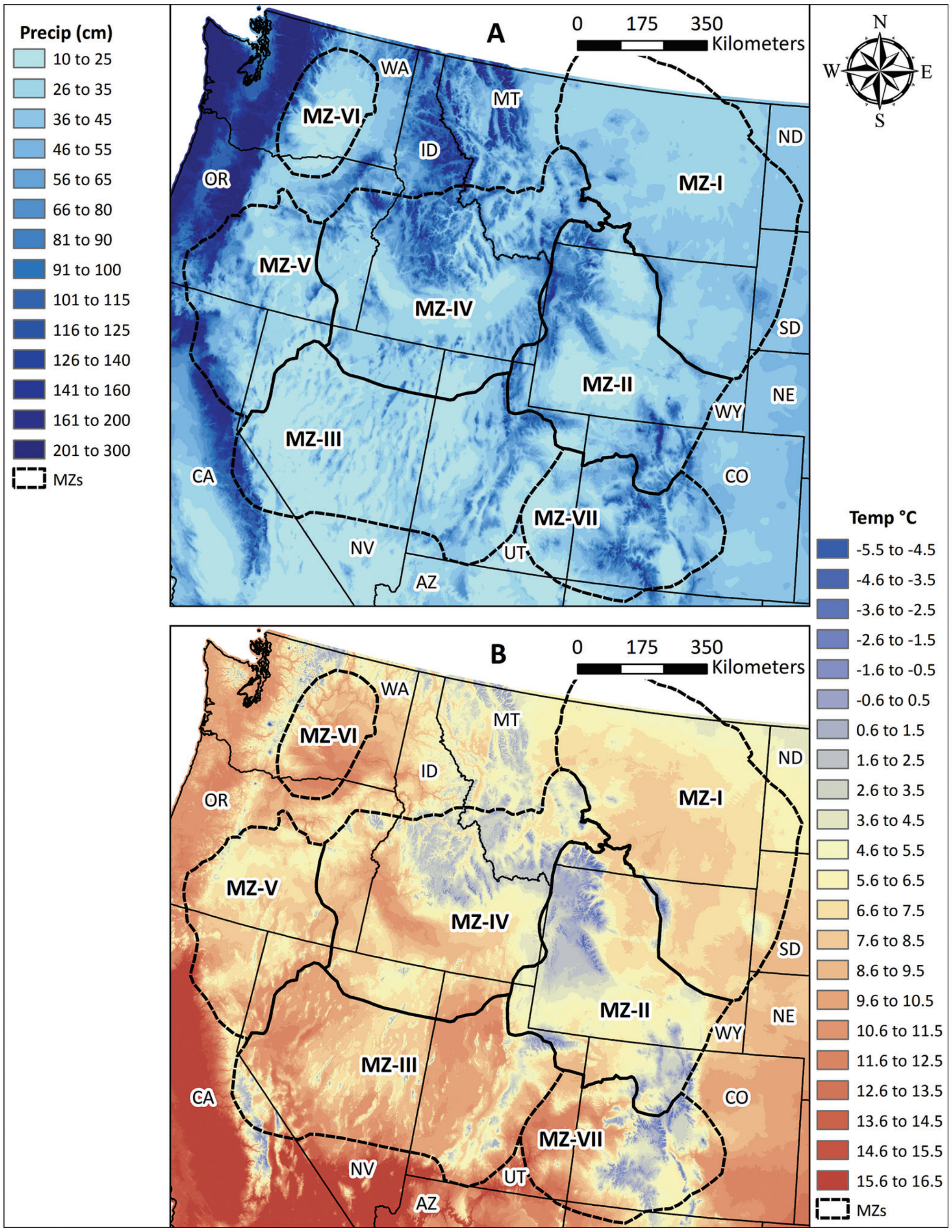


Figure 2—The 30-year normal annual values for (A) precipitation and (B) temperature (PRISM 2016) across ecoregions and management zones.

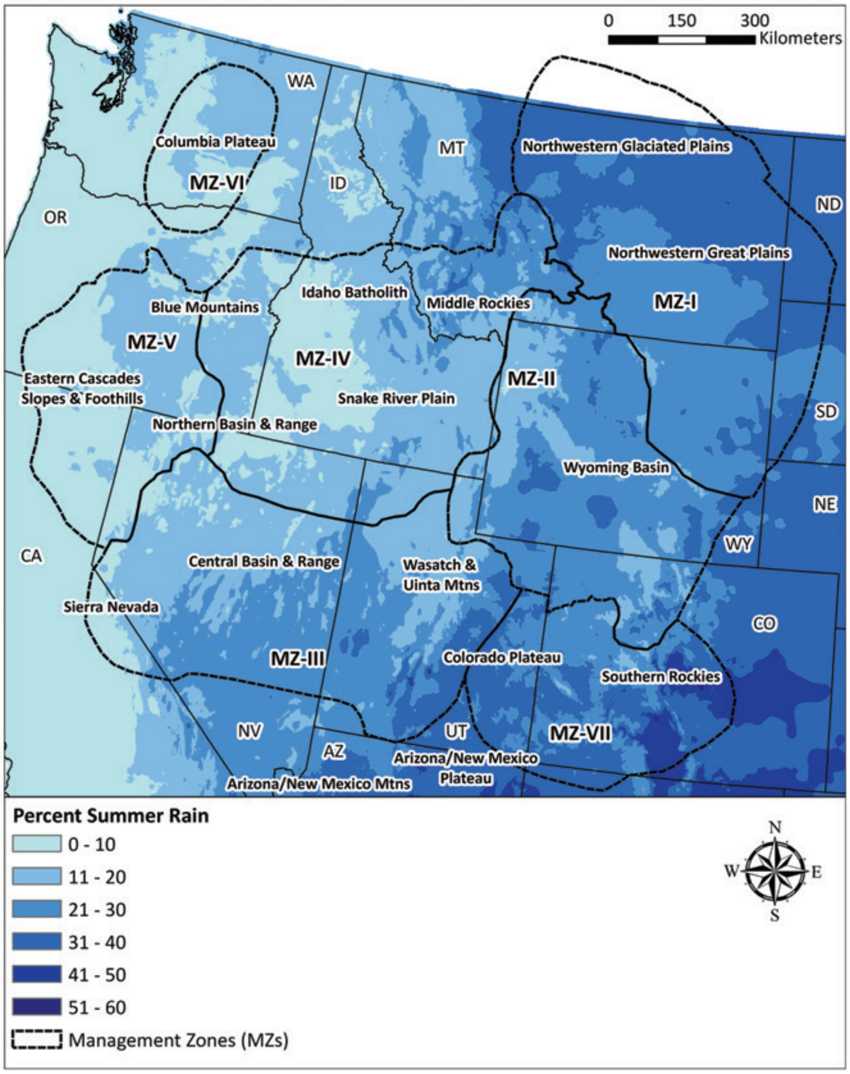


Figure 3—Percentage of annual precipitation occurring during the months of July, August, and September (PRISM 2016). The amount and timing of precipitation affects plant dominance (shrubs vs. grasses) and interactions between native and invasive plants.

Soil climate regimes (temperature and moisture) integrate several different climate variables including mean annual temperature and precipitation and seasonality of precipitation, thus providing a means of assessing climatic differences among ecoregions and effects on vegetation. These regimes are mapped as part of the National Cooperative Soil Survey (NRCS 2013) and can be used in large-scale analyses (Maestas et al. 2016a). See Appendix 2 for an explanation of soil temperature and moisture regimes. The soil temperature and moisture regimes that characterize sagebrush ecosystems vary due to the large latitudinal differences and elevation gradients that the area encompasses as well as the variation in seasonality of precipitation (fig. 6). As with most large-scale mapping products, there are limitations in using the NRCS soil survey information including incongruities in soil regime classifications, especially along mapping boundaries, and variations in the level of survey detail available. However, areas with incongruities represent a relatively minor component of the data set and have been taken into account in this report.

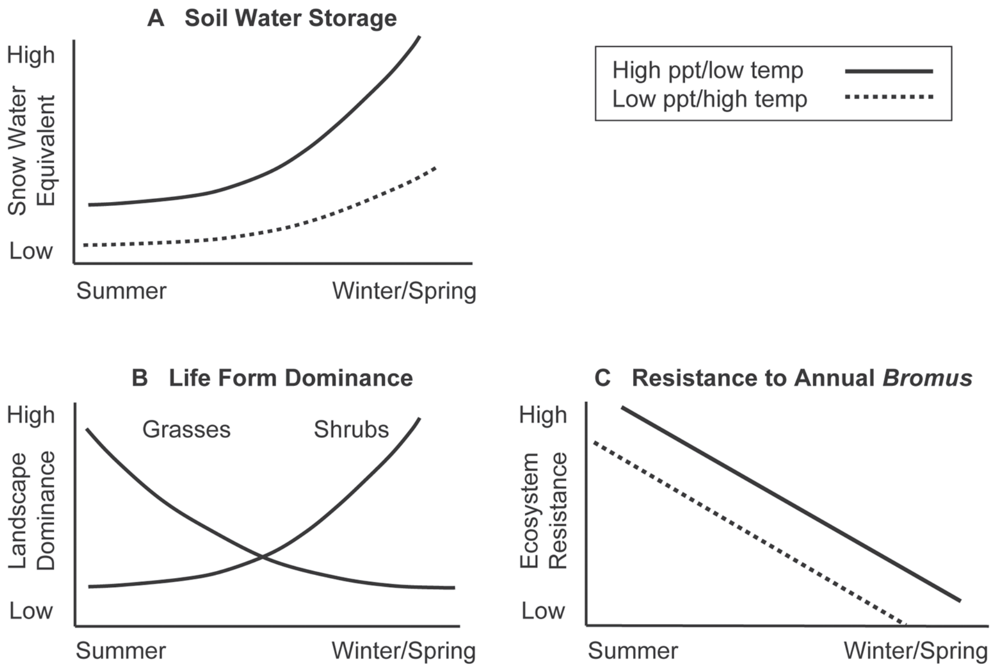


Figure 4—Changes in soil water storage, life form dominance, and resistance to annual *Bromus* as seasonality of precipitation transitions from primarily summer to winter. (A) Soil water storage increases as winter/spring precipitation and snow water equivalent increase and these changes are relatively greater for areas with relatively high precipitation and low temperature. (B) Landscape dominance of grasses is highest with primarily summer precipitation; shrub dominance is greatest with primarily winter/spring precipitation. (C) Resistance to *Bromus* is higher in areas where soil water storage is low and grasses dominate largely due to strong resource competition. Decreases in effective precipitation can increase resource fluctuations and lower resistance to *Bromus*. At more local scales, resistance also is influenced by nutrient availability and disturbance (figure from Chambers et al. 2016b).

Until improved products are developed, the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) provides access to the most complete data set across the biome for understanding ecosystem response to both disturbances and management treatments. Project level planning based on resilience and resistance concepts can be further informed by local climate and soils data.

4.1 West-Central Semiarid Prairies Ecoregions

West-Central Semiarid Prairies include the Northwestern Glaciated Plains in northern Montana and the Northwestern Great Plains in the west and central Dakotas, southeast Montana, and northeast Wyoming (fig. 1; Griffith 2010). The Northwestern Glaciated Plains are comprised of rolling hills and gentle plains mantled by glacial till, outwash, and glaciolacustrine sediments. The Northwestern Great Plains were not glaciated and have rolling plains of shale and sandstone punctuated by occasional buttes. The West-Central Semiarid Prairie Ecoregion has a mostly dry, mid-latitude climate and is characterized by warm to hot summers and cold winters (Griffith 2010; table 3). In the Northwestern Glaciated Plains soil temperature and moisture regimes are predominantly cool (frigid) and summer-moist (ustic), respectively, but in the Northwestern Great Plains both cool (frigid) and warm (mesic) soil temperature regimes and summer-moist bordering on dry (ustic bordering on aridic) soil moisture regimes are typical (fig. 6).

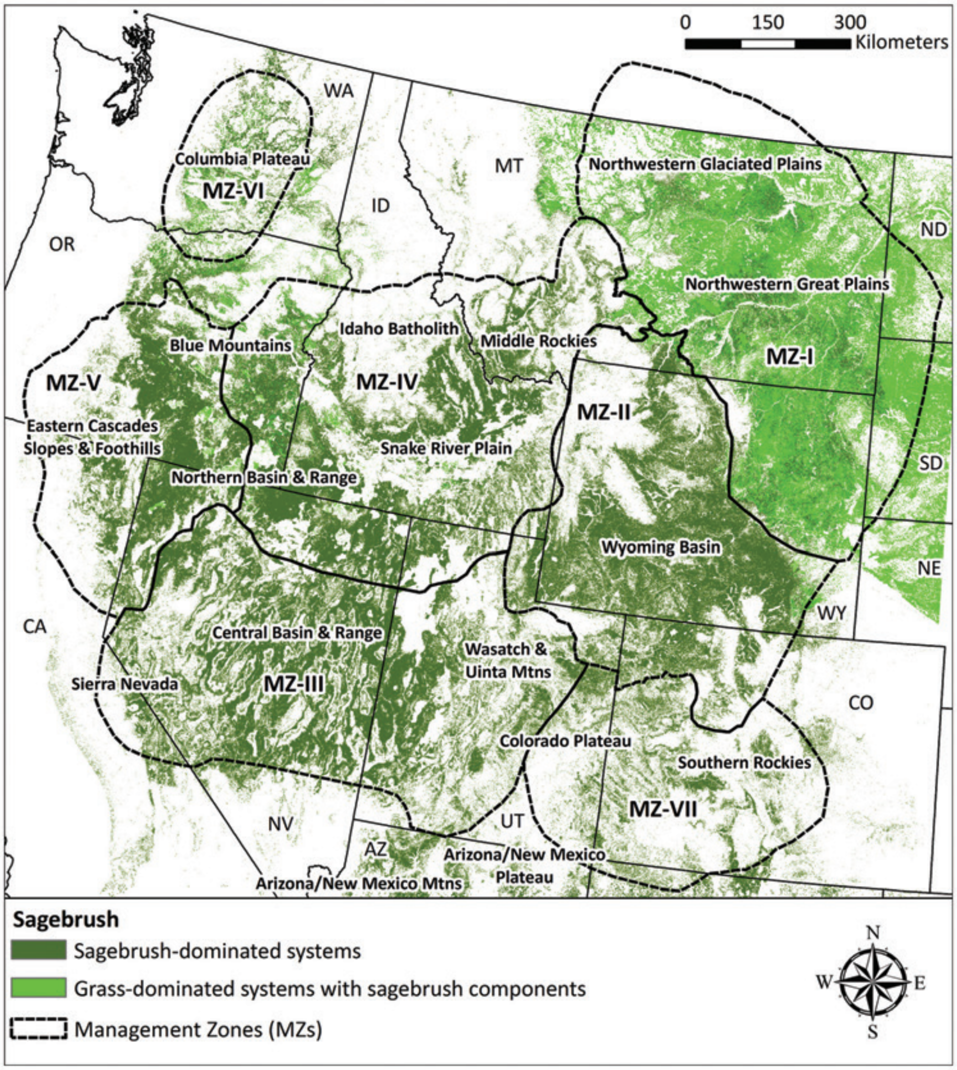


Figure 5—Landscape cover of sagebrush-dominated ecological systems and grass-dominated ecological systems with sagebrush components (USGS 2014). The western portion is characterized by sagebrush-dominated systems, and the eastern portion is characterized by grass-dominated systems with sagebrush components.

Climate patterns in the eastern portion of the Northwestern Great Plains favor grassland communities. Sagebrush species include silver sagebrush (*A. cana* spp. *cana*), Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), fringed sagewort (*A. frigida*), and basin big sagebrush (*A. t.* ssp. *tridentata*) (Miller et al. 2011a; USGS 2013). Dominant grasses include wheatgrasses (*Pascopyrum smithii, Pseudoroegnaria spicata,* and *Elymus* spp.), grama grasses (*Bouteloua* spp.), bluestem species (*Andropogon gerardii, Schizachyrium scoparium*), and needlegrasses (*Hesperostipa* spp., *Nasella* spp., and *Achnatherum* spp.). These grasses vary widely in relative abundance in response to climate, drought conditions, and grazing pressure (Barker and Whitman 1988).

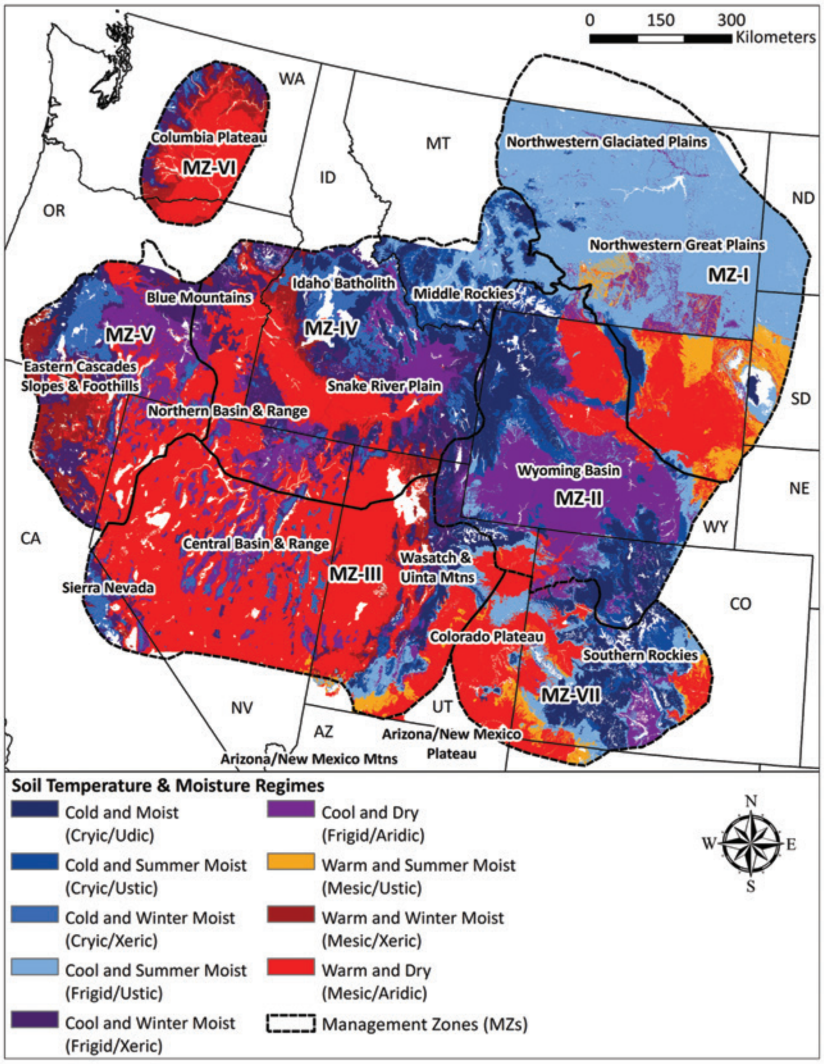


Figure 6—Soil temperature and moisture regimes by soil moisture subclass. See Appendix 2 for an explanation of the soil temperature and moisture regime data used in this report. The area near the border between southeastern Montana and northeastern Wyoming is in a transition zone between the frigid and mesic soil temperature regimes, which resulted in an apparent abrupt change in temperature regime at the State border. Future updates to soil survey information will resolve these boundary issues along State lines, using current climate datasets and additional field data.

4.2 Cold Deserts Ecoregions in the Eastern Part of the Sagebrush Biome

The Cold Deserts in the eastern part of the sagebrush biome and GRSG range include the Wyoming Basin in the western and central portions of Wyoming, and the Colorado Plateau in eastern and southern Utah and western Colorado (fig. 1). The Wyoming Basin is a broad, intermontane basin that ranges in elevation from about 4,000 ft to 9,450 ft (1,220 m to 2,850 m) and is characterized by sedimentary landforms and variable topography, while the Colorado Plateau is deeply dissected tableland comprised of sedimentary rock that ranges from about 2,950 ft to over 9,840 ft (900 m to over 3,000 m) (Griffith 2010; table 3). The Cold Deserts ecoregion in general has a continental climate with warm to hot and dry summers and cool to cold and wet winters. The large topographic gradients in the Wyoming Basin and Colorado Plateau result in considerable variation in mean annual temperature and precipitation but the Colorado Plateau is generally warmer (table 3). Cool and warm (frigid and mesic) soil temperature regimes and dry and summer moist (aridic and ustic) soil moisture regimes occur in the Cold Deserts ecoregion (fig. 6; table 3).

Vegetation is characterized largely by arid to semiarid shrublands that transition from zero to a few warm season grass species west of the Continental Divide, to warm season grasses as a major component east of the Continental Divide (Griffith 2010). Sagebrush types vary along soil temperature and moisture gradients; lower elevation sagebrush types are dominated by Wyoming big sagebrush. Black sagebrush (*A. nova*) occurs on windswept ridges and in areas with shallow soils while early sagebrush (*A. arbuscula* ssp. *longiloba*) occurs on sites with higher clay content. Basin big sagebrush is found in areas with deeper soils and higher available soil moisture across the region, as is silver sagebrush in eastern portions of the Wyoming Basin. In ecotones between Cold Deserts and Western Cordillera Ecoregions at mid-elevations, Wyoming big sagebrush transitions into mountain big sagebrush (*A. t.* ssp. *vaseyana*), and at higher elevations mountain big sagebrush co-occurs with mountain shrubs (e.g., Saskatoon serviceberry [*Amelanchier alnifolia*], chokecherry (*Prunus virginiana*), currant (*Ribes* spp.), antelope bitterbrush [*Purshia tridentata*], and snowberry [*Symphoricarpos* spp.]). In these zones in Colorado, extensive areas of hybridization occur between black sagebrush and mountain big sagebrush, and between Wyoming big sagebrush and mountain big sagebrush (Monsen 2005; Winward 2004). Bunchgrasses are common and include wheatgrasses, needlegrasses, fescues (*Festuca* spp.), and bluegrasses (*Poa* spp.). Utah juniper (*Juniperus osteosperma*) occurs in the more arid basins in the western part of the ecoregion, while Rocky Mountain juniper (*J. scopulorum*) is common at higher elevations and in the east where summer precipitation is higher. In the Colorado Plateau two-needle piñon (*Pinus edulis*) codominates with Utah juniper.

4.3 Cold Deserts Ecoregions in the Western Part of the Sagebrush Biome

The western Cold Deserts include the Columbia Plateau in east central Washington and Oregon; Snake River Plain in central Idaho; Northern Basin and Range in southern Idaho, northern Nevada, and eastern Oregon; and the Central Basin and Range largely in central Nevada and western Utah (fig. 1). These ecoregions are generally characterized by mid-latitude steppe and desert climates, marked by warm to hot summers and cold winters (table 3; Griffith 2010). Topography tends to be characterized by tablelands and hills in the Columbia Plateau and by mountains, basins, and valleys in the other ecoregions. The variable topography results in large ranges in mean annual temperature and number of frost-free days and in mean annual precipitation (table 3; Griffith 2010). Soil temperature regimes range from cold (cryic) to warm (mesic) and soil moisture regimes from winter moist (xeric) to dry (aridic) (fig. 6; table 3).

Vegetation in the Columbia Plateau is largely arid sagebrush steppe and grassland due to the relatively high mean annual precipitation coupled with loess soils (Griffith 2010). Deeper soils occur in the periphery of the Columbia Plateau, but channeled scablands with shallow to very shallow soils that greatly influence soil water availability occur in different parts of the Plateau. Much of the vegetation in the Northern Basin and Range and Snake River Plain is typically classified as sagebrush steppe due to relatively cooler temperatures and more effective precipitation

(West 1983a,b). In contrast, the Central Basin and Range is typically characterized by warmer and/or drier conditions and is classified as sagebrush desert (West 1983a,b). The species of sagebrush are generally similar across these ecoregions, but differ along soil temperature and moisture gradients with mountain big sagebrush dominating on cool to cold sites, Wyoming big sagebrush on warm sites, and basin big sagebrush on warm to cool sites with deep soils (Appendix 2; Miller et al. 2011a). Dwarf species of sagebrush that dominate on warm, gravelly soils are black sagebrush (*A. nova*); dominate species on warm, shallow soils are low sagebrush (*A. a.* spp. *arbuscula*) (Appendix 2; Miller et al. 2011a). Broadly distributed shrubs across the gradient are rabbit brushes (*Chrysothamnus* and *Ericameria* species) and bitterbrush. These ecoregions are dominated largely by bunchgrasses such as Idaho fescue (*F. idahoensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), needle grasses, and bluegrasses (*Poa* spp.). However, warm season, rhizomatous grasses such as James' galleta (*Pleuraphis jamesii*) and sand dropseed (*Sporobolus cryptandrus*) are also relatively common in the southern part of the Central Basin and Range. Western juniper (*J. occidentalis*) occurs largely in the Columbia Plateau, western Snake River Plain, and western part of the Northern Basin and Range. Utah juniper occurs primarily in the eastern part of the Northern Basin and Range and in the Central Basin and Range where it co-occurs with single-leaf piñon (*P. monophylla*).

4.4 Western Cordillera Ecoregions in the Eastern Part of the Sagebrush Biome

The Western Cordillera includes the Middle Rockies that occur in southwestern Montana, eastern Idaho, western Wyoming, the Black Hills of western South Dakota and northeastern Wyoming, and the Southern Rockies which extend from southern Wyoming through Colorado (fig. 1; Griffith 2010). The Western Cordillera Ecoregion is characterized by high elevation mountains and foothills that range from 5,085 ft to over 14,400 ft (1,550 m to over 4,390 m), and by cool to warm short summers and cold winters. Mean annual temperature and precipitation vary greatly with elevation, but precipitation tends to be higher and temperature lower in the Middle Rockies than in the Southern Rockies (table 3). Soil temperature regimes range from cool to cold (frigid to cryic), and moisture regimes are summer moist, and wet and humid (ustic, udic) (fig. 6; table 3).

In the Middle and Southern Rockies, coniferous forests cover much of the region, with a pattern of elevational banding. The foothills are partly wooded or shrub dominated, and intermontane valleys are grass- and/or shrub-covered. In the Southern Rockies, the lowest elevations are generally grass- or shrub-covered, with sagebrush, mountain mahogany (*Cercocarpus* spp.), two-needle piñon, Utah juniper, or scattered Gambel oak (*Quercus gambelii*) woodlands (Griffith 2010). Dominant sagebrush species at higher elevations are mountain big sagebrush, low sagebrush, silver sagebrush, three-tip sage (*A. tripartita*) and spiked big sagebrush (*A. t.* ssp. *spiciformis*), and at lower elevations are Wyoming big sagebrush and black sagebrush (Knight et al. 2014; Miller et al. 2011a). Utah juniper and two-needle piñon occur in the lower and more arid areas in the western and southern part of the ecoregion, while Rocky Mountain juniper is common at higher elevations and latitudes. The Middle Rockies and Southern Rockies are characterized by many of the same grass species as the Cold Deserts ecoregions including wheatgrasses, needlegrasses, fescues, and bluegrasses.

4.5 Western Cordillera Ecoregions in the Western Part of the Sagebrush Biome

The Western Cordillera in the western sagebrush biome includes the Eastern Cascade Slopes and Foothills in northern California and eastern Oregon and Washington, North Cascades in Washington, Northern Rockies in Washington and Idaho, Blue Mountains in Washington, Oregon, and Idaho, Idaho Batholith largely in Idaho, and Wasatch and Uintah Mountains in Utah. These ecoregions are characterized by mountains and plateaus and mountains and foothills with mid-latitude, continental climates (Griffith 2010; table 3). The Eastern Cascade Slopes and Foothills in northern Oregon and southern Washington, northern Rockies north of the Salmon River, and the Blue Mountains have a notable maritime influence in winter due to the presence of the Columbia River gorge and broad, low passes in northern Oregon and southern Washington. Precipitation and temperature are relatively high in the Eastern Cascade Slopes and Foothills but are lower and similar among the other ecoregions (table 3). Soil temperatures are generally cold (cryic) to warm (mesic) or cold (cryic) to cool (frigid), while soil moisture regimes are moist (udic) or winter moist (xeric) (fig. 6; table 3).

Coniferous forests cover much of these ecoregions, with the lower foothills and valleys characterized by sagebrush and grasses. The sagebrush and grass species are largely the same as those that occur in cold to cool soil temperatures and moist soil moisture regimes in the adjacent Cold Deserts of the western part of the sagebrush biome.

5. Threats to Sagebrush Ecosystems and Greater Sage-Grouse

Assessing the persistent ecosystem and land use and development threats to sagebrush ecosystems and GRSG populations (table 4) is a primary component of the strategic approach for the Science Framework (see table 1). The threats included in the Science Framework were identified in the COT Report (FWS 2013), which was a State and Federal interagency product. These threats are largely consistent with those included in: (1) the State Wildlife Action Plans, and (2) the BLM and USFS rangewide planning effort to address the threats identified in both the 2010 FWS finding of “warranted but precluded” from listing and the COT Report (FWS 2013). It is noteworthy that the BLM and USFS planning effort resulted in publication of four separate Records of Decision covering 98 separate land use plans across 11 western States in September 2015.

In this section, an overview of these threats is provided for sagebrush ecosystems and GRSG. We first focus on the interacting effects of persistent ecosystem threats on sagebrush ecosystems and on GRSG. Threats to the West-Central Semiarid Prairies ecoregion and the Cold Deserts and Western Cordillera ecoregions are discussed separately because of the differences in climatic regimes, vegetation types, and responses to disturbance and management treatments. The effects of climate change are also discussed separately to highlight new information developed for the sagebrush biome in the Science Framework. We later focus on the effects of land use and development threats on sagebrush ecosystems and GRSG. Effects of the different threats are discussed separately. A section is included that discusses the interacting effects of persistent ecosystem and development threats.

Table 4—List of persistent ecosystem threats and land use and development threats to sagebrush ecosystems and Greater sage-grouse and associated management objectives. The threats are based on the Greater Sage-Grouse Conservation Objectives: Final Report (FWS 2013) and the Greater Sage-Grouse Monitoring Framework (IGSDMS 2014).

Threats	Management objective
Isolated or small population size of Greater sage-grouse	Landscape connectivity and resilient populations
Weeds and invasive grasses	Minimal weeds
Conifer expansion	Conifer reduction where appropriate to support sagebrush dependent species
Altered fire regimes	Fire regimes/sizes in historic range of variability
Sagebrush elimination	Sagebrush land cover sufficient to support sagebrush dependent species
Climate change	Effective adaptation
Cropland conversion	Low fragmentation
Energy development	Low fragmentation
Mining	Low fragmentation
Urban and exurban development	Low fragmentation
Recreation	Little to no impact
Infrastructure	Low impact disturbance
Livestock grazing	Meets identified vegetation standards
Wild horses and burros	Managed within established appropriate management levels (AML)

5.1 Persistent Ecosystem Threats: Invasive Plant Species, Conifer Expansion, and Altered Fire Regimes

5.1.1 Threats to the West-Central Semiarid Prairies Ecoregion (MZ I)

Herbivory, in conjunction with fire, strongly influenced historical plant community composition, structure, and productivity of the West-Central Semiarid Prairies (Samson and Knopf 1996). Prior to Euro-American settlement, large numbers of bison (*Bos bison*) moved nomadically through the area in response to changes in vegetation associated with drought, past herbivory, and fire (Bragg and Steuter 1996). The interval between grazing episodes may have ranged from 1 to 8 years (Malainey and Sherriff 1996), but the impacts of these herds on the vegetation, soils, and riparian areas were probably extensive. Also, the mixed and short-grass prairies comprising the West-Central Semiarid Prairies may have supported the highest densities of black-tailed prairie dogs (*Cynomys ludovicianus*) in the prairie ecoregions (Knopf 1996). Rocky Mountain locusts (*Melanoplus spretus*), which became functionally extinct by 1900, often erupted in swarms numbering in the billions and their impact on vegetation was presumed to be extensive (Lockwood and DeBrey 1990).

Climate extremes also played an important role in structuring the composition of plant communities in this ecoregion, and resulted in temporal changes in the dominant graminoid species (e.g., shifts from western wheatgrass [*Pascopyrum smithii*] to blue grama [*Bouteloua gracilis*]; Bragg and Steuter 1996). Large fires often occurred, but fire regimes were probably highly variable depending on rainfall and subsequent grass growth (Bukowski and Baker 2013; Umbanhowar 1996). Because fire temporarily removed much of the above-ground vegetation, continual shifts in the abundance and distribution of herbivores across large areas occurred with the direction and extent of vegetation response mediated by drought and grazing by bison and/or locusts (Umbanhowar 1996).

Euro-American settlement had profound impacts on the West-Central Semiarid Prairies. Prior to settlement, fire coupled with herbivory was an integral component of natural landscape dynamics and likely limited expansion of shrub communities, including sagebrush. Following Euro-American settlement, land use and development resulted in changes in vegetation patterns on the landscape. The extent and distribution of fires was reduced and shrub abundance likely increased (Umbanhowar 1996). Although numerous fires burned in this ecoregion in the past 15 years (fig. 7), most large fires were within conifer dominated areas and outside of GRSG Priority Areas for Conservation (PACs) (Marco Perea, BLM, personal communication).

After Euro-American settlement, managed domestic livestock (mostly cattle) largely replaced the native herbivores and their effects on grassland habitats are different in both scale and duration (Umbanhowar 1996). A high proportion of the area was converted from native prairie to cropland (tilled agriculture). Much of this development occurred on sites with more productive (resilient) soils and temperature regimes. However, a number of homesteads were filed on lands not suitable for non-irrigated agricultural development. Following the severe drought ("dust bowl") years of the 1930s, portions of the area were reacquired by the Federal government under The Bankhead Jones Farm Tenant Act (Public Law 75-210, 1937, as amended). The Bankhead Jones Act included provisions for developing a land conservation and utilization program, through purchase of land considered submarginal for cropland, and using this land for purposes to which it was better suited (Maddox 1937). Under management of USDA, conservation measures were taken to restore water and soil resources that included planting nonnative grass species. Several introduced seeded species became widely naturalized including crested wheatgrass (*A. cristatum*) (Lesica and Deluca 1996). More recently, other introduced seeded species such as sweet clover (*Melilotus officinalis*), Kentucky bluegrass (*P. pratensis*), smooth brome (*B. inermis*), and timothy (*Phleum pratense*), as well as nonnative invasive plants such as annual bromes and leafy spurge (*Euphorbia esula*), have altered native communities. Climate change and land use and development in the ecoregion may further exacerbate effects of these species on sagebrush communities.

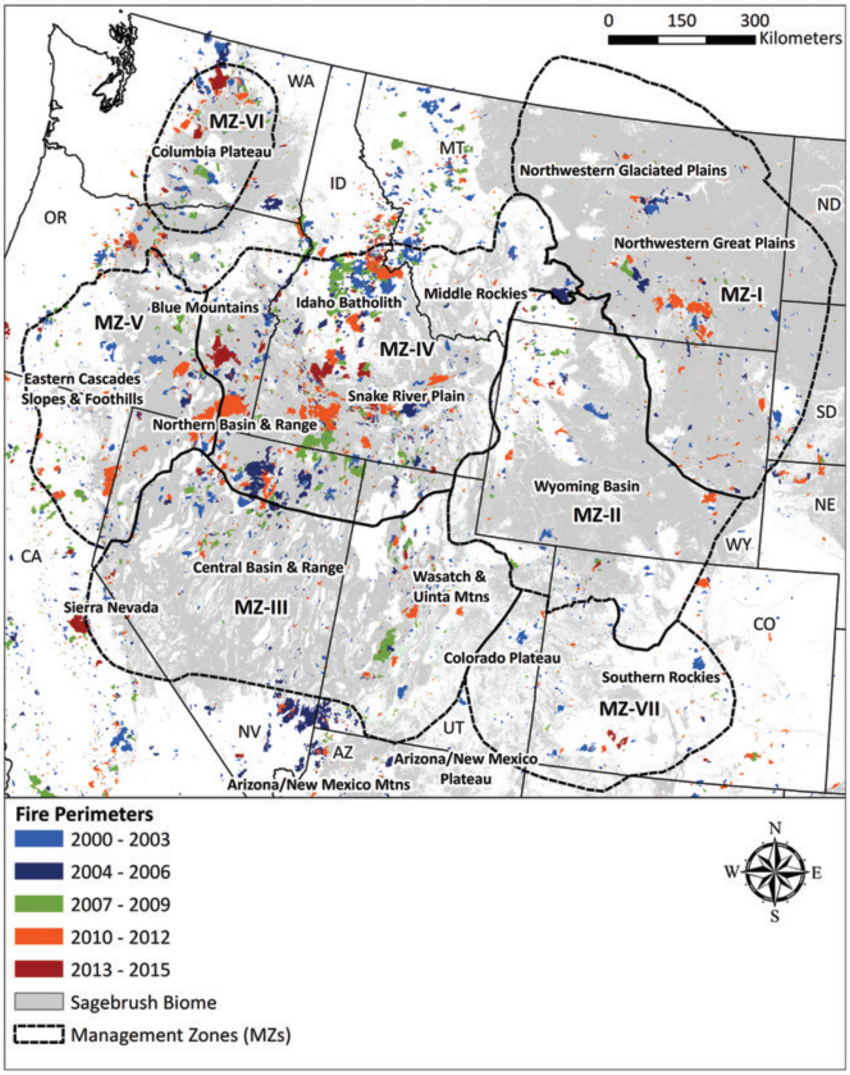


Figure 7—Perimeters of fires that have occurred since 2000. Data for fires larger than 1,000 acres are from MTBS (2014) and data for fires smaller than 1,000 acres are from GeoMAC (2015).

5.1.2 Threats to the Cold Deserts and Western Cordillera Ecoregions (MZs II to VII)

Euro-American arrival in the mid-1800s initiated a series of changes in vegetation composition and structure in the Cold Deserts that had cumulative effects on sagebrush habitats. Native American land use practices, including burning, were curtailed and new land uses and management activities were introduced such as livestock grazing, sagebrush removal, mining and road building, and fire suppression (Morris and Rowe 2014; Romme et al. 2009).

Improper grazing by livestock led to a decrease in native perennial grasses and forbs across much of the area (Miller and Eddleman 2001; Miller et al. 2011a). Decreased competition from perennial herbaceous species coupled with fire suppression resulted in increases in shrub abundance (primarily *Artemisia* species) in many areas (Miller and Eddleman 2001). These factors as well as favorable conditions for juniper and piñon pine establishment at the beginning of the twentieth century also resulted in increases in juniper and piñon pine at mid-elevations (Baker 2011; Miller et al. 2008, 2011a, 2013; Romme et al. 2009).

Invasive annual grasses (e.g., cheatgrass and field brome) were introduced from Eurasia in the late 1800s and spread into low- to mid-elevation ecosystems that had depleted understories due to improper grazing or were disturbed by anthropogenic development (Knapp 1996; Knight et al. 2014; Mealor et al. 2013; Pyke et al. 2016). The invasive annual grasses increased the amount and continuity of fine fuels in lower elevation sagebrush habitats and initiated annual grass/fire cycles characterized by shortened fire return intervals and larger, more contiguous fires (fig. 8; Brooks et al. 2004; D'Antonio and Vitousek 1992). A reduction in fire-free intervals prevented establishment and persistence of fire intolerant species like sagebrush in many of these lower elevation habitats (Miller et al. 2013).

Annual grass/fire cycles are most problematic in the western part of the sagebrush biome (Brooks et al. 2015). Cheatgrass and other invasive annuals now dominate at least 6 percent (650,000 km^2) of the central Great Basin (Balch et al. 2013) and have the potential to spread across many of the remaining low- to mid-elevation sagebrush ecosystems in the western part of the sagebrush biome. For example, Suring et al. (2005b) determined that approximately 58 percent of the combined sagebrush cover types in the Great Basin were at moderate to high risk of displacement by cheatgrass.

In the eastern part of the sagebrush biome, conversion to invasive annual grasses is a rapidly emerging problem (Baker 2011; Brooks et al. 2015; Mealor et al. 2012). These grasses increase with wildfire in both the Wyoming Basin (Knight et al. 2014) and Colorado Plateau, particularly in the eastern portion (Floyd et al. 2006; Shinneman and Baker 2009a). On sites with oil and gas drilling and mining

Figure 8—(A) A wildfire that burned through a Wyoming big sagebrush ecosystem with an invasive annual grass understory in southern Idaho (photo by Douglas J. Shinneman). (B) A wildfire that started in invasive annual grass adjacent to a railroad track and burned upslope into a mountain big sagebrush and Jeffrey pine ecosystem in northeast Nevada. (C) A big sagebrush ecosystem that has converted to invasive annual grass in north central Nevada (photos B and C by Nolan E. Preece).

disturbances, invasive annual grasses and a host of other annual invaders typically increase at the expense of native species diversity and cover (fig. 9; Allen and Knight 1984; Bergquist et al. 2007). Also, vegetation management treatments designed to reduce Wyoming big sagebrush density and increase understory grasses and forbs often result in increases in invasive annuals grasses if these species are already present (Beck et al. 2012; Chambers et al. 2014c) and slow recovery of sagebrush canopy cover (Hess and Beck 2012a).

Localized expansion of juniper and piñon pine trees into sagebrush types at mid to high elevations is reducing the grass, forb, and shrub species associated with these types (figs. 10, 11; Miller et al. 2008, 2011, 2013; Romme et al. 2009). Over the past 150 years, juniper and piñon have exhibited range expansions and stand infilling due to factors such as favorable climate periods for tree establishment, increases in atmospheric CO_2, fire suppression, and livestock grazing (Miller et al. 2011a; Miller et al. 2013; Romme et al. 2009). Also, in areas where Euro-American settlers heavily used juniper and piñon for mining, home structures, fuel, and fencing, natural regeneration has occurred (Miller et al. 2013; Morris and Rowe 2014). Ongoing infill of trees is increasing woody fuels, but is also reducing fine fuels (grasses and

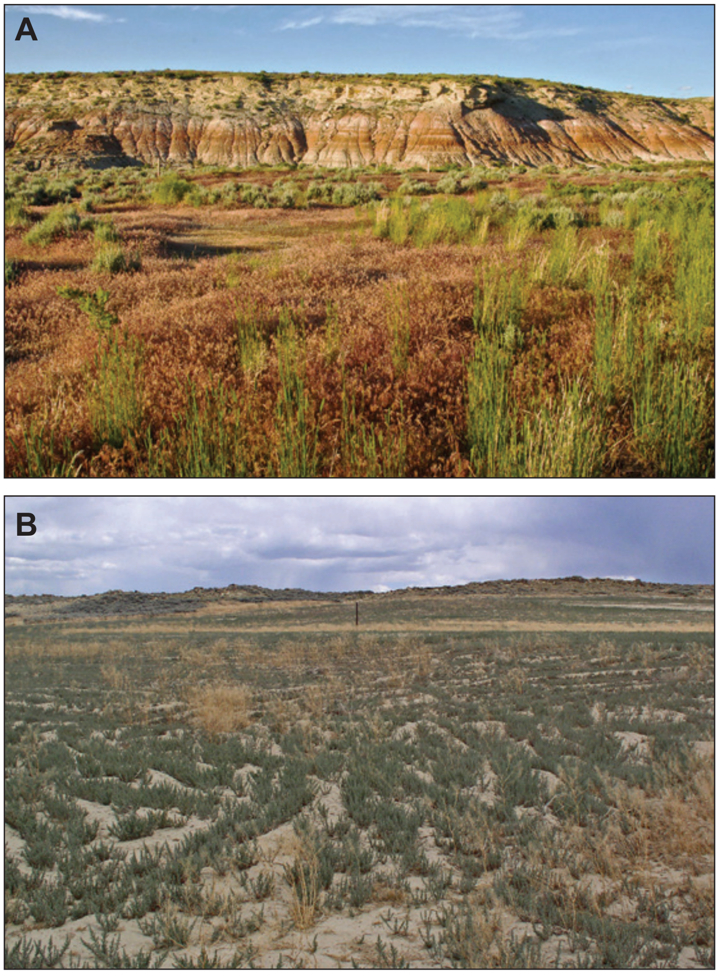


Figure 9—Annual invasive species established on disturbed sites in Wyoming: (A) cheatgrass (*Bromus tectorum*) and (B) saltlover (*Halogeton glomeratatus*) (photos by Kenneth F. Henke).

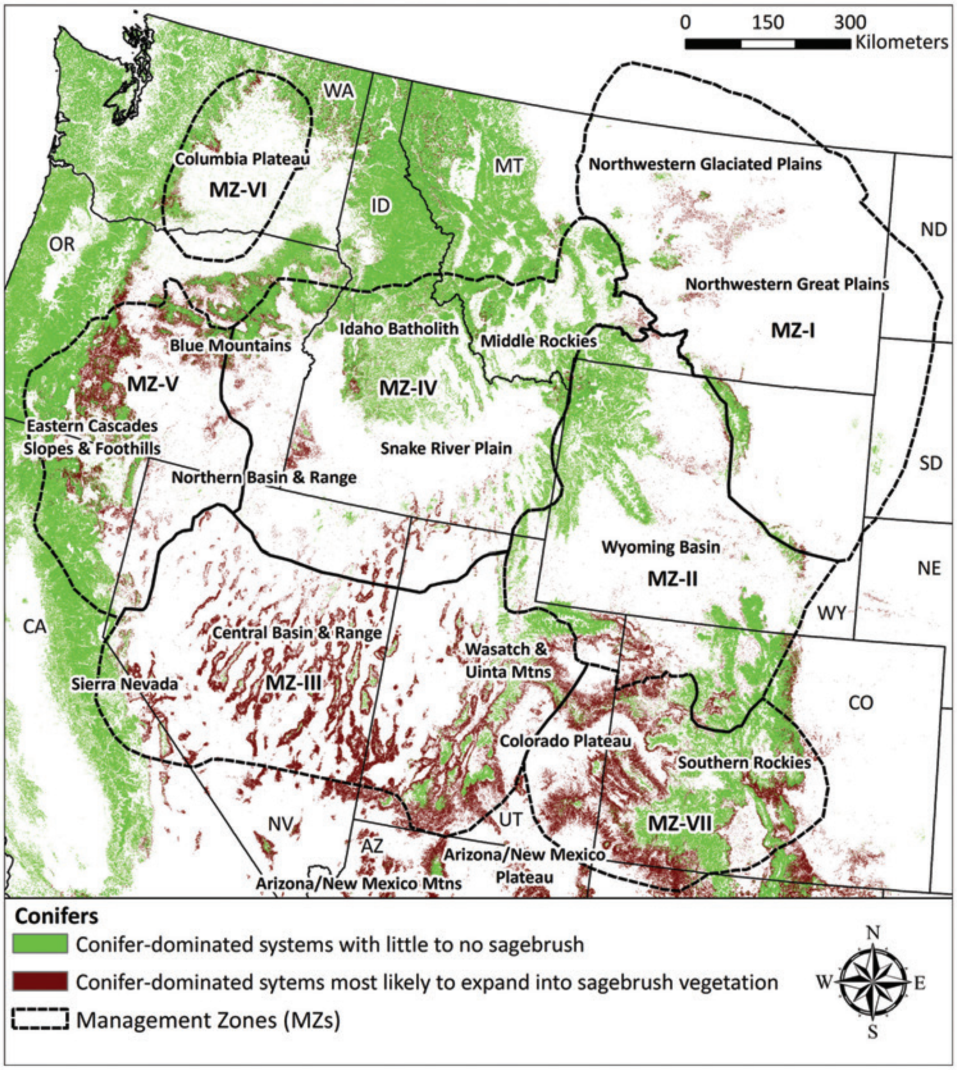


Figure 10—Landscape cover of conifer-dominated ecological systems (USGS 2014). Conifer-dominated systems with little or no sagebrush are differentiated from those with the potential to expand into sagebrush-dominated systems (IGSDMS 2014).

forbs), and resulting in less frequent fires in many mid- to high-elevation sagebrush communities (Miller et al. 2013). Extreme burning conditions (high winds, high temperatures, and low relative humidity) in high density (Phase III) stands are resulting in large and severe fires that result in significant losses of above- and below-ground organic matter (sensu Keeley 2009) and may have detrimental ecosystem effects (fig. 12; Miller et al. 2013). Based on tree-ring analyses at sites in the Northern Basin and Range, Snake River Plain and Central Basin and Range, it is estimated that the extent of juniper and/or piñon woodland increased two- to six-fold since Anglo-American settlement (Miller et al. 2008). Areas with substantial increases may exhibit canopy closure within the next 50 years (Miller et al. 2008). In the eastern part of the biome, juniper and piñon expansion is a more localized issue. For example, infill of persistent woodlands and wooded shrublands and expansion of juniper and piñon into shrublands have been documented for portions of the Uncompahgre Plateau and Mesa Verde in southwestern Colorado (Eisenhart 2004; Floyd et al. 2004, 2006; Shinneman and Baker 2009b).

Figure 11—(A) Expansion of Utah juniper trees into a mountain big sagebrush ecosystem in east central Utah. (B) Progressive infilling of the trees is resulting in exclusion of native understory species such as sagebrush (photos by Bruce A. Roundy).

Warmer temperatures may be increasing the risk of invasive annual grasses and wildfire in both the western and eastern part of the biome (fig. 7; Bradley et al. 2016; Brooks et al. 2015; Littell et al. 2009). Shorter fire rotations caused by interactions with cheatgrass and other fire prone invasives in portions of the Colorado Plateau are leading to a net decline of juniper and piñon cover compared to their historical extent (Arendt and Baker 2013). For example, in southwestern Colorado in Mesa Verde National Park, a greater proportion of the juniper and piñon woodland burned in the decade between 1995 and 2005 than had burned throughout the previous 200 years (Floyd et al. 2006). Those stands that had sparse understories prior to burning are now dominated largely by cheatgrass and other annual invaders (Floyd et al. 2006). Also, severe drought-induced dieback has resulted in up to 90 percent mortality of piñon in portions of the Southwest (e.g., Breshears et al. 2005), perhaps reversing expansion trends in some areas.

Figure 12—A postburn, Phase III, singleleaf piñon and Utah juniper dominated sagebrush ecosystem. The bare soils are highly erosive and few understory plants remain (photo by Jeanne C. Chambers).

5.1.3 Effects of Persistent Ecosystem Threats on Greater Sage-Grouse

The COT Report (FWS 2013) provides a ranking of threats to sagebrush habitats and GRSG for each Management Zone by GRSG population that helps illustrate differences across the sagebrush biome in persistent ecosystem threats and identify management priorities and strategies. In general, persistent ecosystem threats are ranked more highly in the western than the eastern part of the range, and fire, weeds, and invasive annual grasses are ranked more highly than conifer expansion. In the eastern part of the range (MZs I, II, VII), which includes15 GRSG populations, persistent and widespread threats are altered fire regimes in 9 populations, weeds and annual grasses in 10 populations, and conifers in 5 populations. In the western part of the range (MZs III, IV, V, VI), which includes 29 GRSG populations, persistent and widespread threats are fire in 23 populations, weeds and annual grasses in 26 populations, and conifers in 16 populations.

Doherty et al. (2016) developed a model that provides additional information on both the environmental factors and threats affecting GRSG breeding habitat. The model evaluates GRSG breeding habitat probabilities within a 4 mile (6.4 km) radius of leks, which is where most nests occur (Coates et al. 2013; Doherty et al. 2010; Holloran and Anderson 2005). It is based on a multivariate analysis that couples vegetation (i.e., land cover), climate, landform, and disturbance data with densities of male GRSG attending leks from 2010 to 2014. Variables showing the highest importance for predicting breeding habitat within Management Zones are: cover of all sagebrush species (positively associated; MZs II, III, V, and VII), tree canopy cover (negatively associated; MZs I and IV), and elevation (positive quadratic relationship; MZ VI) (Doherty et al. 2016; table 5). Landscape cover of sagebrush is an important predictor variable in all Management Zones; other common predictors are annual drought index (negative quadratic relationship), low sagebrush (positive relationship), and degree days greater than 5 °C (positive quadratic relationship) (table 5). These results clearly illustrate the importance of sagebrush cover and other environmental variables in predicting distribution of GRSG breeding habitats.

Table 5—Top predictor variables and relative importance values from Random Forest models for GRSG (2010–2014) in each management zone from Doherty et al. (2016).

Management zone	1st Variable	2nd Variable	3rd Variable	4th Variable	5th Variable
I	Conifer cover (–)	All sagebrush (+)	Roughness (negative quadratic)	Topographic wetness (positive quadratic)	Gross primary production (positive quadratic)
Importance	1.00	0.63	0.57	0.55	0.45
II	All sagebrush (+)	Conifer cover (–)	Annual drought index (negative quadratic)	Degree days >5 °C (positive quadratic)	Mean annual precipitation (positive quadratic)
Importance	1.00	0.73	0.68	0.59	0.49
III	All Sagebrush (+)	Degree Days >5 °C (positive quadratic)	Elevation (positive quadratic)	Annual Drought Index (negative quadratic)	Conifer Cover (–)
Importance	1.00	0.79	0.70	0.54	0.48
IV	Conifer cover (–)	Annual drought index (negative quadratic)	All sagebrush (+)	Degree days >5 °C (positive quadratic)	Gross primary production (positive quadratic)
Importance	1.00	0.60	0.59	0.51	0.50
V	All sagebrush (+)	Annual drought index (negative quadratic)	Low sagebrush (+)	Mean annual precipitation (positive quadratic)	Degree days >5 °C (positive quadratic)
Importance	1.00	0.96	0.91	0.79	0.65
VI	Elevation (positive quadratic)	Degree Days >5 °C (positive quadratic)	Grassland/ Herbaceous (+)	Annual Drought Index (negative quadratic)	All Sagebrush (+)
Importance	1.00	0.42	0.41	0.27	0.22
VII (GRSG)	All sagebrush (+)	Low sagebrush (+)	Human disturbance index (–)	Oil and gas wells (–)	
Importance	1.00	0.67	0.48	0.4	

Reductions in sagebrush cover due to persistent ecosystem threats, uncharacteristic wildfires, invasive annual grasses, and conifer expansion, are affecting the ability of land managers to achieve the range-wide goal of stable-to-increasing population trends. Sage-grouse are true sagebrush obligate species that require large and intact sagebrush landscapes and that respond negatively when wildfires occur at the extremes of the natural range of variability and remove sagebrush over large areas (Coates et al. 2016c; Knick and Connelly 2011). For example, Coates et al. (2016c) found that wildfire has long-lasting adverse effects and negates increases in sage-grouse population growth that typically occur after years of higher precipitation. Reduction of sagebrush cover is most critical in low- to mid-elevations with moderate to low resilience and resistance where natural recovery of sagebrush can be very limited within timeframes important to GRSG population dynamics (Davies et al. 2011).

Nonnative annual grasses and forbs have invaded large areas of the sagebrush biome, reducing both habitat quantity and quality (Balch et al. 2013; Miller et al. 2011a; Rowland et al. 2006). Due to repeated fires in the western part of the range, some low- to mid-elevation native sagebrush communities are shifting to novel annual grassland states resulting in habitat loss that may be irreversible with current ecological understanding and technical ability (Chambers et al. 2014a; Davies et al. 2011; Miller et al. 2011a). Studies in the western Cold Deserts ecoregions indicate that the presence of nonnative annual grasslands on the landscape may be influencing GRSG distribution and abundance. Recent models indicate that the negative impacts of wildfire on sage-grouse population numbers are largely a function of slow or no postfire recovery of burned areas near leks and increasing abundance of invasive annual grasses (Coates et al. 2016c). In an analysis of active leks, Knick et al. (2013) found that most active leks had very little annual grassland cover (2.2%) within a 3.1-mile (5 km) radius of the leks; leks that were no longer used had almost five times as much nonnative annual grassland cover as active leks. Johnson et al. (2011) found that lek use became progressively less as the cover of invasive annual species increased at both the 3.1-mile (5 km) and 11.2-mile (18 km) scales. Also, few active leks had more than 8 percent invasive annual vegetation cover within both buffer distances.

Patterns of nest site selection also suggest local impacts of invasive annual grasses on birds. In western Nevada, Lockyer et al. (2015) found that GRSG selected large expanses of sagebrush-dominated areas and, within those areas, GRSG selected microsites with higher shrub canopy cover and lower cheatgrass cover. Average cheatgrass cover at selected locations was 7.1 percent compared to 13.3 percent at available locations. Sage-grouse females essentially avoided nesting in areas with higher cheatgrass cover. Kirol et al. (2012) also found nest site selection was negatively correlated with the presence of cheatgrass in south-central Wyoming.

Sage-grouse population demographic studies in northern Nevada show that recruitment and annual survival also are affected by the presence of annual grasslands at larger scales. Blomberg et al. (2012) analyzed land cover within a 3.1-mile (5 km) radius of leks and found that leks impacted by annual grasslands experienced lower recruitment than non-impacted leks, even following years of high precipitation. Leks that were not affected by invasive annual grasslands exhibited recruitment rates nearly twice as high as the population average and nearly six times greater than affected leks during years of high precipitation.

Piñon and juniper expansion at mid- to upper-elevations into sagebrush ecosystems also has altered fire regimes and reduced GRSG habitat availability and suitability over large areas with population-level consequences (Baruch-Mordo et al. 2013; Knick et al. 2013; Miller et al. 2011a). Conifer expansion results in nonlinear declines in sagebrush cover and reductions in perennial native grasses and forbs as conifer canopy cover increases (Miller et al. 2000), and this has direct effects on the amount of available habitat for sagebrush obligate species. Sites in the late stage of juniper and piñon expansion and infill (Phase III from Miller et al. 2005) have reduced fire frequency (due to decreased fine fuels), but are prone to higher severity fires (due to increased woody fuels), which significantly reduces the likelihood of sagebrush habitat recovery (figs. 11, 12; Bates et al. 2013). Even before direct habitat loss occurs, GRSG avoid or are negatively associated with conifer cover during all life stages (i.e., nesting, brood-rearing, and wintering) in both the western and eastern portions of the range (Atamian et al. 2010; Casazza et al. 2011; Dinkins et al. 2014b; Doherty et al. 2008, 2010; Fedy et al. 2014; Walker et al. 2016; Severson et al. 2016).

Population-level impacts are incurred with low amounts of conifer present. No leks remained active when conifer canopy exceeded 4 percent in the immediate vicinity (within 1,000 m) of the lek in an Oregon study (Baruch-Mordo et al. 2013). Also, most active leks averaged less than 1 percent conifer cover at landscape scales in the western part of the range (5 km; Knick et al. 2013). Sage-grouse movement across conifer-expansion areas may be more rapid than across areas without conifer-expansion resulting in lower survival (Prochazka et al. 2017). Also, more productive sites at higher elevations that provide desirable food sources but are exhibiting early phase woodland expansion (>2% conifer cover) may function as ecological traps, likely due to increased predation from raptors (Coates et al. 2017).

Targeted conifer removal can effectively increase habitat availability for nesting and brooding sage-grouse (Sandford et al. 2017; Severson et al. 2017) and can have positive effects on other ecosystem attributes like perennial grass and forb cover (Miller et al. 2017). Consequently, conifer removal is increasingly used to help restore sagebrush habitats (Miller et al. 2017). Since 2010, the Natural Resources Conservation Service (NRCS), through its Sage Grouse Initiative, has worked with private landowners and partners to implement 457,145 acres (185,000 ha) of conifer removal focused in-and-around sage-grouse strongholds (www.sagegrouseinitiative.com). Similar projects have been implemented range-wide on BLM and USFS administered lands. In Utah alone, conifers have been removed from over 494,211 acres (200,000 ha) of sagebrush landscapes since 2006 by Federal, State, and local partners through the Utah Watershed Restoration Initiative (UDNR 2014). Information on the effects of conifer removal on species other than GRSG that use juniper and piñon habitat has been identified as a science need in the Actionable Science Plan (ASPT 2016).

5.2 Persistent Ecosystem Threats: Climate Change

5.2.1 Recent Climate Trends in the Sagebrush Biome

In the last few decades, temperatures have increased across the sagebrush biome, but precipitation has been highly variable (Kunkel et al. 2013a,b). In the Western Great Plains as a whole, the largest increases in average temperatures occurred during the winter months and the number of frost-free days increased (Kunkel et al. 2013a). There were no significant trends in precipitation, but there was a significant upward trend in extreme precipitation events over the last 100 years. In the Southwest part of the sagebrush biome, annual temperature generally increased over the past 115 years and in the southern portion of the area the recent 10 year averages surpassed any previous decadal value (Kunkel et al. 2013b). Nighttime temperatures showed the greatest increase and the recent period of elevated temperatures was most prominent in spring and summer. The frost-free season length increased by about 2 weeks relative to the 1960s and 1970s and by a month relative to the early 1900s. Recent precipitation was highly variable and showed no long-term trend. In the 20th century, two prolonged dry periods occurred. A drought near the turn of the century followed the wet periods of the 1980s and 1990s and set up conditions for record-setting wildfires in several Southwest States. In the Pacific Northwest part of the biome, all but 2 years since 1986 had above average temperatures (relative to 1901−1960), and the frost-free days increased by 11 days in 1991−2010 (relative to

1961−1990) (Kunkel et al. 2013c). Precipitation variability since 1976 has increased with most recent years below the 1901−1960 annual mean.

5.2.2 Climate Change Projections for the Sagebrush Biome

Climate change projections are being used to explore the risk of future changes in temperature and precipitation patterns. Future scenarios of likely carbon dioxide (CO_2) and other trace gases emissions, along with information on the earth's surfaces and oceans, are used as input to climate models (IPCC 2014). To develop climate projections for the sagebrush biome, two scenarios were chosen. One scenario, representative concentration pathway (RCP) 4.5, assumes moderate warming. The second scenario, RCP 8.5, assumes high warming of the earth's atmosphere. Climate was projected for each of these scenarios from eleven general circulation models (GCMs) from the most recent Intergovernmental Panel on Climate Change (IPCC) report (IPCC 2014) for two future time periods: near-term (2020−2050) and longer-term (2070−2100) (Appendix 3). These projections of future climate were compared to the climate of the recent past (1980−2010) to forecast climate change for the sagebrush biome. To examine differences across the sagebrush biome, climate projections were evaluated for the biome as a whole and for different groupings of ecoregions with similar climate and topography.

Across the sagebrush biome, average temperatures were projected to increase by about 1.8 to 5.4 °F (1 to 3 °C; ensemble minimum and maximum, respectively) in the near-term (2020−2050) compared to 1980−2010 under RCP 4.5 and RCP 8.5 (Appendix 3). Variability in these near-term temperature changes was primarily a result of different climate models rather than different assumptions about emissions of greenhouse gases. Longer-term (2070−2100) forecasts of average temperature change showed the magnitude of change associated with different assumptions about future emissions. In the moderate warming scenario (RCP 4.5) temperatures increased about 3.6 to 9 °F (2 to 5 °C), whereas under the higher warming scenario (RCP 8.5), temperatures increased about 5.4 to 12.6 °F (3 to 7 °C) (fig. 13). Temperature increases were projected to be slightly greater in the summer than other seasons; winter, spring, and summer increases for the mean ensemble for 2070−2100 under RCP 8.5 were projected to be approximately 9, 8.5, and 10.8 °F (5, 4.7, and 6 °C), respectively.

Precipitation was projected to increase slightly across most of the sagebrush biome (Appendix 3). However, precipitation is more difficult for climate models to simulate accurately than temperature. In the near term (2020−2050) biome-wide precipitation change varied from a small decrease (<10%) for the ensemble minimum, to an increase of roughly 20 percent for the ensemble maximum. Longer-term (2070−2100) projections showed biome-wide precipitation changes ranging from a 10 percent decrease (about 1.0 in yr^{-1} [25 mm yr^{-1}]) to increases of almost 50 percent (about 5.9 in yr^{-1} [150 mm yr^{-1}]) in RCP 8.5 (fig. 13). The variation in all precipitation projections was high and the differences in the RCP scenarios were not observable. Seasonal precipitation projections for 2070 under RCP 8.5 (ensemble mean) suggest 20 to 40 percent increases in winter (except for the southern edge), 0 to 20 percent decreases in spring (except for the northeast and north central part of the region, where 10 to 20 percent increases are projected), and 0 to 100 percent increases during summer, with the greatest increase in the Sierra Nevada and Central Basin and Range ecoregions.

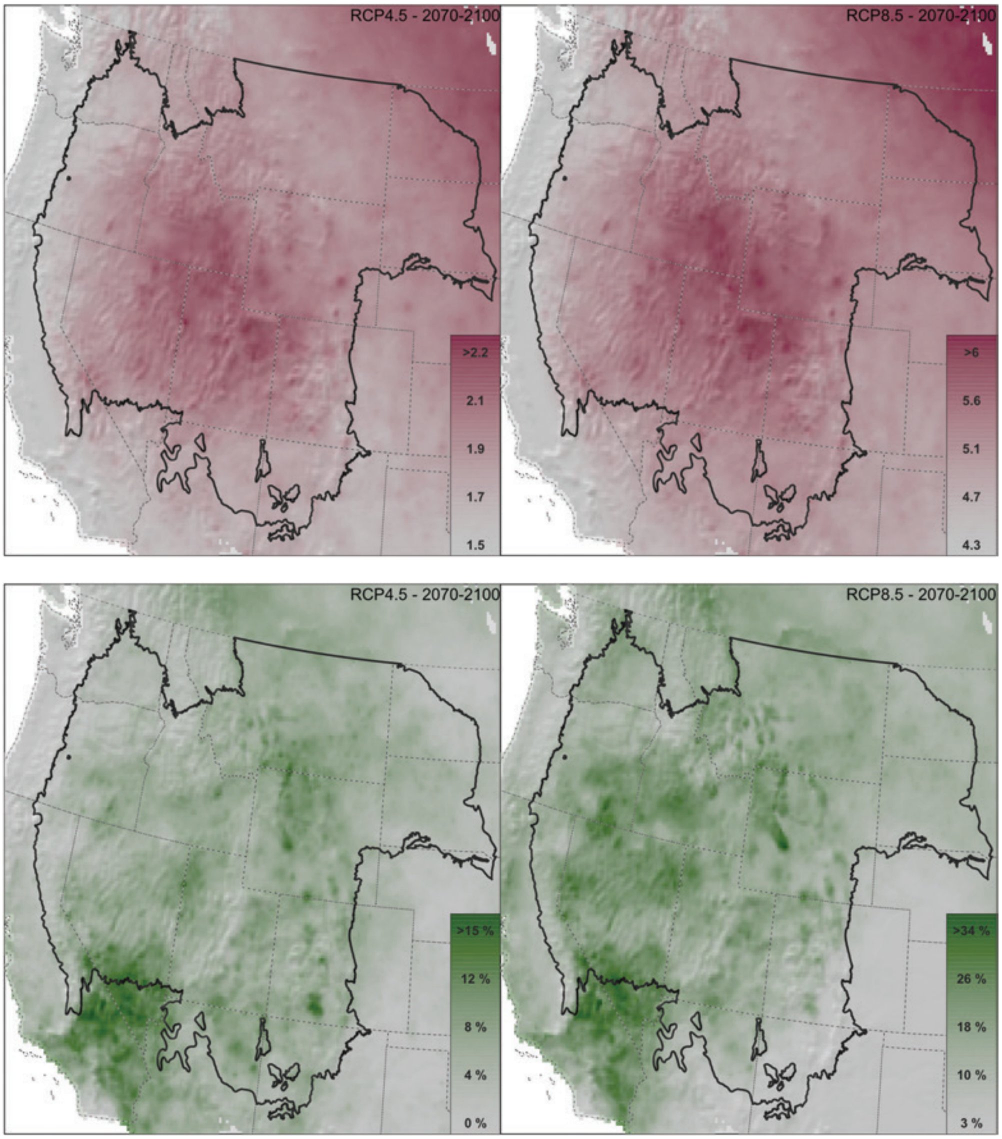


Figure 13— Projected changes in mean annual precipitation and mean annual temperature for 2070–2100 over the distribution of big sagebrush ecosystems. Changes are presented on a 10 km by 10 km cell and show the value from the median climate model within each cell (from a set of 11 models examined). Top panels show temperature change in degrees C and bottom panels show precipitation change in percent of current precipitation for RCP 4.5 on the left and RCP8.5 on the right.

Generally, the scientific community has more confidence in temperature projections, than precipitation projections. These changes in temperature, even if precipitation does not change, can influence water cycling and alter the timing and depth of soil water available to plants. If slightly wetter winters promote greater moisture availability during winter and early spring, higher winter and spring temperatures coupled with longer and drier warm seasons indicate that soils are likely to dry out earlier in the year, further stressing these ecosystems (Palmquist et al. 2016a).

5.2.3 Geographic Patterns in Forecasted Change

Spatial patterns in temperature change suggested that the greatest increases will occur in the center of the range and the far northeastern edge, where temperatures were projected to rise more than 10.8 °F (6 °C) in the high warming scenario (RCP 8.5) by the end of the century (fig. 13). Temperature increases were forecast to be most pronounced in the Wyoming Basin, Idaho Batholith, and Middle Rockies ecoregions (see Appendix 3 for ecoregional differences). Temperature increases in winter were projected to be especially large in the northeastern part of sagebrush range, specifically the Northwestern Glaciated Plains and Northwestern Great Plains ecoregions, where average winter (December−February) temperature were projected to increase by almost 0.9 °F (0.5 °C) by the end of the century. By contrast, temperature increases in spring were projected to be greatest in the central and southern areas, particularly the Wasatch and Uinta Mountains, Wyoming Basin, and Colorado and Arizona-New Mexico Plateau ecoregions. Average January daily minimum temperatures were projected to increase between 0.9 and 5.4 °F (0.5 and 3 °C) in the near-term, and between 5.4 and 14.4 °F (3 and 8 °C) by the end of the 21st century, with the largest increases in the central and northeastern part of the range. Average July daily maximum temperatures were anticipated to increase between 5.4 and 16.2 °F (3 to 9 °C) by the end of the 21st century, with average increases ranging between 9 and 14.4 °F (5 and 8 °C) and generally increasing from south to north.

Absolute increases in annual and winter precipitation were projected to be largest in higher elevation, cooler, and wetter areas throughout the range (fig. 13). However, spring (April−June) precipitation was projected to increase most in the northeastern part of the range, notably the Idaho Batholith, Middle Rockies, Northwestern Glaciated Plains and Northwestern Great Plains ecoregions (see Appendix 3 for ecoregional differences). Furthermore, summer precipitation (July−September) was projected to increase most in the south and western part of the region, specifically the Central Basin and Range, Sierra Nevada, and Arizona-New Mexico Plateau ecoregions. Relative change in precipitation was projected to be greatest in the Central Basin and Range, Northern Basin and Range, Snake River Plain, and Columbia Plateau ecoregions, where annual precipitation was projected to increase by about 20 percent. By contrast, the Colorado and Arizona-New Mexico Plateaus were projected to experience only a 10 percent increase in annual precipitation. Projections indicated a decreasing proportion of precipitation falling between May and October, with the greatest decreases in summer precipitation projected in the northern part of the biome.

Geographic patterns identified in projections of climate change illustrated important variations among big sagebrush ecological types and, thus, sage-grouse habitat types. In particular, the largest increases in spring soil water availability were projected to occur in the high-elevation, big sagebrush and mountain brush areas in the eastern and central portion of the sagebrush biome (Palmquist et al. 2016b). By contrast, the most dramatic decreases in summer soil moisture were projected in the west-central part of the sagebrush biome. Furthermore, days with wet soil were projected to decrease throughout the range of big sagebrush ecosystems due to temperature related increases in evapotranspiration. These decreases were projected to be especially large in the mid- to high-elevation areas in the northern portion of the biome (Palmquist et al. 2016b).

5.2.4 Implications for Species and Ecosystems

The changes in precipitation and temperature regimes described above are projected to have large consequences for species distributions, and because individual species differ in their climatic requirements, for community composition. Warmer temperatures are leading to species distribution shifts to the north and upward in elevation—a trend that has been observed for thousands of species globally (e.g., Chen et al. 2011; Parmesan and Yohe 2003; Root et al. 2003). Bioclimate envelope models for big sagebrush and other sagebrush species project large decreases in climate suitability in southern latitudes and lower elevations, but relatively small increases in northern latitudes and higher elevations (Bradley 2010; Homer et al. 2015; Schlaepfer et al. 2012; Still and Richardson 2015). For Wyoming big sagebrush, which occupies the warmest and driest portions of the species range, a 39 percent reduction (163 million ac; 66 million ha) in suitable climate is projected by mid-century (Still and Richardson 2015). Areas in these regions that retain or gain climate suitability include higher elevations in the Cold Deserts and the entirety of the Northern Great Plains. For juniper and piñon woodlands, 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).

Climate change is also projected to have significant effects on invasive annual grasses. Cheatgrass will likely spread upwards in elevation and red brome (*B. rubens*) might either expand northward, increase 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 resistant to invasion and resilient to fire disturbance (Bradley et al. 2016; Mealor et al. 2012). If average summer plant available water declines, the land area susceptible to cheatgrass invasion may increase by up to 45 percent, particularly in mountain big sagebrush steppe in Montana and higher elevation areas of the Colorado Plateau (Bradley et al. 2016). Warming temperatures and a decreasing proportion of precipitation during summer (Appendix 3) may facilitate the expansion of cheatgrass in the northern mixed-grass prairie, allowing it to more successfully colonize what is currently considered a largely invasion-resistant grassland (Blumenthal et al. 2016).

Greater climate variability likely will favor invasion of annual invasive species in many areas (Bradley 2010) and negatively affect native species persistence in areas that remain otherwise climatically suitable. Reduced soil moisture availability coupled with greater climate variability can result in reduced resilience of seasonal habitats (i.e., nesting, brood-rearing, and wintering) and thus recovery potential of native ecosystems following disturbances such as improper livestock grazing and uncharacteristic wildfire (Chambers et al. 2014a,c). In turn, decreased resilience can lower resistance of these ecosystems to invasive annual grasses like cheatgrass, red brome, and field brome (Chambers et al. 2014a,c).

Climate-driven changes are likely to combine with both persistent ecosystem and land use and development induced stresses to further increase the vulnerability of natural ecosystems to pests, disease, invasive species, and loss of native species. Changes in temperature and precipitation affect the composition and diversity of native animals and plants by altering their breeding patterns, water and food supply, and habitat availability. For GRSG, there is a positive relationship between precipitation and sage-grouse population recruitment rates (Blomberg et al. 2013) and population growth (Coates et al. 2016c). However, information is largely lacking on effects of increased temperature, more variable precipitation, and extreme weather events. In a changing climate populations of some pests, such as mosquitos that are better adapted to a warmer climate, are projected to increase resulting in an increase in diseases such as West Nile virus, which is a threat to sage-grouse (FWS 2014; Schrag et al. 2010).

5.3 Land Use and Development Threats

The effects of land use and development on ecosystem resilience are diverse, but here we focus on changes in native species composition, degradation of soils, increases in exotic annual grasses and other invasive plants, and altered fire regimes. Recent analyses and reviews of the effects of land use and development on the sagebrush biome and GRSG are available for individual ecoregions or areas of concern (BLM Rapid Ecoregional Assessments, http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html; Hanser et al. 2011, Wyoming Basins; Wisdom et al. 2000, Columbia Basin; Wisdom et al. 2005, Central Basin and Range) and for the sagebrush habitats within GRSG Management Zones (Knick et al. 2011, GRSG range). Information on threats to Management Zones and populations are in the COT Report (FWS 2013) and Doherty et al. (2016).

5.3.1 Cropland Conversion

Extensive cultivation and fragmentation of native habitats have been associated with GRSG population declines. Cropland conversion (changing native ecosystems to cropland) directly and indirectly influences up to 77 percent of the area within Management Zones (Knick et al. 2011). In the COT Report, cropland conversion was ranked a present and widespread threat on more productive soils across the range of GRSG (6 of 15 populations in the eastern range and 9 of 29 populations in the western range) (figs. 14, 15; FWS 2013). In Doherty et al.'s (2016) analysis (table 5), the amount of tilled cropland in the analysis was ranked a minor factor in predicting GRSG breeding habitat in MZ I (7th), MZ II (14th), MZ IV (13th), and MZ VI (13th). However, effects of cropland conversion may be underestimated in Doherty et al.'s (2016) analysis as many productive lands with deeper soils that supported GRSG habitat historically were among the first lands converted to cropland (Vander Haegen et al. 2000) and are no longer considered in analyses of GRSG habitat within their current range.

The West-Central Semiarid Prairies (MZ I) have the highest percentage of private lands and highest amount of tilled cropland, followed by the Snake River Plain, and Columbia Basin (Doherty et al. 2016; table 12.1 in Knick et al. 2011). Sage-grouse are known to use agricultural fields periodically, such as for strutting grounds and brood-rearing habitat, but pesticide contamination is a documented concern (Blus et al. 1989; Connelly et al. 2000). The amount and configuration of sagebrush habitat in the surrounding landscape also influences habitat use (Schroeder and Vander Haegen 2011). Several studies indicate that GRSG populations cannot persist in areas with less than 25 percent landscape cover of sagebrush (Aldridge et al. 2008; Knick et al. 2013; Wisdom et al. 2011). Sage-grouse extirpations have occurred in areas where cultivated crops exceeded 25 percent 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 MZ I (SGI 2015; Smith et al. 2016).

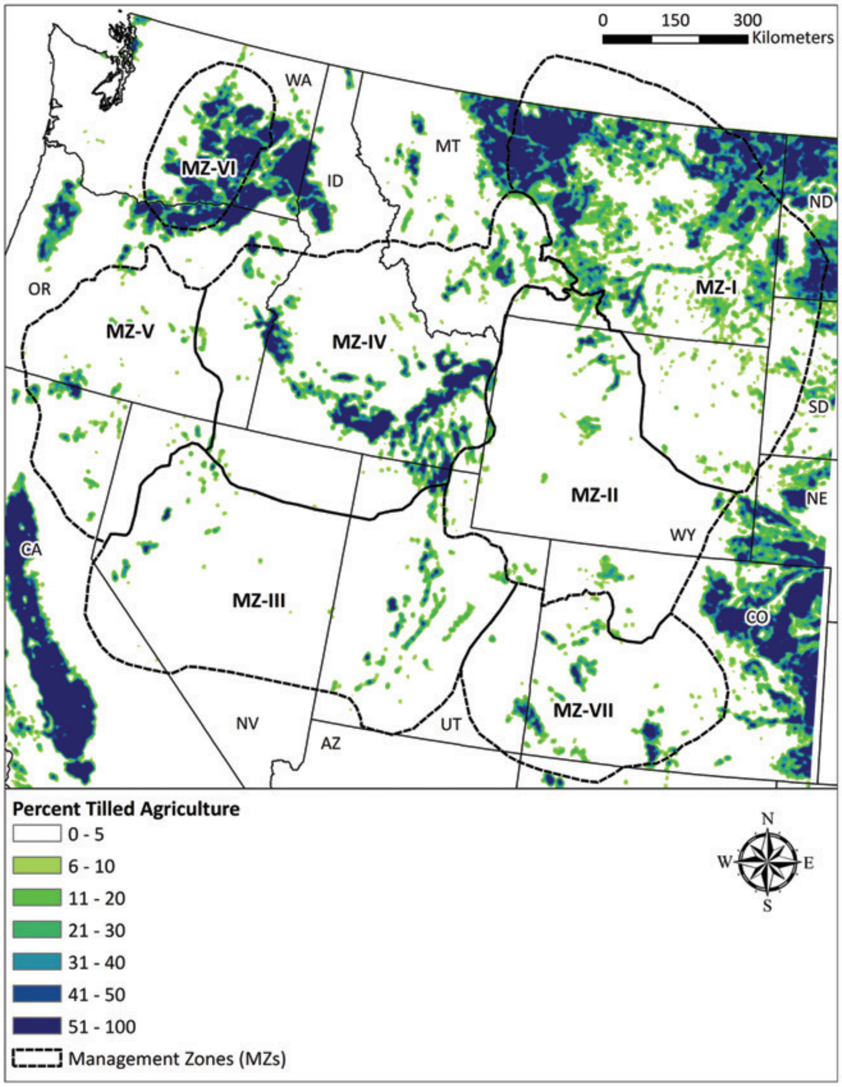


Figure 14—Percent annually tilled agricultural land (cropland; NASS 2014) within 5.0 km of each pixel. Cropland conversion is a threat on more productive soils across the range of Greater sage-grouse.

Figure 15—Conversion of a sagebrush ecosystem in the West-Central Semiarid Prairies to agricultural land (photo by John Carlson, used with permission).

5.3.2 Energy Development and Mining

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 the eastern part of the range (Management Zones I and II); more than 20 percent of the sagebrush land cover is indirectly influenced in the North-West Semiarid Prairies, Wyoming Basin, and Colorado Plateau (figs. 16, 17; table 12.16 in Knick et al. 2011). The "Wyoming Basin Ecoregional Assessment" (Hanser et al. 2011), which included south-central Montana, western and central Wyoming, north-eastern Utah, and northern Colorado indicated that oil and gas development has removed approximately 658 mi^2 (1,703 km^2) of sagebrush and other native habitats in this area since 1900 due to construction of well pads and supporting infrastructure such as roads, power lines, and pipelines (Finn and Knick 2011).

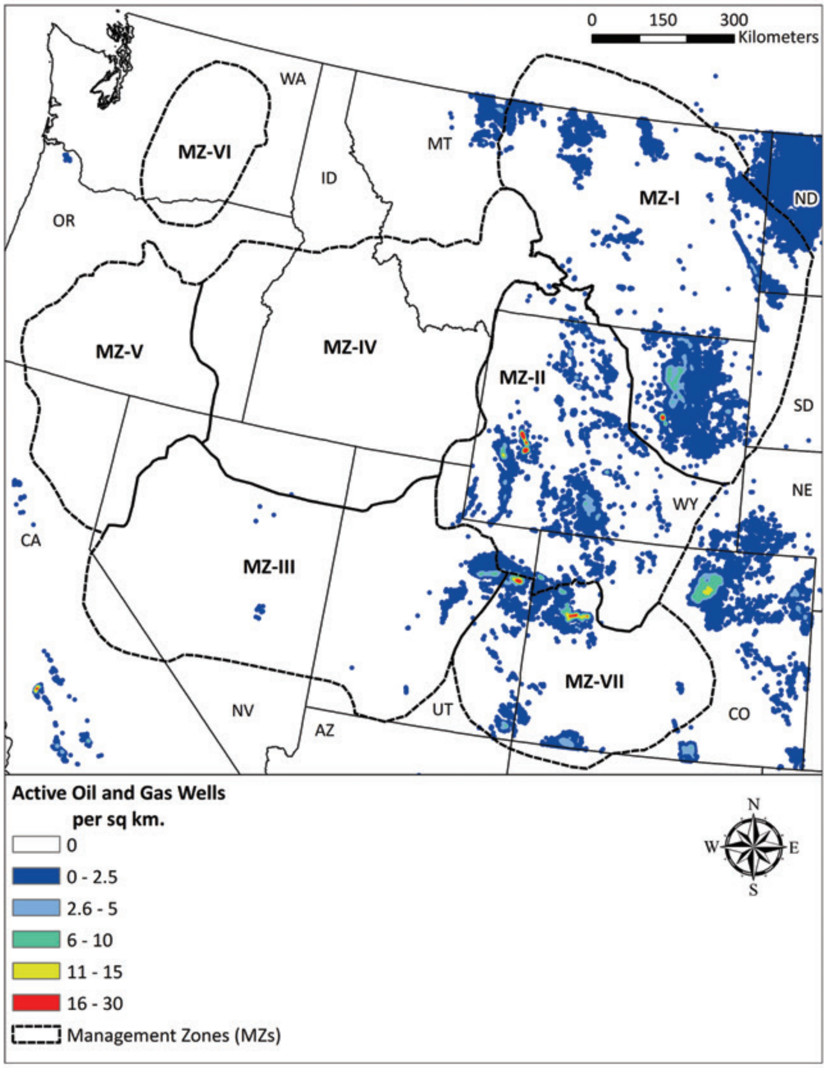


Figure 16—Number of active oil and gas wells per square kilometer. Oil and gas development is a widespread threat in the eastern portion of the range (see Appendix 8 for data source).

Figure 17—(A) Deep gas drill rig outside of Pinedale, Wyoming (photo by Thomas J. Christiansen), and (B) well pad (photo by Kenneth F. Henke).

Geothermal and especially wind energy development are rapidly increasing due to the National Energy Policy (2001), which encouraged development of alternative energy sources. The Energy Policy Act of 2005 (Public Law 109–58, Section 211) directed the Department of the Interior to approve 10,000 megawatts of non-hydro renewable electrical generation within 10 years of the date of enactment. Area leased per year on BLM managed lands for wind energy has increased since 2001, with the highest total leased areas in the Northern Great Basin, Snake River Plain, and Central Great Basin (table 12.18 in Knick et al. 2011). The COT Report identifies those populations across the range where energy development is considered a present and widespread threat (6 of 15 populations in the eastern range and 14 of 29 populations in the western range) (FWS 2013).

Summary data for the effects of mining across the sagebrush biome and range of GRSG are not readily available. However, mining is considered a persistent and widespread threat to 8 of 15 populations in the eastern range and 9 of 29 populations in the western range in the COT Report (FWS 2013). To address this threat, in September 2015, the Department of Interior published notice of the BLM and FS application to withdraw approximately 10 million acres of public and National Forest System lands in Idaho, Montana, Nevada, Oregon, Utah, and Wyoming from location and entry under the United States mining laws, subject to valid existing rights. Consideration of this proposed withdrawal, including the preparation of an environmental impact statement, is ongoing. This land withdrawal is to protect GRSG and its habitat from adverse effects of locatable mineral exploration and mining, (BLM 2015b). Processing of this proposed withdrawal, including the preparation of an environmental impact statement, is ongoing.

A number of studies indicate that energy development activities have significant effects on GRSG and can result in localized extirpations of GRSG populations (Aldridge and Boyce 2007; Duncan 2010; Gregory and Beck 2014; Harju et al. 2010; Walker et al. 2007). Infrastructure related to energy development (e.g., roads, pipelines, storage facilities, mines, wind turbines, transmission lines) decreases the effectiveness of habitat for GRSG (Braun et al. 2002; Dinkins et al. 2014a,b; Doherty et al. 2008; Holloran 2005; Kirol et al. 2015; LeBeau et al. 2014; Lyon and Anderson 2003; Smith et al. 2014). Sage-grouse females with successful nests located their nests farther from roads in oil and gas fields than unsuccessful hens (Lyon and Anderson 2003). In addition, noise from natural gas development activities has been found to lead to immediate and sustained declines in lek attendance (Blickley et al. 2012), indicating the importance of the natural soundscape (Patricelli et al. 2013). Also, transmission towers may provide perches and nesting structures for raptors and ravens and result in increased densities of these predators (Beck et al. 2006; Borell 1939; Coates et al. 2014a,b; Howe et al. 2014; Messmer et al. 2013). Proximity to distribution and transmission lines was related to lower adult female survival for GRSG, which was most likely related to increases in raptors (Dinkins et al. 2014b). Also, West Nile virus and increased abundance of mesocarnivores, both of which are associated with reservoirs created to hold water produced from energy development, can cause declines in GRSG populations (Taylor et al. 2013).

5.3.3 Urban and Exurban Development

Loss of sagebrush land cover due to urban and exurban (residential) development since Anglo-American settlement is estimated at 48.4 percent for the Columbia Basin (MZ VI), 29.2 percent for the Colorado Plateau and adjacent Rockies (MZ VII), and from 12.5 percent to 18.5 percent for the remaining ecoregions and Management Zones (figs. 18, 19; table 12.2 in Knick et al. 2011). In the COT Report, urban and exurban development was considered a present and widespread threat to 7 of 15 populations in the eastern range and 4 of 29 populations in the west (FWS 2013). The rank order of the variables in Doherty et al.'s (2016) analysis showed that human disturbance was a major factor in predicting GRSG breeding habitat in MZ VII (3rd) and a minor factor in MZ I (12th), MZ II (11th), MZ III (15th), MZ IV (14th), and MZ VI (7th). However, within the western portion of the GRSG range (MZ III, IV, and V) disturbance was an important determinate of GRSG occurrence and GRSG habitat suitability was significantly higher in areas with less than 3 percent development (Knick et al. 2013).

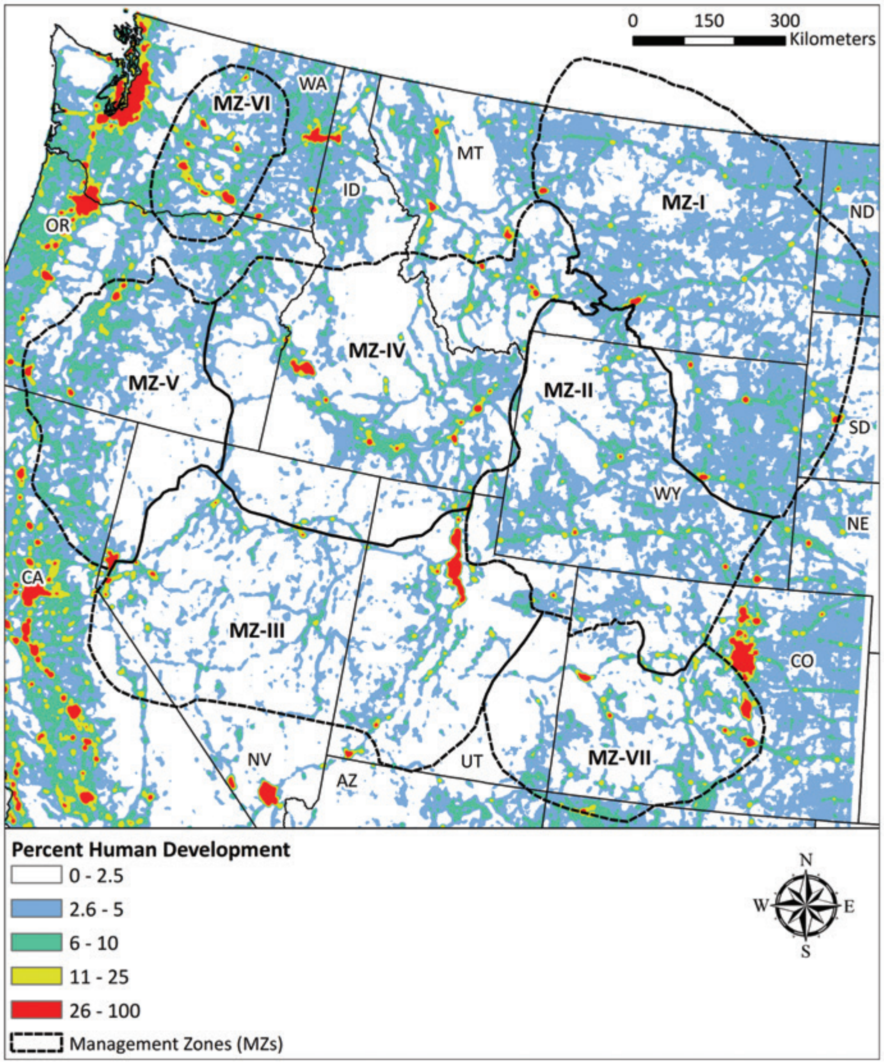


Figure 18—Percentage of developed land (NLCD 2011) within 5.0 km of each pixel. Loss of sagebrush land cover due to urban and exurban (residential) development since Anglo-American settlement has been extensive.

Figure 19—Rural subdivision in Sublette County, Wyoming (photo by Thomas J. Christiansen).

Most residential areas are on the edge of the current distribution of sagebrush and GRSG rather than within core areas, but resource use and connecting infrastructure can extend well beyond the boundaries of developed areas (figs. 19, 20; Knick et al. 2011). Low-density exurban developments support lower native species abundance, and more human-commensal bird and mammal species and invasive plants than comparable unfragmented sagebrush ecosystems (Maestas et al. 2003).

5.3.4 Recreation

Recreational activities (off-highway vehicle [OHV] use, snowmobiling, mountain biking, hiking, camping, hunting, fishing) can have both direct and indirect impacts on sagebrush ecosystems and sage-grouse. Recreational use of OHVs is one of the fastest growing outdoor activities, although the effects of OHV use on sagebrush and GRSG have not been studied (Knick et al. 2011). In the COT Report (FWS 2013) recreation is considered a present and widespread threat or a localized threat in 9 of 15 populations in the eastern range and 19 of 29 populations in the western range.

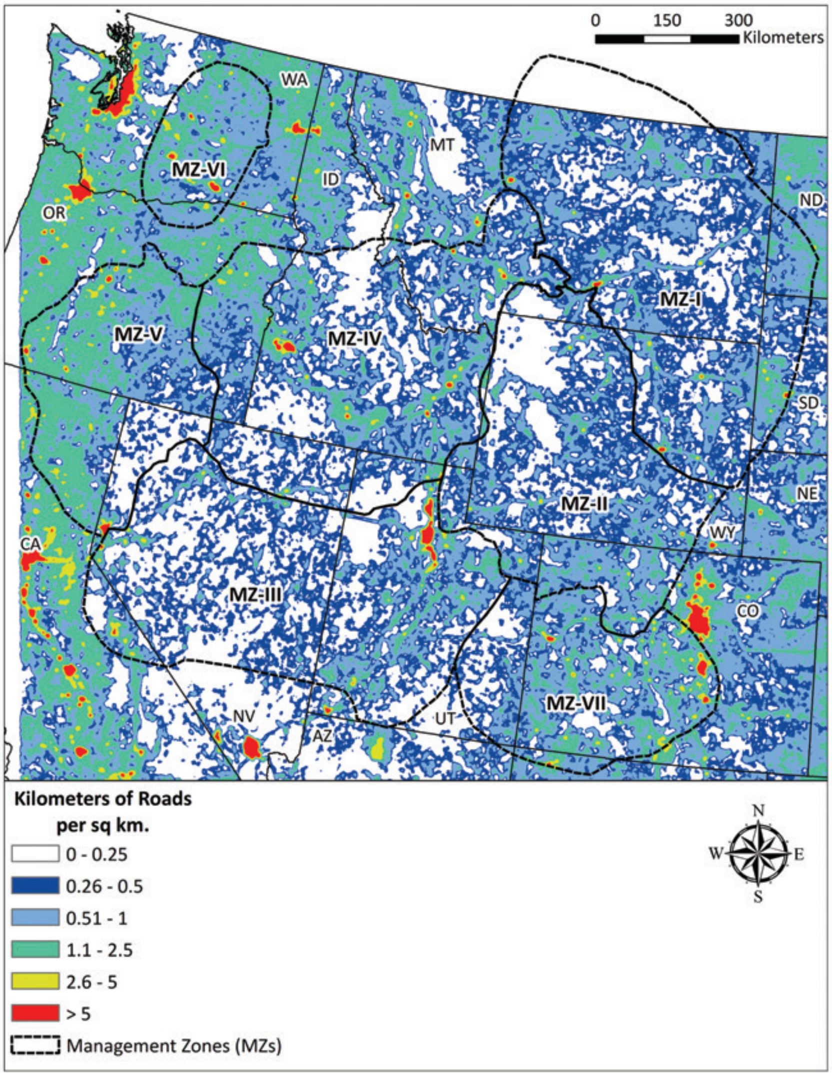


Figure 20—Density of all roads (surface roads, major roads, and interstate highways; ESRI Street Map Premium) in kilometers per square kilometer. Connecting infrastructure can extend well beyond the boundaries of developed areas.

Recreation, including hiking, hunting, fishing, and OHV use was a major cause of species endangerment in the Great Basin and a primary factor endangering 12 species in Nevada and Utah (Czech et al. 2000). Even activities perceived to have low impacts like hiking and mountain biking can affect sagebrush habitats and have negative effects on species (Gaines et al. 2003; Miller et al. 1998; Taylor and Knight 2003).

5.3.5 Infrastructure

Although interstate and major paved highways cover an estimated 0.1 percent of the land cover in the Management Zones, they influence 38 percent of the sagebrush land cover when their effect size is considered (fig. 20; table 12.3 in Knick et al. 2011; effect area of 4.3 mi [7 km]). Secondary roads, railroads, and especially power lines may have additional fragmentation effects, with the greatest overall influence on sagebrush area in the Columbia Basin, Wyoming Basins, and Colorado Plateau (table 12.3 in Knick et al. 2011; Manier et al. 2014b). The COT Report ranked infrastructure a present and widespread threat in 14 of 15 populations in the eastern range and 20 of 29 populations in the west (FWS 2013).

The connecting infrastructure of roads, motorized trails, railroads, powerlines, and communications corridors fragment or remove sagebrush cover (Knick et al. 2013; Leu and Hanser 2011). Additional ecological impacts of roads and motorized trails include: (1) increased mortality of wildlife from collisions with vehicles, (2) modification of animal behavior due to habitat changes or noise, (3) alteration of the physical and chemical environment via changes in vegetation structure, soil erosion, leaching, etc., (4) spread of nonnative invasive plants and wildlife, and (5) increased habitat alteration due to use by humans (Forman and Alexander 1998; Gelbard and Belnap 2003; Ouren et al. 2007; Trombulak and Frissel 2000).

5.3.6 Interactions Among Development and Persistent Ecosystem Threats

Removal of sagebrush vegetation as a function of development can increase soil resources such as available nitrogen and alter soil properties that can favor various invasive plant species (fig. 9; Bergquist et al. 2007; Nielson et al. 2011). When compared to sites not influenced by development activities, sites disturbed by energy development had higher species richness (numbers) of exotic than native plant species and cover of exotic species was similar to that of native species (Bergquist et al. 2007). Similar effects have been documented for croplands and populated areas (Nielson et al. 2011). Invasive plant species are also associated with development infrastructure such as roads, highways, oil and gas well pads, pipelines, and power lines (Manier et al. 2011; 2014a,b; Nielson et al. 2011). Although many invasive plant species decline at distances beyond 50 to 100 m of these structures, several species, including halogeton (*Halogeton glomeratus*) and cheatgrass, show low rates of decline in abundance with increasing distance from roads and reclaimed sites (Manier et al. 2011; Nielson et al. 2011). Once these species are established, restoration is much more difficult, especially in areas with warm or dry soil temperature and moisture regimes (Pyke 2011).

Effects of development on sagebrush communities interact with other disturbance processes such as wildfire and drought. In southwest Wyoming, 10 to 15 percent of sagebrush ecosystem changes in the area were directly related to anthropogenic disturbances (Xian et al. 2011). Decreases in precipitation and increases in temperature between 1996 and 2006 appeared to impact sagebrush communities across all canopy cover ranges by increasing the extent of bare ground and reducing herbaceous cover (Xian et al. 2011). Also, fires that occurred largely after 1996 accounted for approximately 12 to 23 percent of the changes in sagebrush landscape cover (Xian et al. 2011). These types of changes also affect GRSG populations. Numbers of oil and gas well pads, percent area burned by wildfire, and variability of shrub height within 1 km of leks were all correlated with GRSG lek abandonment in the Bighorn Basin of northcentral Wyoming (Hess and Beck 2012b). This indicates that anthropogenic development can decrease ecosystem resilience by reducing resistance to invasive plant species, which in turn can increase fire frequency and extent. In addition, anthropogenic ignitions increase in proximity to roads and other types of development (Narayanaraj and Wimberly 2012).

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 with relatively low resilience and resistance, and may increase as the climate warms. Both current climate and climate change trends are important factors driving the negative effects of habitat loss and fragmentation on species density and diversity (Mantyka-Pringle et al. 2011). Current studies indicate that contemporary habitat loss and fragmentation may outweigh the responses of climate change on species and ecosystems (Franco et al. 2006; Jetz et al. 2007), but the impact of climate change is predicted to increase over time and exacerbate the effects of land use on species population trends (Lemoine et al. 2007). Populations in fragmented landscapes are more vulnerable to environmental drivers, such as climate change, than those in continuous, intact landscapes (Opdam and Wascher 2004; Travis 2003).

5.3.7 Livestock Grazing

Livestock grazing is currently the most widespread land use in the sagebrush biome. Grazing has well-recognized effects on ecosystem composition, pattern, and function (Beck and Mitchell 2000; Boyd et al. 2014b; Cagney et al. 2010; Freilich et al. 2003; Fuhlendorf and Engle 2001; Knick et al. 2011). In the COT Report, improper livestock grazing was considered a present and widespread threat to GRSG in 8 of 15 populations in the eastern portion of the range (MZ I, II, VII), and in 19 of 29 populations in the western part of the range (MZ III, IV, V, VI) with differences in the ranking drawn primarily along state boundaries (FWS 2013).

The potential landscape effects of livestock grazing have been difficult to evaluate because of a lack of area-wide spatial data (Knick et al. 2011). To address this lack of data, Veblen et al. (2011, 2014) compiled spatial allotment boundaries for all BLM grazing allotments and combined those spatial boundaries with tabular data from the Rangeland Administration System, including billed animal unit months (AUMs), type of animal, and season of use by pasture and allotment. Veblen et al. (2011, 2014) demonstrated that allotment spatial data can be combined with other allotment-related data, for example BLM's land health data, and with additional spatial vegetation data to examine relationships between livestock grazing and vegetation. Veblen et al. (2011, 2014) suggested that these types of analyses could assist managers in identifying allotments where livestock were potentially the cause of not meeting land health standards and prioritizing allotments for further evaluation. Similar data are being used to model vegetation phenology, timing of grazing, and intensity of grazing by allotment to relate spatial data for the population growth rates of GRSG to the multivariate effects of livestock grazing on management units in Wyoming (Adrian Monroe, Colorado State University, personal communication). Currently, the BLM maintains grazing allotment boundary data in a geospatial format at BLM State offices. The data are compiled at the national level and include allotment numbers by State that are related to the information tracked in the Rangeland Administration System. Livestock effects on sagebrush ecosystems and GRSG habitat at mid- to local-scales are evaluated on a case-by-case basis that typically does not involve spatial data analyses.

Major differences in plant responses to herbivory 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. Plants in the Cold Deserts evolved without large numbers of grazing animals (Mack and Thompson 1982). In contrast, plants in the West-Central Semiarid Prairies were grazed regularly and many have adapted to regular defoliation (Coughenour 1985). In the Western Cordillera colder and snow-covered winter landscapes protected low-statured plants from grazing until the growing season when moisture was available and plants typically evolved without large numbers of grazers.

Season of defoliation relative to availability of water for plant regrowth after defoliation is an important factor related to livestock grazing and plant tolerance of defoliation. Water storage and plant growth in the Cold Deserts depend on winter precipitation, especially in the western portion of the range (fig. 4). Cool-season plants (C_3 photosynthesis pathway) dominate plant communities in this ecoregion. Generally, water becomes limiting during late spring and perennial plants become dormant if they are not able to extract deep-soil moisture or photosynthesize during the heat of summer. The West-Central Semiarid Prairies have more available moisture during summer and have a mixture of cool-season plants and warm-season (C_4 photosynthesis) grasses that have greater water use efficiency.

The effects of livestock grazing on sagebrush ecosystems are likely more pronounced in Cold Deserts where stocking rates (Briske et al. 2011) and grazing season together affect plant responses to grazing (Briske and Richards 1995). In Cold Deserts, defoliation of perennial grasses during inflorescence development (late spring) occurs when moisture is becoming limited and plant regrowth and recovery can be compromised (Briske and Richards 1995). In the Western Cordillera and West-Central Semiarid Prairies, precipitation during the growing season may allow greater tolerance to grazing, but cool-season grasses can be eliminated by seasonal use that impacts them yet allows warm-season plants to remain ungrazed.

The greatest potential for livestock grazing to affect GRSG habitat is by changing composition, structure, and productivity of herbaceous plants used for nesting and early brood-rearing (Beck and Mitchell 2000; Boyd et al. 2014b; Cagney et al. 2010; Hockett 2002). The effects of specific grazing systems on sage-grouse likely depend on their longer-term effects on these plant community attributes, especially the relative abundance of perennial grasses and forbs versus sagebrush (Dahlgren et al. 2015). Empirical studies and meta-analyses have reported that GRSG nest and early brood micro-habitat selection and brood-rearing success are closely tied to areas with greater sagebrush and grass canopy cover and height than are randomly available in sagebrush landscapes (Dinkins et al. 2016; Doherty et al. 2011a, 2014; Hagen et al. 2007; Kirol et al. 2012; Thompson et al. 2006). The reported effects of grass-related variables on nest site selection and nest survival have been less consistent in the literature. In particular, some studies have reported grass height as important for GRSG (Aldridge and Brigham 2002; Doherty et al. 2011a, 2014; Gregg et al. 1994; Herman-Brunson et al. 2009; Kaczor et al. 2011; Sveum et al. 1998) and GUSG (Stanley et al. 2015) nesting, whereas others have reported weak (Davis et al. 2014; Dinkins et al. 2016; Holloran et al. 2005) or no effects (Kolada et al. 2009; Lockyer et al. 2015; Popham and Gutierrez 2003). Additionally, other studies concluded no influential effects on GRSG nest survival with any studied grass-related microhabitat variable (Coates and Delehanty 2010; Gibson et al. 2016; Kolada et al. 2009; Lockyer et al. 2015). Recently, Gibson et al. (2016) demonstrated that reported positive effects of grass height may have been an artifact of timing in sampling procedures. Data on grass height were generally collected when nest fate was determined rather than using a predicted hatch date, which can result in a bias towards greater grass heights relative to the true effect. Thus, revisiting management prescriptions based on potential regional variation and potential confounding effects associated with plant phenology within nesting habitat is advised. Nevertheless, repeated heavy grazing of sagebrush bunchgrass communities in MZ II removes bunchgrasses and leads to a sagebrush and rhizomatous grass or bluegrass state, which has reduced resource value for GRSG reproduction (Cagney et al. 2010). Sagebrush cover is inherently lower in the West-Central Semiarid Prairies (MZ I) than in other portions of the species range (Herman-Brunson et al. 2009), suggesting greater reliance by breeding GRSG on herbaceous cover than in other portions of the range.

Infrastructure related to domestic livestock grazing (e.g., water developments) can result in loss of vegetation structure and plant species diversity near these features (Rinehart and Zimmerman 2001). Also, fences to control livestock and manage grazing on western rangelands can contribute to collision related mortality, particularly when located on flat terrain in close proximity to leks (Stevens et al. 2012). Coates et al. (2016d) found that the odds of raven occurrence, a pervasive sage-grouse nest predator, increased by approximately 46 percent in areas where livestock were present. The authors suggested that the increased raven predation may be partially due to the presence of features such as stock ponds and troughs and associated perching structures (e.g. windmills, tanks, and fences) that may increase raven presence.

5.3.8 Wild Horses and Wild Burros

Wild horses (*Equus caballus*) and wild burros (*E. asinus*), like all large-bodied herbivores, can alter sagebrush ecosystem structure and composition and affect habitat quality for sagebrush obligate species (Beever and Aldridge 2011). In the COT Report (FWS 2013) wild horses and wild burros were considered a present and widespread threat in only 1 of 15 populations in the eastern portion of the range (Parachute-Piceance-Roan Basin, MZ VII), but in 10 of 29 populations in the western portion of the range. Wild horses and wild burros were considered a persistent but localized threat in two populations in MZ II (Wyoming Basin and Northwest Colorado), and in one population in MZ IV (Northern Great Basin) (FWS 2013). BLM Herd Management Areas (HMAs) that overlap with GRSG occur in the Northern Basin and Range, Central Basin and Range, and Wyoming Basins (MZs II, III, and IV) (Beever and Aldridge 2011).

Wild horse and burro populations pose long-term challenges to habitat conservation and restoration efforts that differ in several key ways from the challenges posed by managed livestock grazing (FWS 2013). Wild horse and burro management is primarily limited to managing numbers of animals and their distribution. Wild horses and burros live on the range the entire year and roam freely, and the locations and timing of wild horse and burro grazing are not regulated like livestock grazing.

Wild horse populations have the potential to grow on the order of 15 to 20 percent per year (National Research Council 2013; Ransom et al. 2016), and wild horse population sizes on Federal lands have almost doubled since the COT Report (FWS 2013) was published. It was estimated that 67,027 wild horses and burros occurred on BLM-administered land as of March 1, 2016. Approximately 60 percent of those (39,285 horses) occur within 13 million ac (5.3 million ha) of GRSG habitat. On USFS-administered lands, an estimated 6,000 wild horses and 900 wild burros occupy approximately 2 million ac (8 million ha). An estimated 3,400 of these animals occur within about 446,065 ac (180,516 ha) of GRSG general and priority habitat. In addition, an estimated 650 wild horses occur within bi-State sage-grouse habitat on about 70,000 ac (28,329 ha) administered by the USFS and 82,403 ac (33,347 ha) administered by the BLM.

Wild burros are not nearly as numerous as wild horses in the sagebrush biome. However, the tendency of burros to use low-elevation habitats throughout the year may lead to a high degree of overlap between burros and sage-grouse habitat, where burros and GRSG co-occur (Beever and Aldridge 2011). Also, wild burros can substantially affect riparian habitats (e.g., Tiller 1997) and native wildlife, and have grazing and trampling impacts similar to wild horses (Douglas and Hurst 1993).

The direct effects of wild horses on sagebrush ecosystems have been summarized by FWS (2008) and Beever and Aldridge (2011). Horse presence has broad effects on sagebrush ecosystem functioning. In general, wild horse presence is associated with lower overall plant cover, but greater relative abundance and cover of grazing-tolerant, unpalatable, and invasive plant species (Smith 1986), including cheatgrass. In the Great Basin, areas without wild horses have greater native plant cover, shrub cover, species richness, and overall plant biomass compared to areas with horses (Beever et al. 2008; Davies et al. 2014; Ziegenfuss et al. 2014). Also, there are measurable differences in soil structure, soil penetration resistance, and erosion as well as in invertebrate, small mammal, and reptile communities (Beever and Aldridge 2011; Ostermann-Kelm et al. 2009).

Many studies corroborate the general conclusion that high densities of wild horses can lead to biologically significant changes in sagebrush ecosystems. Although horses are usually considered to be grazers (Hanley and Hanley 1982), sagebrush can represent a large part of their diet in the Great Basin during the summer (Nordquist 2011). Wild horses are potential agents for the spread of nonnative plant species (Couvreur et al. 2004; Loydi and Zalba 2009) and may limit the effectiveness of restoration projects (Jessop and Anderson 2007). Grazing by wild horses can also have severe impacts on aquatic ecosystems and riparian communities (Barnett 2002; Beever and Brussard 2000; Earnst et al. 2012; FWS 2008, 2012). Wild horses can degrade the quality of limited water sources and behaviorally exclude ungulates and other native wildlife (e.g., pronghorn) from these water sources (Gooch et al. 2017; Hall et al. 2016; Ostermann-Kelm et al. 2008; Perry et al. 2015; FWS 2008). Even in areas with long histories of livestock grazing, once domestic livestock are removed, continued wild horse grazing may cause ongoing detrimental ecosystem effects (Davies et al. 2014; FWS 2008). In the sagebrush-steppe ecosystem, plant communities can take several decades to recover from such impacts (e.g., Anderson and Inouye 2001).

6. Resilience to Disturbance and Resistance to Invasive Annual Grasses in Sagebrush Ecosystems

An understanding of the factors that determine resilience to stress and disturbance and resistance to invasion by nonnative plants can be used to address persistent ecosystem and land use and development threats to sagebrush habitats (Brooks and Chambers 2011; Chambers et al. 2014a,b, 2017; Wisdom and Chambers 2009). In sagebrush ecosystems resilience to stress and disturbance changes along climatic and topographic gradients at both landscape and local scales (figs. 21, 22, 23, 24).

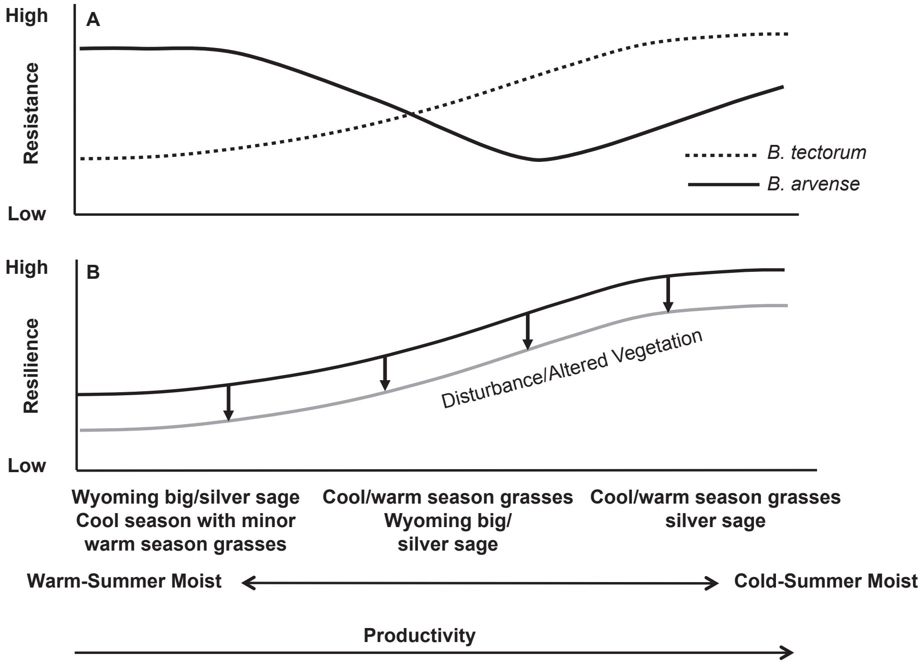


Figure 21—Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil moisture and temperature gradient in the West-Central Semiarid Prairies. Dominant ecological sites occur along a continuum from relatively warm and summer moist with Wyoming big sagebrush, silver sagebrush, and cool season grasses and a minor component of warm season grasses to cold and summer moist with a mixture of cool and warm season grasses and silver sagebrush. Resistance to annual brome grasses varies along the temperature and precipitation gradient as a function of their ecological amplitudes and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. Resilience also increases along the gradient and is influenced by site characteristics like soils and aspect (figure adapted from Brooks et al. 2016).

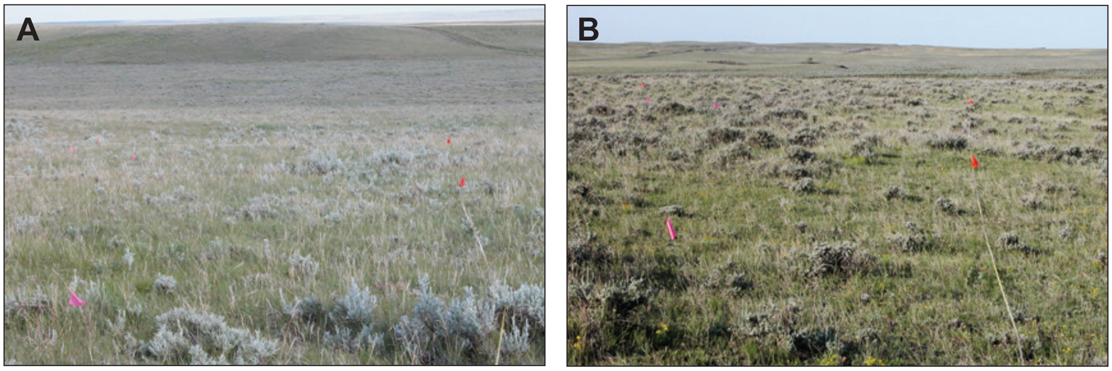


Figure 22—Representative sagebrush ecological types in the eastern portion of the range. (A) Cool and warm season grasses with silver sage characterized by high resilience and resistance. (B) Wyoming big and silver sage with cool and warm season grasses characterized by low resilience and resistance (BLM file photos).

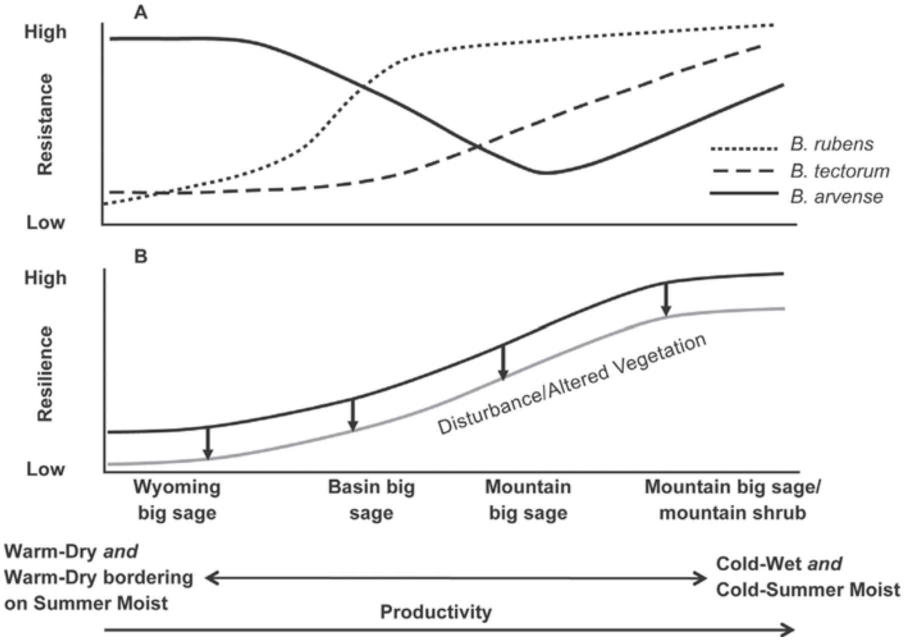


Figure 23—Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil temperature and moisture gradient in the Cold Deserts. Dominant ecological sites occur along a continuum from relatively warm and dry to cold and wet conditions that includes salt desert shrub, Wyoming big sagebrush, basin big sagebrush, mountain big sagebrush, and mountain big sagebrush with root-sprouting shrubs. Resistance to annual brome grasses varies along the temperature and precipitation gradient as a function of their ecological amplitudes and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. Resilience also increases along the temperature and precipitation gradient and is influenced by site characteristics like soils and aspect (figure adapted from Chambers et al. 2014a).

At landscape scales higher precipitation and cooler temperatures typically result in greater resource availability, more favorable environmental conditions for plant growth and reproduction, and higher ecosystem productivity (Alexander et al. 1993; Dahlgren et al. 1997). In contrast, lower precipitation and higher temperatures result in reduced resource availability for plant growth and reproduction and thus lower ecosystem productivity (Smith and Nowak 1990; West 1983a,b). Higher levels of available resources coupled with greater productivity generally result in increased ecosystem resilience to both disturbances and management treatments (Chambers et al. 2014a,c). More resilient ecosystems typically exhibit smaller changes following disturbances and recover more rapidly than less resilient ecosystems (Chambers et al. 2014c; Davies et al. 2012). These relationships also are observed at local scales where aspect, slope, and topographic position affect solar radiation, effective precipitation, and erosion processes, and thus soil development and vegetation composition and structure (Condon et al. 2011; Johnson and Miller 2006).

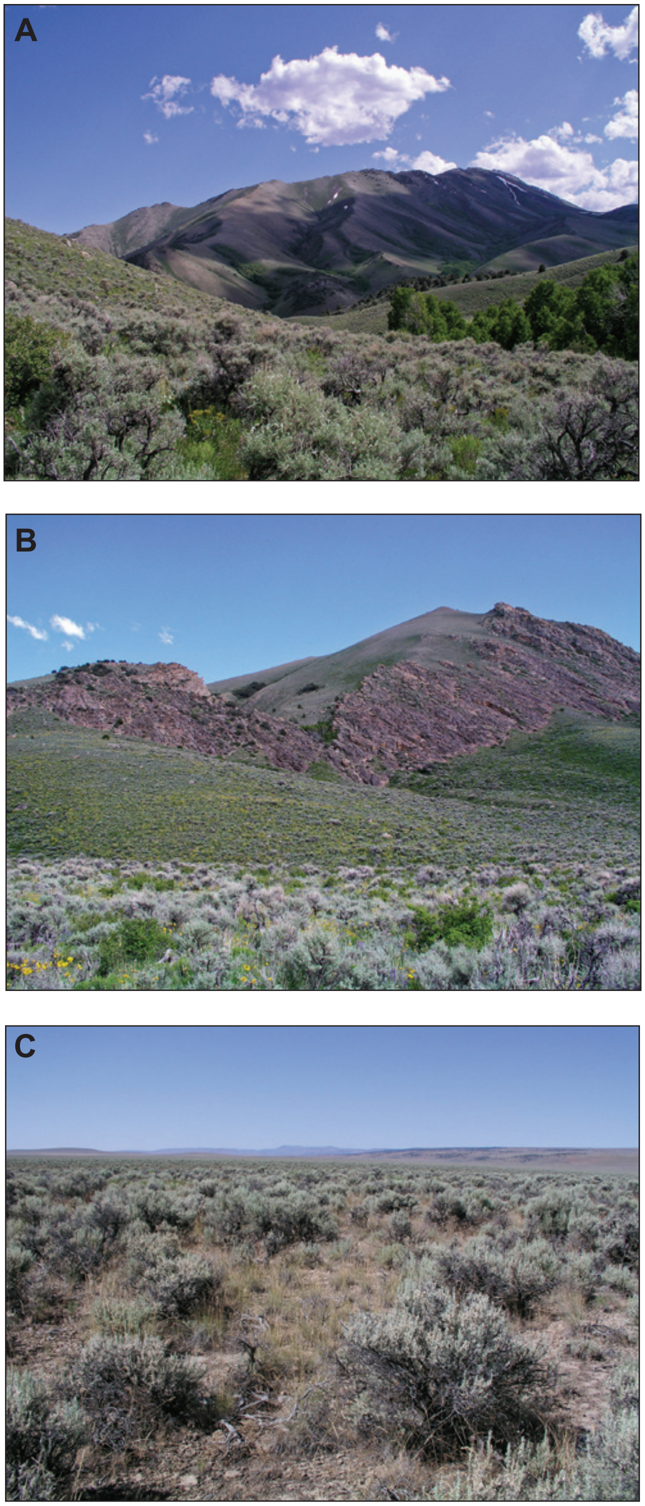


Figure 24—Representative sagebrush ecological types in the Cold Deserts: (A) Mountain big sagebrush/mountain brush type with relatively cold and moist soils characterized by high resilience and resistance, (B) mountain big sagebrush type with cool and moist soils and moderate resilience and resistance, and (C) Wyoming big sagebrush type with warm and dry soils and low resilience and resistance (photos by Jeanne C. Chambers).

Resistance to nonnative invasive plant species depends on environmental factors and ecosystem attributes and is a function of: (1) the invasive species' physiological and life history requirements for establishment, growth, and reproduction; and (2) interactions with the native perennial plant community including interspecific competition and response to herbivory and pathogens. Soil temperature and moisture regimes strongly influence resistance to invasive plant species. The importance of soil temperature and moisture regimes in determining invasibility is well illustrated for nonnative invasive brome grasses, which are among the most widespread and problematic invasive plant species in sagebrush ecosystems (figs. 21, 23; Brooks et al. 2016; Chambers et al. 2007, 2016b). For example, germination, growth, and/or reproduction of cheatgrass is physiologically limited in relatively warm and dry sites at lower elevations by frequent, low precipitation years, constrained by low soil temperatures at high elevations, and optimal under relatively moderate temperature and water availability at mid-elevations (Chambers et al. 2007; Meyer et al. 2001). In contrast, red brome is found primarily on warm and dry salt desert sites (Salo 2005). Field brome (*B. arvensis*) is limited on warm and dry as well as cold sites but is relatively abundant on cool and moist sites (Baskin and Baskin 1981). Slope, aspect, and soil characteristics modify soil temperature and water availability and influence resistance to brome grasses at landscape to plant community scales (Chambers et al. 2007; Condon et al. 2011; Mealor et al. 2012, 2013; Reisner et al. 2013, 2015; Salo 2005).

The occurrence and persistence of nonnative plants in sagebrush habitats are strongly influenced by interactions with the native perennial plant community. For example, cheatgrass is a facultative winter annual that can germinate from early fall through early spring, exhibits root elongation at low soil temperatures, and has higher nutrient uptake and growth rates than most perennial species (Arredondo et al. 1998; James et al. 2011; Mack and Pyke 1983). Seedlings of native, perennial plant species are generally poor competitors with cheatgrass, but mature plants, especially those with similar growth forms and phenology, can be highly effective competitors with the invasive annual (Blank and Morgan 2012; Booth et al. 2003; Chambers et al. 2007). Also, biological soil crusts, which are an important component of plant communities in warmer and drier sagebrush ecosystems, can reduce germination or establishment of cheatgrass (Eckert et al. 1986; Kaltenecker et al. 1999). Disturbances or management treatments that reduce abundance of native perennial grasses and biological soil crusts and increase the distances between these perennial grasses often are associated with higher resource availability and increased competitive ability of cheatgrass (Chambers et al. 2007; Reisner et al. 2013, 2015; Roundy et al. 2014). Similarly, decreases in native perennial grasses and elevated resources result in increased abundances of red brome (Salo et al. 2005), field brome (Collins and Uno 1985), and species like spotted knapweed (*Centauria stoebe* ssp. *micranthos* syn. *C. maculosa*) (Willard et al. 1988).

The type, characteristics, and historical range of variability of stress and disturbance strongly influence both resilience and resistance. Disturbances like improper grazing of perennial plants by livestock or wild horses and burros and uncharacteristic fire regimes are outside of the natural range of conditions and can reduce the resilience of sagebrush ecosystems (Pyke et al. 2016). Reduced resilience is triggered by changes in environmental factors like temperature regimes, abiotic attributes like water and nutrient availability, and biotic attributes such as vegetation structure, composition, and productivity (Chambers et al. 2014a) and cover of biological soil crusts (Reisner et al. 2013). Changes in abiotic and biotic attributes can result in decreased resistance to nonnative invasive annual grasses (Chambers et al. 2007). Increased resource availability or altered habitat suitability can both influence an invasive species' ability to establish and persist as well as compete with native species (Chambers et al. 2007, 2014c). Progressive reduction of resilience and resistance can result in the crossing of abiotic and biotic thresholds and an inability of the system to recover to the reference state (Briske et al. 2008).

7. Integrating Resilience and Resistance With Species Habitat Requirements to Prioritize Areas For Management and Inform Management Strategies

A strategic, multi-scale approach is needed to conserve sagebrush ecosystems and sagebrush obligate species because of the differences in the extent and magnitude of persistent ecosystem and land use and development threats and ecosystem resilience and resistance to those threats (Chambers et al. 2014b, 2016a; Meinke et al. 2009; Pyke 2011; Wisdom and Chambers 2009; Wisdom et al. 2005). This type of approach includes: (1) prioritizing management actions that can increase ecosystem resilience to stress and disturbance and resistance to nonnative invasive plants, (2) identifying those locations that provide current or potential sagebrush habitat for focal species, and (3) efficiently allocating management resources to minimize threats and improve habitat conditions (Pyke 2011; Wisdom and Chambers 2009). At biome to mid-scales, key biophysical characteristics such as soil temperature and moisture regimes can be used as indicators of ecosystem resilience and resistance and thus likely ecosystem response to disturbance and management treatments (Chambers et al. 2014 a,b, 2016a, 2017; Maestas et al. 2016a). Key habitat characteristics, such as land cover type, climate, landform, and type and magnitude of disturbance can be used as indicators of potential habitat for GRSG and other sagebrush obligate species. Linking information on resilience and resistance with species habitat characteristics provides the basis for a decision support process to prioritize management actions based on the likelihood of maintaining or increasing ecosystem and species persistence.

7.1 Soil Temperature and Moisture Regimes as Indicators of Ecosystem Resilience to Disturbance and Resistance to Invasive Annual Grasses at Biome to Mid-Scales

Soil temperature and moisture regimes are available through the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) and currently provide one of the most complete data sets for understanding ecosystem resilience and resistance in the sagebrush biome. To facilitate landscape analyses and prioritization, relative resilience to disturbance and resistance to invasive annual grasses were categorized as high, moderate, or low based on soil temperature regime and moisture regime subclasses. Resistance was categorized in terms of invasive annual grasses because: (1) the potential exists for widespread conversion of sagebrush ecosystems to annual grass dominance, and (2) substantial scientific information exists relating resistance to invasive annual grasses to soil temperature and moisture regimes or climatic regimes (e.g., Brooks et al. 2016; Chambers et al. 2007; Condon et al. 2011; Davies et al. 2012; Meyer et al. 2001).

An explanation of soil temperature and moisture regimes and a cross-walk between soil temperature and moisture regimes and relative resilience and resistance are in Appendix 2. The dominant sagebrush ecological types are characterized according to soil temperature and moisture regimes, major characteristics, and resilience to disturbance and resistance to invasive annual grass species in table 6. In the Science Framework, ecological type is defined in a broad sense and refers to ecological site/type groups. The methods used to develop the ecological types are described in Appendix 4. State-and-transition models based on soil temperature and moisture regimes, ecological type characteristics, and relative resilience and resistance were developed for those ecological types that represent the greatest area in the eastern and western portion of the range (Appendices 5 and 6, respectively). These state-and-transition models 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.

In general, higher resilience and resistance occurs with ***cool*** to ***cold*** (frigid to cryic) soil temperature regimes and ***moist*** (udic), ***winter moist*** (xeric) or predominantly ***summer moist*** (ustic) soil moisture regimes, while lower resilience and resistance occur with ***warm*** (mesic) soil temperatures and relatively ***dry*** (aridic) or ***summer moist bordering on dry*** (ustic bordering on aridic) soil moisture regimes (figs. 6, 21, 23; Chambers et al. 2014b, 2016a; Maestas et al. 2016a). The ecoregions and Management Zones differ in soil temperature and moisture regimes and, consequently, in dominant ecological types and relative resilience and resistance (figs. 21, 23; table 6). Much of the West-Central Semiarid Prairies (MZ I) is characterized by moderate to high resilience and resistance as indicated by relatively cool and summer moist regimes (fig. 6; table 6a). However, the southeastern part of this ecoregion has low to moderate resilience and resistance as indicated by warm and drier regimes. The dominant ecological types are comprised of varying amounts of cool season and warm season grasses, Wyoming big sagebrush, and plains silver sagebrush (table 6a). The Western Cordillera in MZs II and VII grades into the foothills of the Wyoming Basin and Colorado Plateau and is characterized by cold and wet to cool and summer moist soil temperature and moisture regimes with generally high to moderate resilience and resistance (fig. 6; table 6b). Ecological types are typically comprised of mountain big sagebrush, snowberry and other shrubs, and cool season grasses (table 6b).

The Cold Deserts in MZs II and VII encompass a broad range of soil temperature and moisture regimes—cool bordering on cold and summer moist bordering on dry to warm and dry with generally moderate to low resilience and resistance (fig. 6; table 6c). The ecological types are characterized by mountain big sagebrush on the coolest sites, Wyoming big sagebrush and salt desert shrubs on the warmest and driest sites, and basin big sagebrush and sometimes silver sagebrush in drainages. Cool season grasses predominate with warm season grasses occurring in some types with summer moisture.

Table 6—Predominant sagebrush ecological types in the West-Central Semiarid Prairies (MZ I; 6a), Western Cordillera (MZs II, VII; 6b), Cold Deserts in the eastern portion of the range (Wyoming Basin, Colorado Plateau; MZ II, VII; 6c), and Cold Deserts in the western portion of the range (Snake River Plain, Northern Basin and Range, Central Basin and Range; MZs III, IV, V; 6d). Information for the eastern part of the range is based on a mid-scale analysis (ecoregions/Management Zones) that used data from the National Soil Information System (NASIS) to summarize the predominant ecological types occurring in the Priority Areas for Conservation (PACs). For detailed methodology, see Appendix 4. Information for the western part of the range is based on Chambers et al. (2014b,c). The ecological types are characterized by soil temperature and moisture regimes (to moisture subclass), vegetation, resilience to disturbance, and resistance to invasive annual grasses. Relative abundance of sagebrush species and composition of understory vegetation vary depending on Major Land Resource Area (MLRA) and ecological site. Definitions of MLRAs, ecological types, state-and-transition models, and ecological sites are in Appendix 1. An explanation of the soil temperature and moisture regimes is in Appendix 2. State-and-transition models for ecological types comprising the largest area are in Appendices 5 and 6. A detailed description of how to use this information is in the section on "Determining Appropriate Management Treatments at Local Scales."

a—West-Central Semiarid Prairies (Northwestern Glaciated Plains and Northwestern Great Plains)

Ecological type	**Characteristics**	**Resilience and resistance**
Cool bordering on cold/ Summer moist bordering on dry (Frigid bordering on Cryic/Ustic bordering on Aridic) Representative Area: Northwestern Glaciated Plains—MLRA 52 in northern Montana	Precipitation: 10–14 inches Typical vegetation: *Green needlegrass, wheatgrasses, needle-and-thread, plains silver sagebrush* Grass dominated—cool with some warm season grasses	*Resilience*—**High.** High precipitation and high productivity result in high resilience. *Resistance*—**High.** Climate suitability to invasive annual bromes is low due to low soil temperature and club mosses.
Cool/Summer moist (Frigid/Ustic-Typic) Representative Area: Northwestern Great Plains—MLRA 60A in South Dakota	Precipitation: 13–18 inches Typical vegetation: *Western wheatgrass, green needlegrass, blue and sideoats grama, buffalograss, plains silver sagebrush, Wyoming big sagebrush on shallow clay sites* Grass dominated—mixture of cool and warm season grasses	*Resilience*—**Moderate to high.** Effective moisture and productivity are high, depending on soil texture. *Resistance*—**Moderate to high**. Climate suitability to invasive annual grasses is moderate to high increasing on warmer sites.
Cool/Summer moist bordering on dry (Frigid/Ustic bordering on Aridic) Representative Area: Northwestern Great Plains—MLRA 58A in Montana and 58D in SD, 58C in North Dakota	Precipitation: 10–14 inches Typical vegetation: *Wyoming big sage, plains silver sagebrush, wheatgrasses, green needlegrass, needle-and-thread, and blue grama* Shrub dominated—cool with some warm season grasses	*Resilience*—**Moderate to high.** Effective moisture and productivity are relatively high, depending on soil texture. *Resistance*—**Moderate to high**. Climate suitability to invasive annual grasses is low and increases on warmer and drier sites.
Warm/Summer moist (Mesic/Ustic-Typic) Representative Area: Northwestern Great Plains—wetter portions of MLRA 58B in Wyoming near Black Hills	Precipitation: 15–17 inches Typical vegetation: *Wyoming big sagebrush, western wheatgrass, green needlegrass, needle-and-thread* Ponderosa pine potential Shrub dominated—cool and warm season grasses	*Resilience*—**Moderate to high.** Effective precipitation and productivity are relatively high. *Resistance*—**Moderate**. Climate suitability to invasive annual grasses is moderate to low depending on soil temperature and texture.
Warm/Summer moist bordering on dry (Mesic/Ustic bordering on Aridic) Representative Area: Northwestern Great Plains—drier portions of MLRA 58B in Wyoming, and probably warmer portions of 58A, Land Resource Unit E in southeastern Montana	Precipitation: 10–14 inches Typical vegetation: *Wyoming big sagebrush, silver sagebrush, wheatgrasses, green needlegrass, needle-and-thread, blue grama* Shrub dominated—cool and warm season grasses	*Resilience*—**Low to moderate.** Effective precipitation and productivity are relatively low. *Resistance*—**Low to moderate**. Climate suitability to invasive annual grasses is moderate to high depending on soil temperature and texture.

b—Western Cordillera (Middle and Southern Rockies).

Ecological Type	**Characteristics**	**Resilience and resistance**
Cold/Wet (Cryic/Udic-Typic) Representative Area: Middle and Southern Rockies—MLRA 43B in Wyoming and Montana; 48A in Colorado; MLRA 47 in Utah	Precipitation: 20+ inches Typical vegetation: *mountain big sagebrush, spiked big sagebrush, snowberry, mountain silver sagebrush , aspen, lodgepole pine, slender wheatgrass, fescues, needlegrasses, bromes* Shrub dominated—cool season bunchgrasses	*Resilience*—**High.** High precipitation and high productivity result in high resilience. *Resistance*—**High.** Climate suitability to invasive annual bromes is low due to low soil temperature.
Cold/Summer moist (Cryic/Ustic-Typic) Representative Area: Middle and Southern Rockies—MLRAs 46/43B Foothills in Wyoming and Montana; MLRA 48A in Wyoming and Northern Colorado; MLRA 49 in Wyoming	Precipitation: 15–19 inches Typical vegetation: *mountain big sagebrush, bitterbrush, snowberry, serviceberry, mahogany, aspen, fescues, needlegrasses, bluebunch wheatgrass* Shrub dominated—cool season bunchgrasses	*Resilience*—**High.** High precipitation and high productivity result in high resilience. *Resistance*—**High.** Climate suitability to invasive annual bromes is low due to low soil temperature. Lower resistance on south-facing aspects.
Cool/Summer moist (Frigid/Ustic-Typic) Representative Area: Uinta Mountains (MLRA 47 Land Resource Unit C) in Utah and Wyoming; Southern Rockies in Colorado and Utah—MLRA 48A;	Precipitation: 16–22 inches Typical vegetation: *mountain big sagebrush, serviceberry, snowberry, bitterbrush, western wheatgrass, needlegrasses, bluegrasses* Shrub dominated—cool season grasses with some warm season grasses in southern extent	*Resilience*—**Moderate to high.** Precipitation and productivity are moderate. Decreases in herbaceous perennial species and ecological conditions can decrease resilience. *Resistance*—**Moderate to high.** Climate suitability to invasive annual grasses is relatively high.
Cool/Winter moist (Frigid/Xeric-Typic) Described in Chambers et al. 2014b. Representative Area: Wasatch and Uinta Mountains in Utah (MLRA 47)	Precipitation: 12–22 inches Typical vegetation: *mountain big sagebrush, antelope bitterbrush, snowberry, and/or low sagebrush, bluebunch wheatgrass, basin wildrye, Nevada bluegrass* Piñon pine and juniper potential in some areas Shrub dominated—cool season grasses	*Resilience*—**Moderately high**. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resilience. *Resistance*—**Moderate**. Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.

c—Cold Deserts (Wyoming Basin and Colorado Plateau).

Ecological Type	**Characteristics**	**Resilience and resistance**
Cool bordering on cold/ Summer moist bordering on dry (Frigid bordering on Cryic/Ustic bordering on Aridic) Representative Area: Wyoming Basin—MLRA 34A in Wyoming west of continental divide into Rich Co., UT	Precipitation: 9–14 inches Typical vegetation: *Wyoming big sagebrush, Gosiute sagebrush, mountain big sagebrush, basin big sagebrush in drainages, Indian ricegrass, needle-and-thread, wheatgrasses* Shrub dominated—cool season grasses	*Resilience*—**Moderate to low.** Effective precipitation and cold temperatures can limit site productivity and plant establishment. *Resistance*—**Moderately high.** Climate suitability to invasive annual bromes is relatively low due to low soil temperature.
Cool/Summer moist bordering on dry (Frigid/Ustic bordering on Aridic) Representative Area: Wyoming Basin—MLRA 34A in Wyoming east of continental divide and southern extent of MLRA 34A in Colorado west of continental divide.	Precipitation: 10–14 inches Typical vegetation: *Wyoming big sagebrush; basin big sagebrush or silver sagebrush in drainages, wheatgrasses, needle-and-thread, Indian ricegrass* Shrub dominated—cool season grasses with some warm season grasses (blue grama)	*Resilience*—**Moderate**. Precipitation and productivity are moderate. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resilience. *Resistance*—**Moderate.** Climate suitability to invasive annual bromes is relatively low, but increases with temperature and soil sand content.
Cool bordering on warm/ Summer moist (Frigid bordering on Mesic/Ustic-Typic) Representative Area: Colorado Plateau—MLRA 48A/34A Piceance Basin-Book Cliffs in Colorado and Utah	Precipitation: 14–18 inches Typical vegetation: *Wyoming big sagebrush, basin big sagebrush in drainages, mountain big sagebrush, Utah juniper, twoneedle pinyon, Gambel oak, basin wildrye, rhizomatous wheatgrasses, Sandberg bluegrass* Pinyon-juniper potential Shrub dominated—cool season with some warm season grasses	*Resilience*—**Moderate to high.** Effective precipitation and productivity are high, depending on soil texture. Erosive soils and steep terrain can decrease resilience. *Resistance*—**Moderate to Low**. Climate suitability to invasive annual grasses is moderate. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resistance.
Cool/dry bordering on summer moist (Frigid/Aridic bordering on Ustic) Representative Area: Wyoming Basin—MLRA 34A in Green River Basin (west of continental divide) and Great Divide Basin	Precipitation: 7–10 inches Typical vegetation: *Wyoming big sagebrush and salt desert shrubs, bottlebrush squirreltail, needleandthread, Indian ricegrass, wheatgrasses* Shrub dominated—cool season grasses	*Resilience*—**Moderate to Low**. Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. *Resistance*—**Moderate.** Climate suitability to invasive annual grasses is moderate, but depends on soil texture and temperature.
Warm/summer moist bordering on dry (Mesic/Ustic bordering on Aridic) Representative Area: Wyoming Basin—MLRA 32 foothills in Wyoming, MLRA 34B and 36 in Colorado and Utah	Precipitation: 10–14 inches in WY; 12-16 inches in UT and CO Typical vegetation: *Wyoming big sagebrush, Utah juniper and two needle pinyon, wheatgrasses, needleandthread, Indian ricegrass* Shrub dominated—cool season grasses with warm season grasses increasing in south	*Resilience*—**Moderate to low.** Effective precipitation and productivity are moderately low, and vary with soil temperature and texture. *Resistance*—**Low**. High climate suitability to invasive annuals.

d—Cold Deserts (Snake River Plain, Northern Basin and Range, Central Basin and Range).

Ecological type	**Characteristics**	**Resilience and resistance**
Cold/Winter moist (Cryic/Xeric-Typic)	Precipitation: 14 inches + Typical vegetation: *Mountain big sagebrush, snowfield sagebrush, snowberry, serviceberry, silver sagebrush, and/or low sagebrush, slender wheatgrass, Idaho fescue, needlegrasses, bromes* Shrub dominated—cool season grasses	*Resilience*—**Moderately high.** Precipitation and productivity are generally high. Short growing seasons can decrease resilience on coldest sites. *Resistance*—**High.** Low climate suitability to invasive annual grasses
Cool/Winter moist (Frigid/Xeric-Typic)	Precipitation: 12–22 inches Typical vegetation: *mountain big sagebrush, antelope bitterbrush, snowberry, and/or low sagebrush, slender wheatgrass, Idaho fescue, June grass, needle grasses, bromes* Piñon pine and juniper potential Shrub dominated—cool season grasses	*Resilience*—**Moderately hig**h. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. *Resistance*—**Moderate.** Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.
Cool bordering on warm/Winter moist (Frigid bordering on Mesic/Xeric-Typic)	Precipitation: 12–16 inches Typical vegetation: *mountain big sagebrush, antelope bitterbrush, and/or low sagebrush, Idaho fescue, bluebunch wheatgrass, needle grasses, bromes* Shrub dominated—cool season grasses	*Resilience*—**Moderate**. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. *Resistance*—**Moderate.** Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.
Warm bordering on cool/Winter moist (Mesic bordering on Frigid/Xeric-Typic)	Precipitation: 12–16 inches Typical vegetation: *Basin big sagebrush, Bonneville big sagebrush, and/or low sagebrush, bluebunch wheatgrass, needle grasses, bromes* Piñon pine and juniper potential Shrub dominated—cool season grasses	*Resilience*—**Moderate.** Precipitation and productivity are moderately high. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resilience. *Resistance*—**Moderately low.** Climate suitability to invasive annual grasses is moderately low, but increases as soil temperatures increase.
Cool bordering on warm/Dry (Frigid bordering on Mesic/Aridic-Typic)	Precipitation: 6–12 inches Typical vegetation: *Wyoming big sagebrush, black sagebrush, and/or low sagebrush, bluebunch wheatgrass, needle grasses, Sandberg's bluegrass, bottlebrush squirreltail* Shrub dominated—cool season grasses	*Resilience*—**Low.** Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. *Resistance*—**Moderately low.** Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.
Warm/Dry bordering on winter moist (Mesic/Aridic bordering on Xeric)	Precipitation: 8–12 inches Typical vegetation: *Wyoming big sagebrush, black sagebrush and/or low sagebrushes, Sandberg's bluegrass, bottlebrush squirreltail, needleandthread, Indian ricegrass* Shrub dominated—cool season grasses	*Resilience*—**Low.** Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. Cool season grasses susceptibility to grazing and hot, dry summer fire conditions promote cheatgrass establishment and persistence. *Resistance*—**Low.** High climate suitability to cheatgrass and other invasive annual grasses. Resistance generally decreases as soil temperature increases, but establishment and growth are highly dependent on precipitation.

The Cold Deserts in MZ III, IV, V, and VI (primarily the northern and central Great Basin and Columbia Plateau) differ from those of the Wyoming Basin and Colorado Plateau largely because most precipitation is received in winter (fig. 6; table 6d). Soil temperature and moisture regimes vary with elevation and range from cool bordering on cold and winter moist to warm and dry with generally moderate to low resilience and resistance. The ecological types are characterized by mountain big sagebrush and mountain brush on the coolest sites, and Wyoming big sagebrush on the warmest and driest sites. Cool season grasses predominate in these ecoregions.

7.2 Greater Sage-Grouse Breeding Habitat Probabilities and Population Indices

7.2.1 The GRSG Breeding Habitat Model

Two models were recently developed for the FWS status assessment (Doherty et al. 2016) to quantify GRSG breeding habitat probabilities and create a population index to spatially identify population centers of breeding male GRSG within each Management Zone (MZ). The Occupied Breeding Habitat Distribution Model (hereafter, breeding habitat model) was developed to more accurately portray important breeding areas for GRSG (Doherty et al. 2016), because information available to the FWS regarding occupied GRSG range was developed at a broad scale and included large areas of unsuitable habitat. The breeding habitat model used GRSG lek data (2010−2014) as a proxy for landscapes important to breeding birds, because leks are central to the breeding ecology of GRSG and the majority of nests occur relatively close (within 4 miles; 6.3 km) to leks (Coates et al. 2013; Holloran and Anderson 2005). The breeding habitat model evaluated characteristics such as vegetation (i.e., landscape cover), climate, landform, and disturbance variables around leks, i.e., within a radius of 4 miles (6.4 km; Doherty et al. 2016). The model provided an estimate of the probability of occurrence of breeding sage-grouse at a spatial resolution of 120 x 120 m based on habitat characteristics for each Management Zone (fig. 25). Breeding habitat for GUSG in MZ VII was recently modeled following the same methodology used by Doherty et al. (2016) for GRSG (see Chambers et al. 2016a).

Breeding habitat probabilities for GRSG in Doherty et al. (2016) (table 7; Chambers et al. 2016a) were used to develop three categories of breeding habitat probability for prioritizing management actions on the landscape. The categories were based on the probability of areas near leks, i.e., within a radius of 4 miles (6.4 km; Doherty et al. 2016), providing suitable breeding habitat and included: low (0.25 to <0.50), moderate (0.50 to <0.75), and high (0.75 to 1.00). Areas with probabilities of 0.01 to less than 0.25 were considered to be unsuitable for breeding habitat. However, it is important to note that these areas may provide habitat during other life stages or linkages between areas of suitable breeding habitat. To obtain these categories, probability values were estimated with data from existing active lek locations and used to define thresholds in breeding habitat probabilities. Probability values were then estimated for inactive lek locations and used to conduct an accuracy assessment of the categorization of habitat probabilities (table 7). This categorization achieved the goal of clearly differentiating where management actions to improve habitat are warranted (<10% of active leks and >90% of inactive leks occurred in the low and moderate probability ranges; table 7).

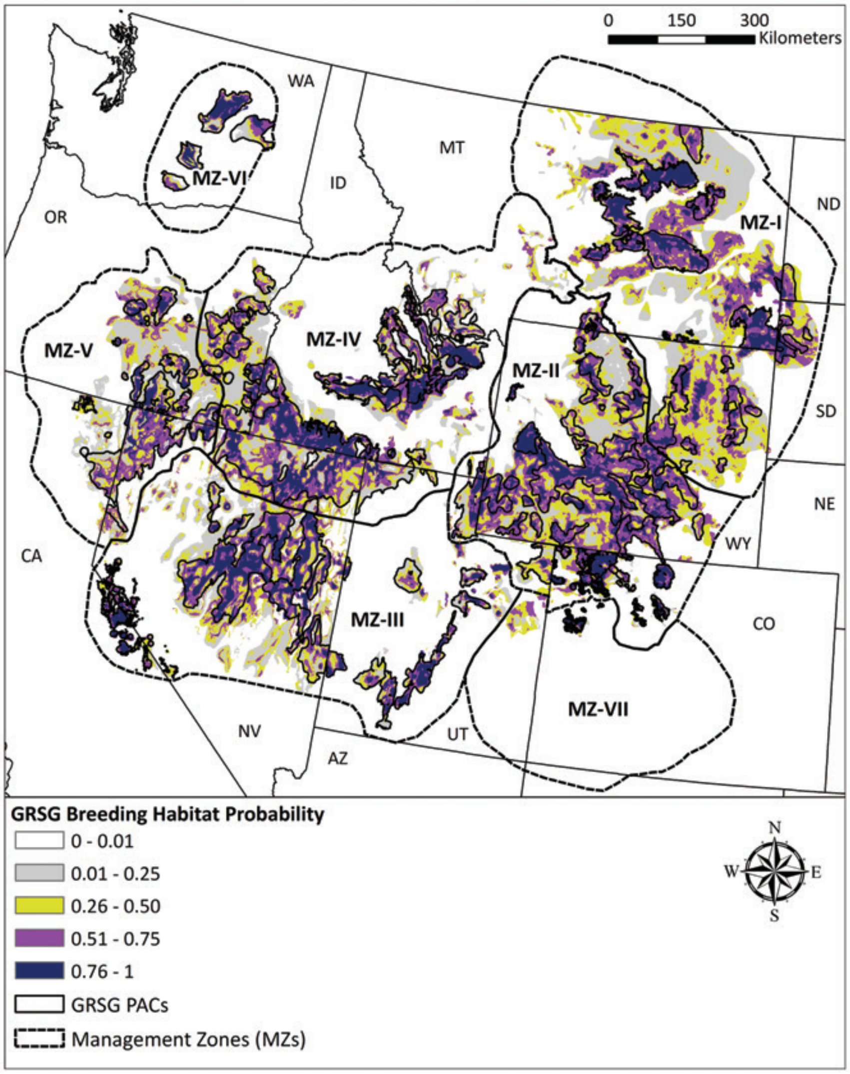


Figure 25—GRSG breeding habitat probabilities based on 2010–2014 lek data (Doherty et al. 2016). Priority Areas for Conservation (PACs; FWS 2015) are overlaid. The breeding habitat probability model was developed to more accurately portray important breeding areas for GRSG.

Table 7—Percentage (and number) of active and inactive leks within four breeding habitat model probability classes. Breeding habitat model probabilities (Doherty et al. 2016) for all Management Zones were grouped into ranges relative to their probability of supporting sage-grouse leks. Habitat probabilities for GRSG were modeled by comparing habitat characteristics within 4 mi (6.4 km) around active and inactive lek locations (Doherty et al. 2016). Active and inactive GRSG lek data were provided by the Western Association of Fish and Wildlife Agencies. The categorization differentiates where management actions to improve habitat are warranted (<10% of active leks and >90% of inactive leks occurred in the low and moderate probability ranges).

	Breeding habitat model probability classes			
Lek type	**Unsuitable 0.01 to <0.25**	**Low 0.25 to <0.50**	**Moderate 0.50 to <0.75**	**High 0.75 to 1.0**
Active	0.1% (*n* = 4)	1.1% (*n* = 38)	9.3% (*n* = 308)	89.5% (*n* = 2978)
Inactive	5.9% (*n* = 71)	22.5% (*n* = 272)	36.8% (*n* = 446)	34.8% (*n* = 422)

Managers can consult table 5 to identify the top predictor variables for GRSG breeding habitat in each Management Zone to help identify specific issues relating to why individual leks may be located in low, moderate, or high probability ranges. For example, energy development structures or wildfire may have eliminated sagebrush near inactive leks in the moderate or low probability range.

7.2.2 The GRSG Population Index Model

Doherty et al. (2016) also developed a Population Index Model (hereafter, population index) to spatially identify areas that contain population centers of breeding male GRSG based on a combination of breeding habitat probability and 2010−2014 lek data (fig. 26). Past work has shown that GRSG populations are highly clumped (Coates et al. 2015; Doherty et al. 2016). Relatively small areas can contain a disproportionate number of males attending leks (Doherty et al. 2011b), and large differences in the density of birds can occur even within the high GRSG breeding habitat probability category. The population index serves as a proxy for relative abundance of GRSG, which allows for a spatial delineation of where threats (e.g. conifer expansion) can be targeted for management. This population index model is representative of GRSG populations between 2010 and 2014 and will need periodic updates.

7.2.3 Use and Limitations of the Breeding Habitat and Population Index Models

Partial probability plots were used to elucidate habitat relationships among the variables in the final breeding habitat model for GRSG (Doherty et al. 2016). These types of figures demonstrate how the probability of the landscape supporting a breeding population of GRSG changes relative to specific habitat variables (e.g., landscape cover of sagebrush) (fig. 27). Partial probability plots of habitat relationships can also be used to identify thresholds in which non-habitat features exceed the tolerance of a species. However, because the habitat characteristics of species are defined by multiple variables (e.g., James 1971), use of a spatially explicit model is preferred over using threshold values of a single habitat variable such as that identified in fig. 27. However, graphing the probability of lek occurrence relative to a single variable can be used to evaluate the effect of the variable of interest.

One of the primary limiting factors of these models is the focus on the breeding location. Although the majority of nesting occurs within a radius of 4 miles (6.4 km; Coates et al. 2013; Holloran and Anderson 2005) around the leks, seasonal habitat (e.g., winter) and areas that link seasonal habitats may be located elsewhere and may be a limiting factor in some populations. Identification of seasonal habitats for Greater sage-grouse across their entire range is a priority science need (ASPT 2016).

The metrics used to develop these models are very broad in scale and the modeled response is not specific to any particular life stage. Lek based models do not account for habitat selection or demographic responses. For those populations where data regarding the needs of each life stage and spatially explicit maps are available at finer resolution, this information may be more useful for management purposes.

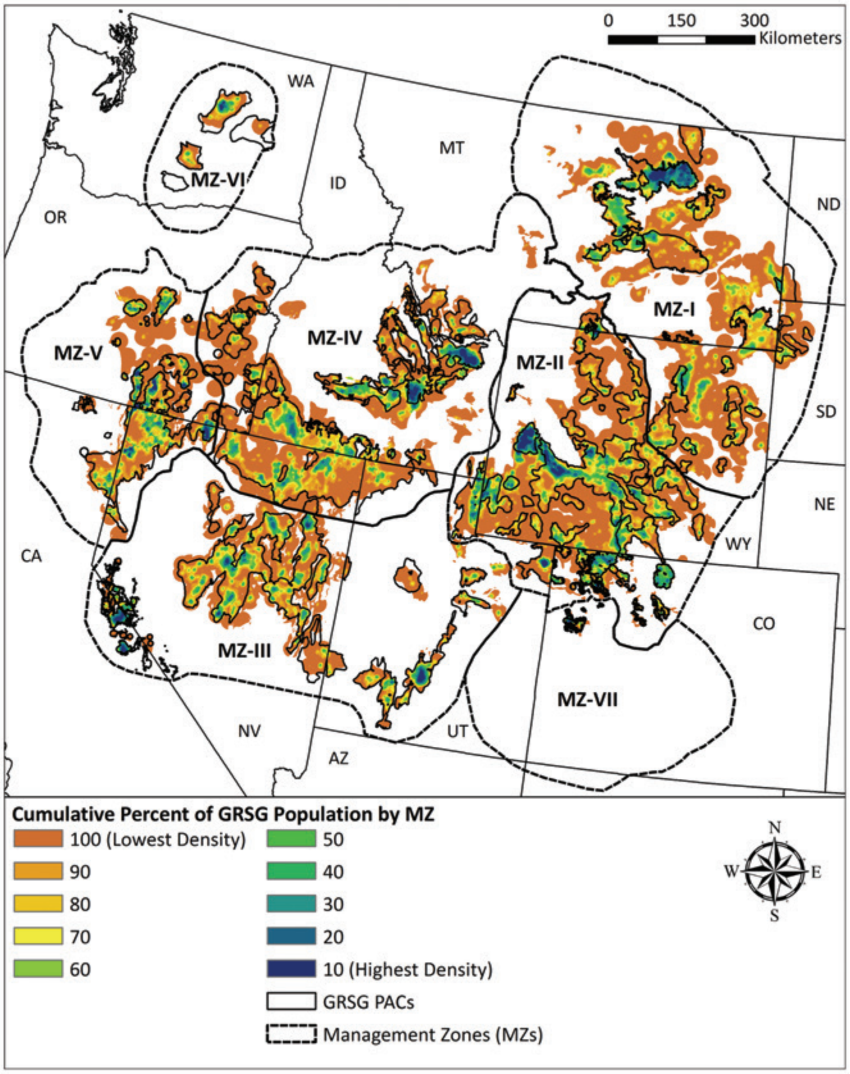


Figure 26—Cumulative percent of the GRSG population based on breeding bird abundance during 2010–2014 (Doherty et al. 2016). The 10 percent bin includes 10 percent of the GRSG population; the blue and green colors include 60 percent of the GRSG population; all colors include 100 percent of the population. This population index was developed to spatially identify areas that contain population centers of breeding male Greater sage-grouse.

7.3 Landscape Cover of Sagebrush as an Indicator of Habitat

In the absence of spatially explicit habitat models such as those developed by Doherty et al. (2016), habitat variables such as type and extent of landscape cover and type and magnitude of predominant disturbances can provide a viable alternative for assessing the probability of suitable habitat and informing management decisions. Landscape cover of sagebrush has been shown to be an important predictor of persistence of GRSG and other sagebrush obligate species (Aldridge et al. 2008; Donnelly et al. 2016; Hanser et al. 2011; Knick et al. 2013; Rowland et al. 2006; Wisdom et al. 2011). Sagebrush landscape cover is typically derived from remotely sensed land cover data such as LANDFIRE (USGS 2013) using a moving window

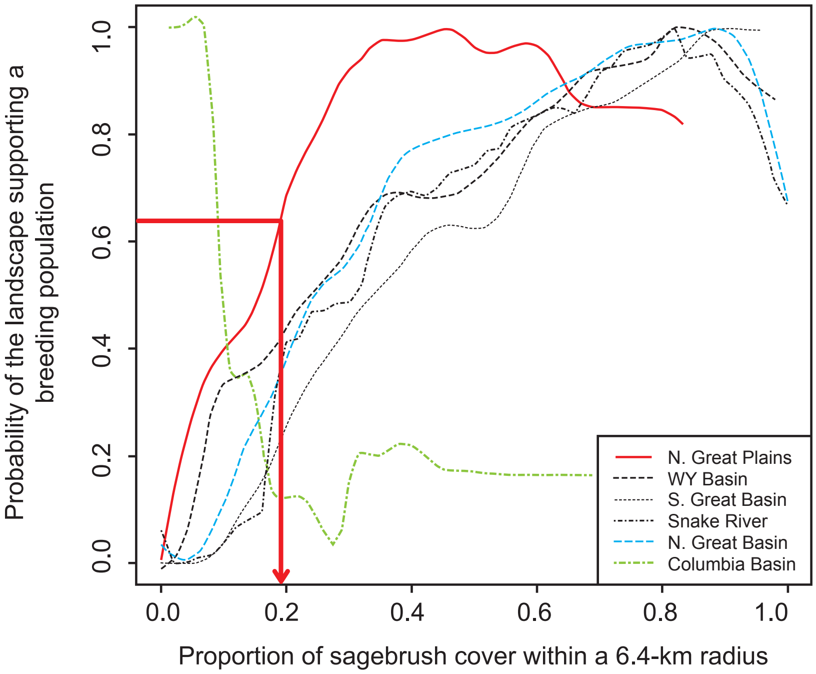


Figure 27— Partial probability plot depicting the effect of landscape cover of sagebrush on the probability of a landscape supporting a breeding population of GRSG (modified from Doherty et al. 2016). The red line shows the minimum level of sagebrush landscape cover needed to support a breeding population of GRSG based on a 4 mi (6.4 km) radius in the Northern Great Plains (Management Zone I). Landscape cover of sagebrush was derived from Landfire (USGS 2014).

analysis (figs. 28, 29; see Appendix 7 for an explanation of landscape cover and moving window analyses). Analyses of the landscape cover of sagebrush around GRSG leks in various portions of the range (Aldridge et al. 2008; Knick et al. 2013; Wisdom et al. 2011) indicated that the relative probability of lek persistence can be estimated using percentage landscape sagebrush cover. In general, low GRSG lek persistence occurs with 1 to 25 percent landscape cover of sagebrush, intermediate persistence with 25 to 65 percent, and high persistence with less than 65 percent (Chambers et al. 2014b).

These three categories of landscape cover of sagebrush were used to indicate the potential of an area to provide GRSG habitat in the western range GTR (MZs III, IV, V) that was published in 2014 (Chambers et al. 2014b), prior to development of the multi-variate breeding habitat models by Doherty et al. (2016). This approach was subsequently incorporated into the “Greater Sage-Grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment” (BLM 2014). In the analyses described in the General Technical Report (GTR) (Chambers et al. 2014b) and implemented in the assessment (BLM 2014), landscape cover of sagebrush was evaluated in conjunction with the GRSG breeding density data as in the Doherty et al. (2016) breeding habitat suitability model. In the Doherty et al. (2016) breeding habitat suitability model, landscape cover of sagebrush was among the top predictor variables in MZs III, IV, and V (table 5). Thus, while the Doherty et al. (2016) models may have provided additional information to inform the western range GTR and assessment, it is likely that highly similar results would have been obtained.

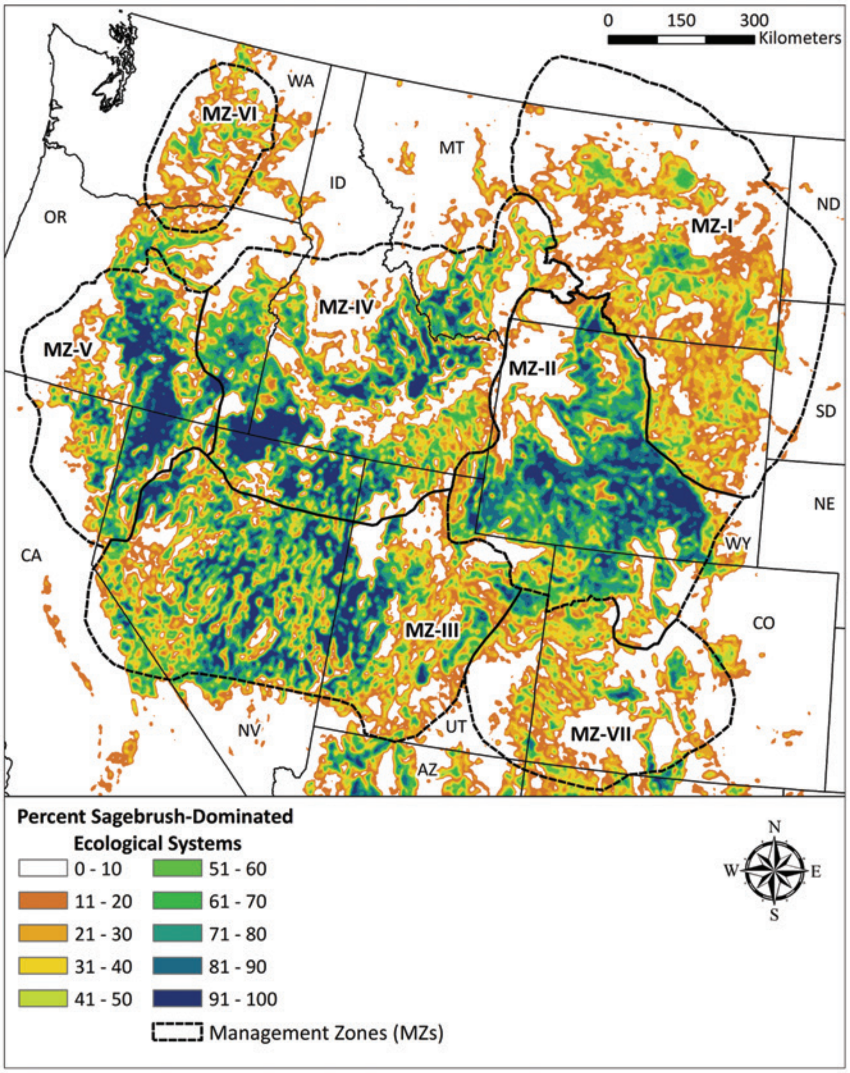


Figure 28—The landscape cover of sagebrush-dominated ecological systems (USGS 2014) displayed in 10 percent increments. Percentage of sagebrush within each of the categories was determined within a 3.1 mi (5 km) radius of each sagebrush pixel.

Analyses based on landscape cover of sagebrush and species population abundance can be used for other sagebrush obligate species until multi-variate models are developed for these species. For example, a recent rangewide analyses of sagebrush-obligate passerine birds indicates that there is a threshold of about 40 percent landscape cover of sagebrush for predicted counts of several species (Brewer's sparrow, *Spizella breweri*; sagebrush sparrow, *Artemisiospiza nevadensis*; sage thrasher, *Oreoscoptes montanus*) (fig. 30; Donnelly et al. 2016).

Analyses conducted for MZ I show that active leks are distributed across all of the above landscape sagebrush cover categories (when measured within 6.4 km of leks) (Chambers et al. 2016a). This is probably a function of: (1) the difficulty of accurately classifying sagebrush pixels in remotely sensed data for the West-central

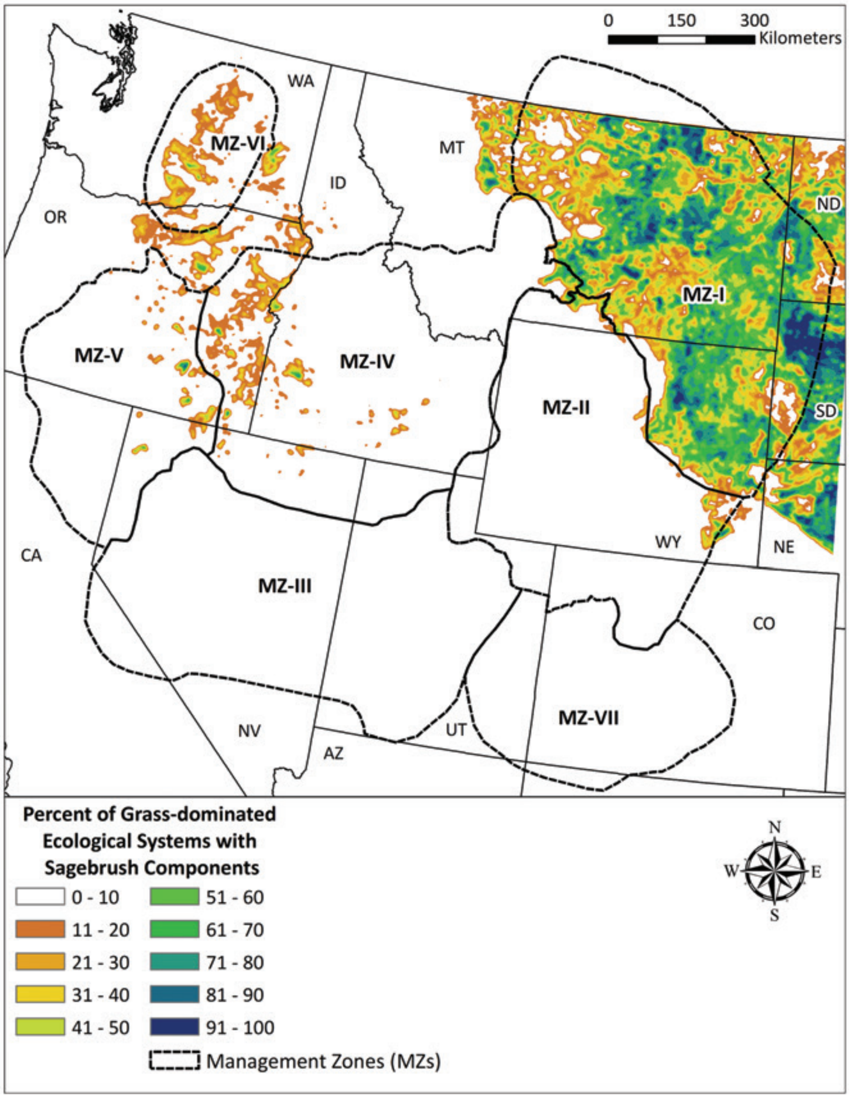


Figure 29—The landscape cover of grass-dominated ecological systems with sagebrush components (USGS 2014) displayed in 10 percent increments. Percentage of sagebrush within each of the categories was determined within a 3.1 mi (5 km) radius of each sagebrush pixel.

Semiarid Prairies, and (2) selection of breeding habitat by GRSG across a broader range of sagebrush landscape cover in MZ I than in other Management Zones. This finding reflects the fact that sagebrush land cover is only 14 percent in MZ I, compared to 45 percent in MZ II (Knick et al. 2011), where most active GRSG leks occur in areas of high sagebrush land cover.

Evaluating the type, extent, and magnitude of the threat(s), such as the dates and perimeters of past fires and locations and densities of oil and gas wells, can provide additional information on habitat characteristics. Coupling information on landscape cover of sagebrush and the predominant threats for a region provides necessary information for evaluating habitat characteristics.

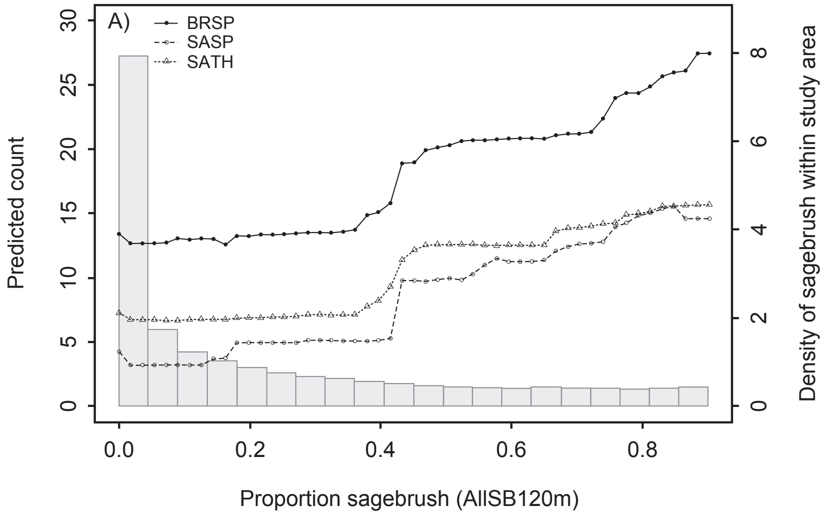
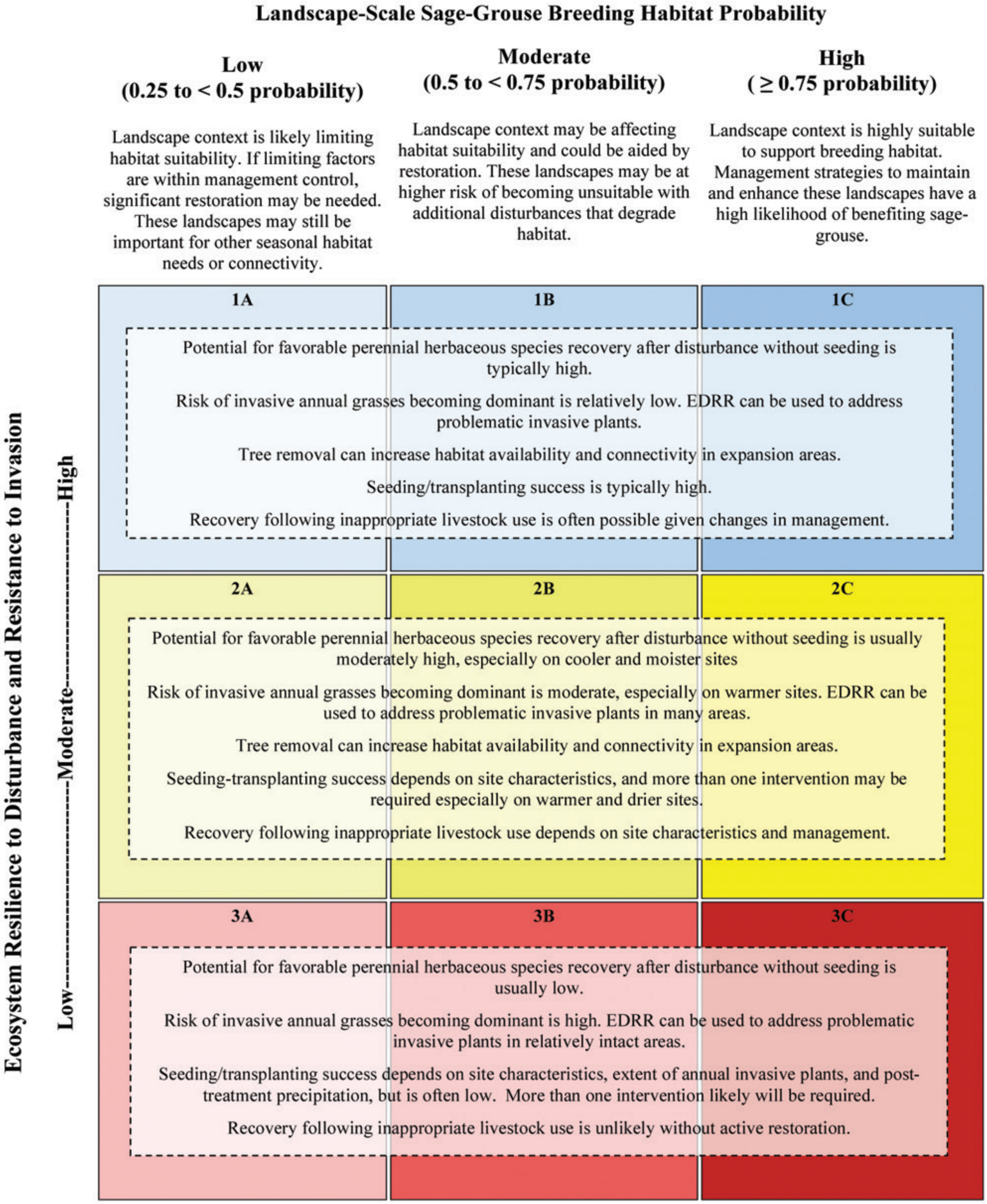


Figure 30—Partial dependence plot showing the predicted relationships among the proportion of sagebrush within a 120-m buffer and counts of Brewer's sparrow (BRSP), sagebrush sparrow (SASP), and sage thrasher (SATH) (Donnelly et al. 2016). There is an apparent threshold value of 40 percent landscape cover of sagebrush above which abundance of the different species increases. The background histogram is the frequency of covariate values across the landscape, and shows that a large proportion of sampled areas had low density of sagebrush (right y-axis).

7.4 Sage-Grouse Habitat Resilience and Resistance Matrix: A Key Prioritization Tool

Knowledge of resilience and resistance of sagebrush ecosystems can be used in conjunction with the probability that an area will provide GRSG breeding habitat to determine priority areas for management and identify effective management strategies (Chambers et al. 2016a). The sage-grouse habitat resilience and resistance matrix (table 8) 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. As resilience and resistance go from high to low, as indicated by the rows in the matrix, the amount of time required for sagebrush regeneration and perennial grass and forb regrowth progressively limits the capacity of sagebrush ecosystems to recover after disturbances without management assistance. Also, the risk of invasive annual grasses increases, and the ability to successfully restore burned or otherwise disturbed areas decreases. As the probability of GRSG breeding habitat goes from low to high within these same ecosystems, as indicated by the columns in the matrix, the capacity to sustain populations of GRSG increases. Areas with breeding habitat probabilities of 0.25 to less than 0.5 are unlikely to provide adequate breeding habitat for GRSG (table 7; Chambers et al. 2016a). Areas with breeding habitat probabilities of 0.5 to less than 0.75 can provide breeding habitat for GRSG, but are at risk if sagebrush loss occurs without regeneration or if other factors negatively impact the area, such as conifer expansion, development, or infrastructure (table 7; Chambers et al. 2016a). Areas with breeding habitat probabilities greater than or equal to 0.75 can provide the necessary breeding habitat conditions for GRSG to persist.

Table 8—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 (see Appendix 2; Maestas et al. 2016a) and relate to the sagebrush ecological types in table 6. Columns show the landscape-scale sage-grouse breeding habitat probability based on 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 text. Potential management strategies for persistent ecosystem threats, anthropogenic threats, and climate change are in table 9.



		Landscape-Scale Sage-Grouse Breeding Habitat Probability	
Ecosystem Resilience to Disturbance and Resistance to Invasion	Low (0.25 to < 0.5 probability)	Moderate (0.5 to < 0.75 probability)	High (≥ 0.75 probability)
	Landscape context is likely 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.	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.	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.
High	1A	1B	1C
	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. Recovery following inappropriate livestock use is often possible given changes in management.		
Moderate	2A	2B	2C
	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.		
Low	3A	3B	3C
	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.		

The sage-grouse habitat resilience and resistance matrix is a decision support tool that allows land managers to better evaluate risks at mid- to local-scales and decide where to focus specific activities to promote desired species and ecosystem conditions (table 8; Chambers et al. 2014c, 2016a). Management strategies can be determined by considering: (1) an area's resilience to disturbance and resistance to nonnative invasive plants, (2) GRSG breeding habitat index values, and (3) the predominant threats to both sagebrush ecosystems and their associated GRSG populations.

Management strategies for sagebrush ecosystems have been organized by threat and are found in table 9. Management strategies often cross-cut multiple program areas for land management agencies and an integrated approach is typically used to address the predominant threats. For example, agency program areas such as invasive plant management, fuels management, range management, wildlife, and others may all contribute to vegetation management strategies designed to address persistent ecosystem and land use and development threats.

Areas with high GRSG breeding habitat probabilities and high concentrations of birds are typically comprised of intact habitats and thus are higher priorities for management (table 8 cells 1C, 2C, 3C). Protective management can be used in and adjacent to these areas to maintain habitat connectivity and ecosystem resilience and resistance. Protective management can include a diverse set of strategies such as reducing or eliminating disturbances from land uses and development, establishing conservation easements, utilizing an early detections and rapid response approach (EDRR) (USDOI 2016) for invasive plant species, and suppressing fires (table 9). Areas with high GRSG breeding habitat probabilities but lower resilience and resistance are slower to recover following fire and surface disturbances and are more susceptible to invasive plant species than areas with higher resilience and resistance (Chambers et al. 2014a). Consequently, these low resilience and resistance areas are at greater risk of habitat loss than areas with moderate to high resilience and resistance and are high priorities for protective management (table 8, cell 3C; Chambers et al. 2014c, 2016a).

Areas with moderate GRSG breeding habitat probabilities are comprised of habitat that supported a higher proportion of leks in the past than currently (table 7) and that may be improved through various management strategies (table 8 cells 1B, 2B, 3B). Management objectives may include increasing resilience and resistance by promoting perennial grasses and forbs and biotic soil crusts, identifying and correcting improper livestock management, removing conifers, reducing or eliminating new infestations of invasive plants through EDRR approaches, or restoring sagebrush habitat through seeding or transplanting (table 9). Management strategies often have synergistic effects (Chambers et al. 2017). Increasing abundance of native perennial grasses and forbs can decrease the probability of invasion or expansion of annual invasive grasses (Chambers et al. 2007; Reisner et al. 2013). This, in turn, can reduce the risk of altered fire regimes, transitions to undesired states, and decreased connectivity. Similarly, management strategies aimed at reducing the risk of wildfires outside of the historical range of variation, such as removing conifers in Phase I and Phase II expansion areas, can increase the functional capacity of plant communities to resist invasive annual grasses (Chambers et al. 2014c; Roundy et al. 2014) as well as enhance habitat connectivity (Baruch-Mordo et al. 2013).

The relative resilience and resistance of an area strongly influences its response to management strategies such as conifer removal or postfire rehabilitation and the likelihood of nonnative annual grass invasion (Chambers et al. 2014a,c; Miller et al. 2013, 2014, 2015). Areas with lower resilience and resistance may still be high priorities for management in areas with moderate breeding habitat probabilities, but management activities such as restoring sagebrush habitat through seeding or transplanting may require greater investment and repeated interventions (table 8 cell 3B; Chambers et al. 2014b; 2016a). In areas projected to exhibit large changes in climate, favoring or restoring native species that are expected to be better adapted to the future range of climatic and site conditions may help increase restoration success (Butler et al. 2012).

Areas with low GRSG breeding habitat probabilities are characterized by habitat that supported active GRSG leks in the past, but that currently support few leks (table 8 cells 1A, 2A, 3A). If land use and development threats such as oil and gas development or cropland conversion are causing low GRSG breeding habitat probabilities, then habitat improvement may not be feasible. However, if the area has the capacity to respond to management treatments and if breeding populations are close enough for recolonization, improvement of these areas to increase breeding habitat probabilities may still be possible. Managers may decide to restore critical habitat in these types of areas, but the degree of difficulty and time frame required for habitat restoration increase as resilience and resistance decrease (Chambers et al. 2014b, 2016a). In those areas where interactions between climate change and stressors are projected to be severe, management actions may be needed that help ecosystems transition to new climatic regimes (e.g., Millar et al. 2007, 2012).

Careful assessment of the area of concern will always be necessary to determine the relevance of a particular strategy or treatment because sagebrush ecosystems occur over continuums of environmental conditions, such as soil temperature and moisture, have differing land use histories and species composition (Miller et al. 2014, 2015; Pyke et al. 2015a,b), and are projected to experience different climate change effects (Appendix 3). Also, areas with low GRSG breeding habitat probabilities may support other resource values or at-risk species (Rowland et al. 2006) that could benefit from management strategies designed to improve habitat. Knowledge of the locations of other priority resources and at-risk species and their response to management treatments can help ensure that treatments are located and strategies are implemented in a manner that will not harm and ideally benefit these other resources and species.

Table 9—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 8). Threats and strategies are cross-cutting and affect multiple program areas. While many of these fall under the broad umbrella of vegetation management, a coordinated and integrated approach will likely be used in addressing threats. For example, it is expected that multiple agency program areas such as nonnative invasive plant management, fuels management, range management, wildlife, and others 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 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 (crested wheatgrass, smooth brome, etc.) in postfire rehabilitation or restoration in moderate to high resilience and resistance areas because these species can dominate sagebrush communities; and
        - Practice Early Detection-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 will likely 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, fuels 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.

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 (cell 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.

Fuels Management: Fuels management is a subset of vegetation management. Fuels 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 fuels 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 and/or more fire resistant species where native perennial grasses and forbs are depleted. When setting priorities for fuels 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 and 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) post-settlement conifer stands to maintain shrub/herbaceous cover and reduce fuel loads;
    - Tree removal in later phase (Phase III) post-settlement conifer stands to reduce risks of large or high severity fires; and
    - Herbicide and/or seeding associated with mechanical treatments to reduce invasive species and restore native perennial herbaceous species where native perennial species are depleted.

Mechanical Treatments—Conifer Removal

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 (greenstrips).

- 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 are:
    - Implemented where fire managers believe they will benefit suppression efforts;
    - Designed at large landscape scales, providing multiple options for fire managers;
    - Designed collaboratively with interdisciplinary specialists, private landowners, fire response partners, and other agencies;
    - Include plans for long-term monitoring and maintenance;
    - Designed 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;
    - Includes conservation buffers around sagebrush leks, habitat fragmentation thresholds and minimum habitat patch sizes;
    - Includes the influence on habitat connectivity between seasonal sage-grouse habitats;
    - Follow technical guidance related to recommended design features (see Maestas et al. 2016b).

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 (30.5 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 postburn
- Use prescribed fire cautiously and selectively in moderate to high resilience and resistance areas, after consultation 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;
    - Historic 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).

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 (top soil 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):
    - 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.

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 towards 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 and/or cool season species 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.

7.5 Adapting the Sage-Grouse Resilience and Resistance Matrix and Management Strategies to Other Sagebrush Obligate Species

Management strategies associated with the sage-grouse habitat matrix are designed to maintain or restore large contiguous areas of sagebrush habitat and to recover species distributions and population abundance. Consequently, the priorities and strategies are applicable to all sagebrush obligate species that benefit from large extents of intact sagebrush habitat at landscape scales. Adapting the habitat matrix for species other than GRSG first requires accurately delineating the occupied range of the species to ensure that management strategies and treatments target the right locations. It then requires identifying the probability of suitable habitat for the focal species. Ideally, this would be based on the suite of land cover, climate, landform and disturbance variables that characterize species habitat. However, rangewide habitat probability models that incorporate these variables have only been developed for GRSG and GUSG (Chambers et al. 2016a; Doherty et al. 2016). The majority of other sagebrush-associated species have poorly defined range maps. Until range-wide models are developed for other species, models developed at the ecoregion scale can help guide habitat management strategies for individual species or species groups.

For example, in the Wyoming Basins Ecoregion, models for three sagebrush obligate passerines (Brewer's sparrow, sagebrush sparrow, and sage thrasher) have been developed (fig. 31; Aldridge et al. 2011). Both the scale and strength of the relationship between density and landscape cover of sagebrush differ among these species, and these models highlight the challenge of utilizing a single metric to characterize the landscape for multiple species within the sagebrush biome (fig. 31). However, all three species were more likely to occur, and increase in abundance, in areas

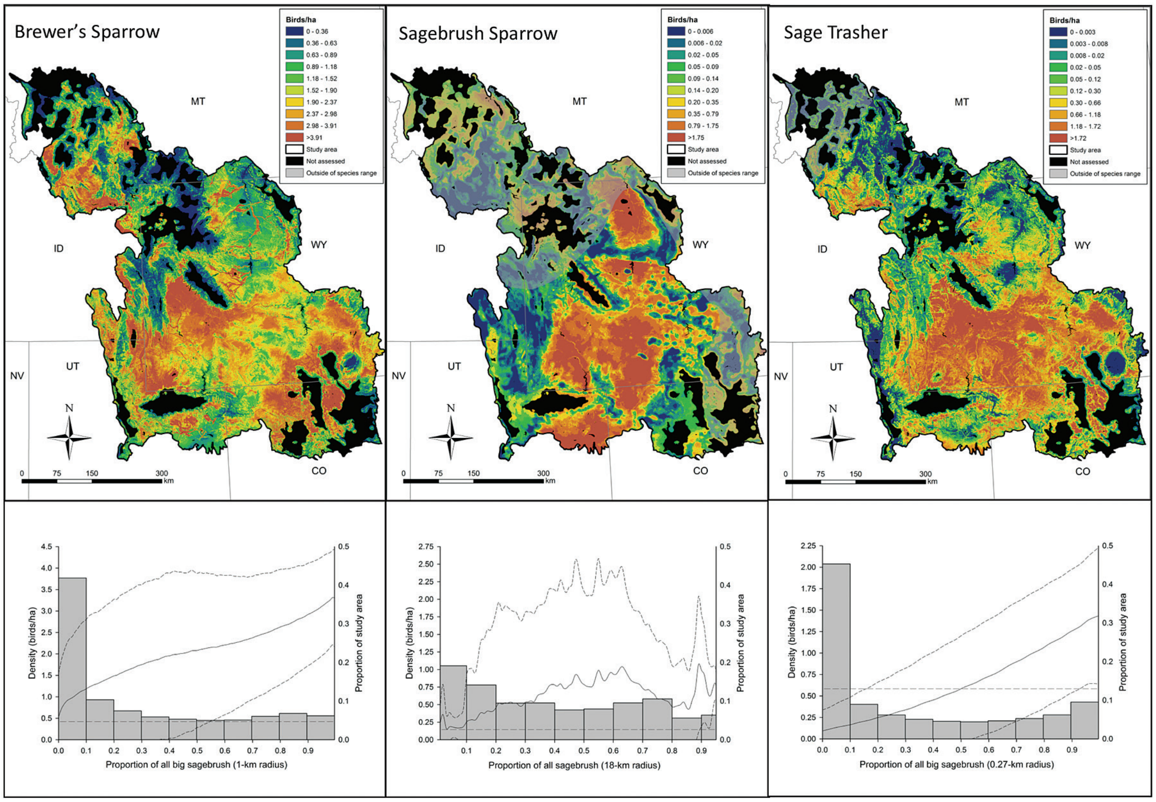


Figure 31—Maps at the top of the figure depict model output of relative bird density for three sagebrush obligate passerine species (Brewer's sparrow, sagebrush sparrow, and sage thrasher) in the Wyoming Basins Ecoregional Assessment area (Aldridge et al. 2011). Relationship between bird density and landscape cover of sagebrush for each species and the availability of sagebrush in the landscape are shown in the graphs below the map for each species. The scale and strength of the relationship between bird density and landscape cover of sagebrush differ among species highlighting the challenge of utilizing a single metric to characterize the landscape for multiple species within the sagebrush biome.

with higher landscape cover of sagebrush. Thus, improving the overall extent and condition of sagebrush land cover will likely benefit all three species. Development of range-wide models for these species using Breeding Bird Survey data (Pardieck et al. 2015) is underway (Donnelly et al. 2016). Preliminary results indicate that thresholds for occurrence exist at finer spatial scales (250 m radius) and that three occurrence probability categories could be developed at this scale: low = 0 to 40 percent, moderate = 40 to 70 percent, and high = 70 to 100 percent (fig. 30).

For other sagebrush-associated species that do not currently have these types of models, developing habitat requirements will likely involve deriving categories of landscape cover of sagebrush for the species of interest (see Chambers et al. 2014b). If data are available, an evaluation of the appropriate scale for measuring sagebrush land cover and the strength of the species' relationship to sagebrush land cover could help ensure that the spatial scale and habitat management strategies represent landscapes appropriate for the species. Also, depending on the species habitat requirements, other landscape and local factors, such as soil characteristics or water availability, may be needed to support other sagebrush dependent species. The WAFWA coordinated Sagebrush Science Initiative hopes to facilitate the development of habitat suitability models for additional sagebrush-obligate species in the near future.

8. Delineating Habitats For Targeted Management Intervention at the Biome and Ecoregion or Management Zone Scale

Effective conservation of sagebrush habitat and sagebrush obligate species benefits from an approach that prioritizes the best management practices in the most appropriate places. This section describes an approach for targeting areas for management based on four types of data: (1) species distribution and population abundance, (2) species habitat requirements, (3) ecosystem resilience and resistance, and (4) persistent ecosystem threats and land use and development threats. The approach involves a geospatial analysis in which the four types of data are overlaid and mapped. Here, key data layers are identified, the steps used to overlay and analyze the various data layers are discussed, and interpretations of the maps and analyses are provided. The geospatial data, maps, and models used to support these analyses are listed in Appendix 8 and provided through the USGS ScienceBase (https://www.sciencebase.gov/catalog/item/576bf69ce4b07657d1a26ea2) and BLM Landscape Approach Data Portal (http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/dataportal.html).

8.1 Assessing Priority Areas for Habitat Management: Key Data Layers and Their Use

8.1.1 Priority Areas for Conservation of GRSG

Priority Areas for Conservation (PACs) have been delineated using available habitat and population data to identify areas critical for conserving GRSG populations (FWS 2013). These areas can be used as a first filter in prioritizing management actions for GRSG. Habitats outside of PACs are also important to consider where they capture important seasonal habitats and provide genetic and habitat linkages (FWS 2013). The PACs were generally created using coarse scale approaches and do not always capture entire populations.

Many new products and habitat models have been developed since the PACs were delineated that can be used to help target conservation actions. Crist et al. (2017) recently evaluated habitat connectivity among PACs. Targeting conservation actions in the areas of high movement potential identified in Crist et al. (2017) may help maintain connected populations across PACs. See Appendix 9 for a detailed description. Without maintaining corridors to larger priority areas or a clustered group, isolation of small priority areas could lead to regional loss of GRSG.

8.1.2 Breeding Habitat Probabilities and Population Indices for GRSG

Mapping areas with high breeding habitat probabilities and population indices is a key aspect of prioritizing areas for management. The breeding habitat models provide information on habitat characteristics (fig. 25; table 5; Doherty et al. 2016), and the breeding habitat model probability classes show the proportion of active and inactive leks in each Management Zone for GRSG (table 7). These areas can be used to prioritize areas for management based on the probability of an area providing breeding habitat.

The population index model combines information from the breeding habitat model with lek count data to provide indices and spatial depictions of GRSG relative abundance (fig. 26; Doherty et al. 2016). Because the output of the population index model is a continuous surface or map, it can be used to focus conservation efforts on specified portions of GRSG populations identified by stakeholders (e.g., highest 25 percent or 85 percent of the population). Because of the large area currently occupied by GRSG, the population index model can be used to better focus management actions on areas that: (1) currently support viable populations, (2) provide connectivity between population centers, and (3) ensure that habitat restorations outside of breeding concentration areas occur in close enough proximity to allow successful recolonization of reclaimed habitat (Coates et al. 2016a).

The breeding habitat probability and population index models provide key elements in prioritizing target areas for management. However, because the habitat and population index models are based on lek data, other important seasonal habitats such as late brood-rearing and winter habitat may not be included. Models of seasonal habitat selection have been developed for Wyoming (Fedy et al. 2014), Nevada and northeastern California (Coates et al. 2016b), and Utah (Dahlgren et al. 2016), which can be used to inform management actions in these areas. Also, efforts are underway to develop rangewide GRSG seasonal habitat information (Cameron Aldridge, USGS, personal communication). Until this product is available, managers can rely on local knowledge or existing local-scale information (e.g., telemetry locations and genetic data) about seasonal movements, linkages among areas of sage-grouse use, and relative habitat quality.

8.1.3 Distribution and Species Population Data for Other Sagebrush Obligate Species

For most sagebrush obligate species, less information is available on species distributions and populations than for GRSG. An exception is sagebrush obligate passerines, but analyses of habitat requirements for these birds have focused on local populations and smaller scales (Donnelly et al. 2016; Hanser et al. 2011). For other species of interest, such as mule deer (*Odocoileus hemionus*), analyses are generally focused on specific ecoregions or are State-based (e.g., Copeland et al. 2014). For most invertebrates, reptiles, amphibians, and small mammals, only coarse habitat distribution data and little population data are available. The Sagebrush Science Initiative coordinated by WAFWA is working to identify focal species, compile available data for these species, and determine information gaps on these species for the sagebrush biome. Regional analyses may also help identify resources and species of concern (BLM Rapid Ecoregional Assessments); http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html; Hanser et al. 2011, Wyoming Basin; Wisdom et al. 2000, Columbia Basin; Wisdom et al. 2005, central Great Basin).

8.1.4 Landscape Cover of Sagebrush

In the absence of spatially explicit habitat models like those developed for GRSG (Doherty et al. 2016) and GUSG (Chambers et al. 2016a), landscape cover of sagebrush can provide important information on species habitat requirements (figs. 5, 28, 29). Landscape cover of sagebrush is a measure of large, contiguous patches of sagebrush on the landscape and is calculated from remote sensing databases such as LANDFIRE (see Appendices 7, 8). Categories of sagebrush landscape cover required to sustain species populations can be developed as illustrated for Brewer's sparrow, sagebrush sparrow, and sage thrasher (fig. 30). Sagebrush landscape cover datasets can be created using a moving window to summarize the proportion of area dominated by sagebrush that surrounds each 30-m pixel (radius determined by species habitat requirements), and then assigning those areas to the different categories (figs. 28, 29; see Appendix 7). Sagebrush cover from sources such as LANDFIRE may not exclude recent fire perimeters, therefore it may be necessary to either include recent fires in the analysis of landscape cover of sagebrush or display them separately. The time required for a burned area to provide desired GRSG habitat will depend on the characteristics of the fire, resilience and resistance of the area, and postfire management.

8.1.5 Resilience to Disturbance and Resistance to Nonnative Invasive Plants

Soil temperature and moisture regimes provide one of our best available data sets for evaluating resilience and resistance in the sagebrush biome (Chambers et al. 2014b, 2016a; Maestas et al. 2016a). The available data for soil temperature and moisture regimes were recently compiled for the western and eastern range of GRSG (Maestas et al. 2016a; Appendix 2), and relative resilience and resistance categories were developed from soil temperature and soil moisture subclass data (figs. 6, 32; Appendix 2; Maestas et al. 2016a). The soil temperature and moisture

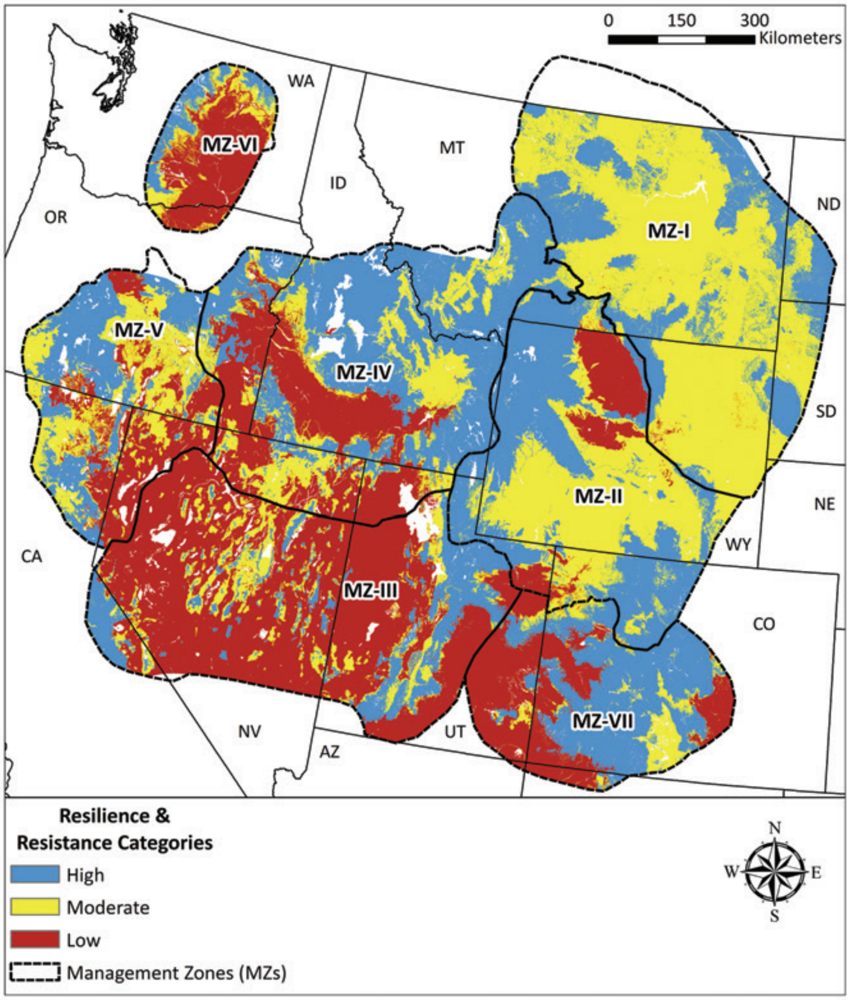


Figure 32—The soil temperature and moisture regimes categorized according to high, moderate and low resilience and resistance. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. More detailed categorizations can be used at finer regional and local scales. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 6.

regimes have been linked to dominant ecological types (table 6) and their associated state-and-transition models (Appendices 5, 6) for sagebrush ecosystems. Soil temperature and moisture regimes are a key component in prioritizing areas for management and evaluating effective management strategies at multiple scales (tables 8, 9).

8.1.6 Habitat Threats

Assessing the magnitude of persistent ecosystem and land use and development threats provides important insights into target areas for treatment and the most appropriate management strategies. Although habitat threats are considered in GRSG breeding habitat and in the GRSG population index models (Doherty et al. 2016), depicting threats to different populations is necessary to assess the magnitude of the threats and determine viable management strategies. Depicting threats is also necessary for determining management strategies for other sagebrush obligate or dependent species. The threats and data sources considered in this report largely follow those in IGSDMS (2014) and are in Appendix 8. New data layers included in the Science Framework are cheatgrass occurrence and large fire probability.

8.1.6.1 Cheatgrass Occurrence

Knowledge of the current distribution and abundance of cheatgrass on the landscape is a key component in planning and executing strategies to protect sagebrush ecosystems. Models of cheatgrass occurrence developed using biophysical and climate data can identify environmental characteristics that increase invasion risk, and the spatial outputs can help identify invaded areas. Downs et al. (2016) recently used ecological models based on a suite of climatic and biophysical variables and remotely sensed measures of peak NDVI (normalized difference vegetation index) to develop a map of cheatgrass occurrence (0 to 2 percent cover and >2 percent cover) across the historic range of sage-grouse (fig. 33). Field measurements of cheatgrass cover across the study area were used to develop correlations to these variables for use in the models. However, limited field measurements may have resulted in an underestimate of cheatgrass occurrence in the eastern portion of the range where cheatgrass is an emerging threat (Mealor et al. 2013). Thus, although the cheatgrass occurrence data layer can help inform management decisions in the eastern portion of the range, additional ecoregional or local information may be needed.

8.1.6.2 Large Fire Probability

Large fire probability can be used by managers in fire risk assessments to identify where habitats may be at a higher risk from fire and where recovery from fire may be more challenging based on resilience and resistance (see Appendix 10). A large fire probability layer was developed to depict the likelihood of large fires (>300 ac) over a 100-year period across the conterminous United States (Short et al. 2016). Spatial burn probabilities were modeled using LANDFIRE ecological systems, fuel and terrain data, historical fire occurrence and weather data, and fire danger rating information. To obtain estimates of large fires, fire ignition and growth were simulated for 10,000 to 100,000 potential annual weather scenarios using a geospatial Fire Simulation (FSim) system developed by the U.S. Forest Service, Missoula Fire Sciences Laboratory (Finney et al. 2011). The large fire burn probability layer shown here was extracted from the national dataset to represent likelihood

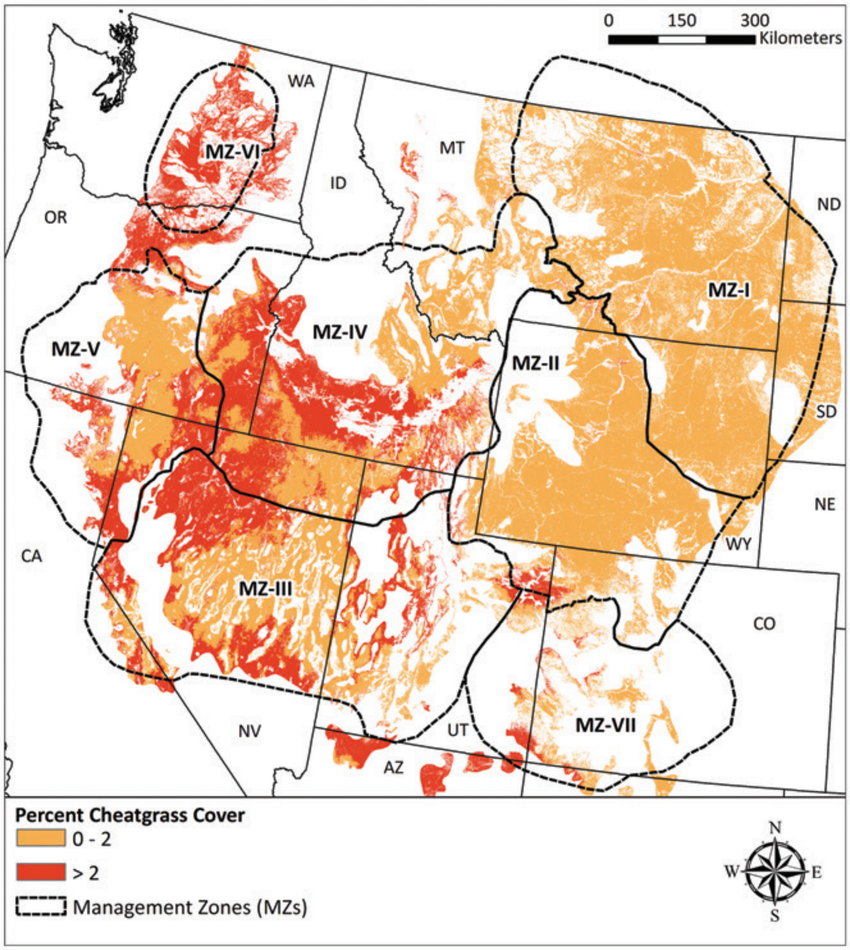


Figure 33—Percent cover of cheatgrass from ecological models based on climate and biophysical variables, remotely sensed measures of NDVI (normalized difference vegetation index), and field measurement of cheatgrass cover for the historic range of sage-grouse (Downs et al. 2016).

of wildfire in absence of suppression efforts specifically for the sagebrush biome (fig. 34). Large fire probability can be used by managers in the sagebrush biome for mid-scale fire risk assessments to identify where habitats may be at a higher risk from fire and where recovery from fire may be more challenging based on resilience and resistance (see Appendix 10).

8.1.6.3 Other Data Sources for Threats

More refined data products are often available at mid- to local-scales. For example, BLM Rapid Ecoregional Assessments contain a large amount of geospatial data that may be useful in providing regional information on vegetation types and persistent and land use and development threats across most of the range of GRSG (https://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html). High resolution geospatial data for cultivation risk layers are available (Smith et al. 2016), and piñon and juniper landscape cover (Falkowski et al. 2017) is available for the western portion of the range and is being developed for the eastern portion of the range (http://map.sagegrouseinitiative.com/). Also, a

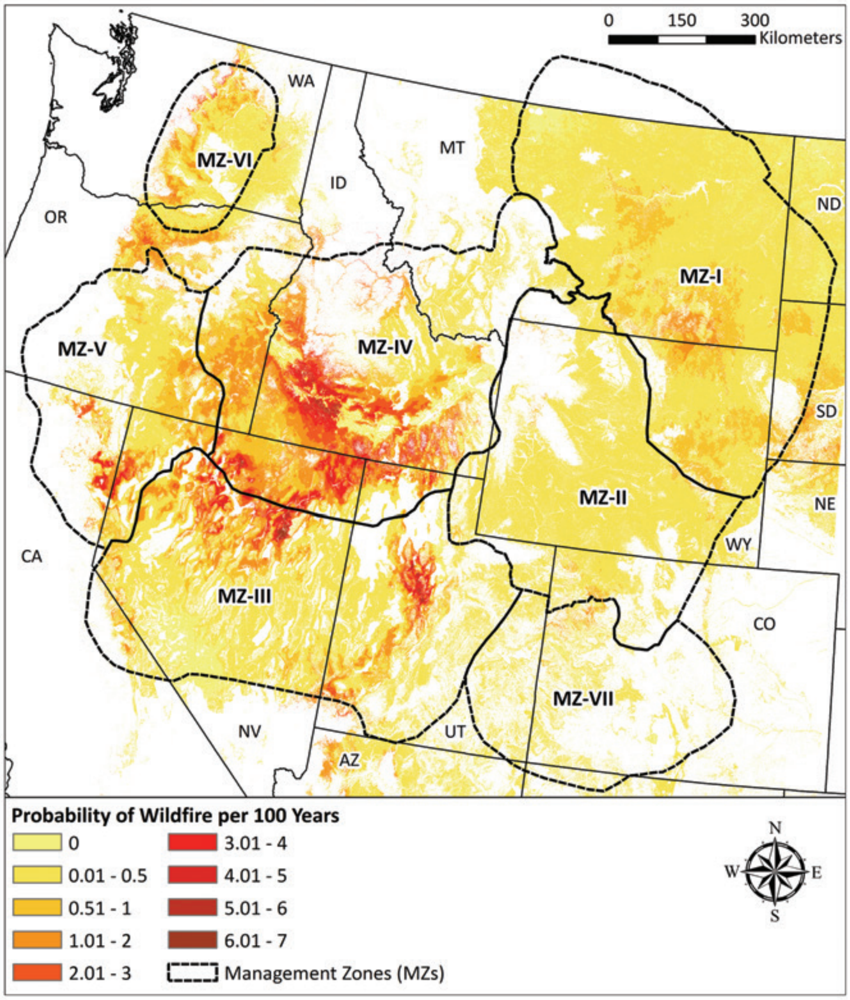


Figure 34—Large fire probability for the sagebrush biome derived by simulating fire ignition and growth using the Fire Simulation (FSim) system (Finney et al. 2011; Short et al. 2016).

cheatgrass data layer was developed for the northern Great Basin in 2015 based on high frequency remote sensing data https://www.sciencebase.gov/catalog/item/55ad3a16e4b066a2492409d5 (Boyte and Wylie 2016). Land managers can evaluate the available land cover datasets for the targeted area and select those datasets with the highest resolution and accuracy.

8.1.7 Climate Change

Climate change projections allow managers to consider potential changes in climate when prioritizing areas for management and evaluating management strategies.

8.1.7.1 Climate Change Projections for Key Climate Variables

For the Science Framework, climate change projections were developed for climate variables important to sagebrush ecosystems (see Appendix 3). Eleven general circulation models (GCMs) were used to project climate changes for two future time periods (2020−2050 and 2070−2100) and for two representative concentration pathways (RCP 4.5 and RCP 8.5), which assume moderate and high greenhouse gas emission scenarios, respectively. The climate projections for the entire sagebrush biome and the different geographic areas are in Section 5.2, “Persistent Ecosystem Threats: Climate Change.” The maps and graphs in the appendix illustrate the magnitude of change projected and can be used similarly to data layers for persistent ecosystem threats.

8.1.7.2 Wyoming Big Sagebrush Climate Niche Models

Climate is the predominant factor affecting plant distributions and species adaptations to their environment. Understanding how climate change could affect species distributions requires two data elements: (1) species and subspecies presence and absence locations and (2) gridded climate surfaces. Still and Richardson (2015) projected the contemporary and mid-century distribution of Wyoming big sagebrush using presence and pseudo-absence points. This data has been reanalyzed using two representative concentration pathways (RCP 4.5 and RCP 8.5) from the fifth phase of the IPCC and CMIP5 for the Science Framework. Following Crookston and Rehfeldt (2008), gridded climate surfaces of RCP 4.5 and 8.5 were downscaled (~1 km^2) for three time periods: 2025−2035, 2055−2065, and 2085−2095. The presence and absence model of Wyoming big sagebrush developed from climate variables (see Appendix 3) were mapped for these time periods and RCPs (fig. 35).

This modeling process provided a projection of areas more susceptible and more resilient to climate change. The model also indicated a potential major decline in the area suitable for Wyoming big sagebrush, which is currently the most prevalent big sagebrush species in the Great Basin. These projections of climate can also serve to overlay adaptive genetic variation to assess the impact of climate change at the population level and provide guidance in seed transfer for restoration (Chaney et al. 2016; Richardson et al. 2016). See Appendix 11 for an explanation of seed transfer guidelines for the sagebrush biome.

8.2 Assessing Priority Areas for Habitat Management: Overlaying Data Layers

8.2.1 Assessing Differences in Resilience and Resistance and Persistent Ecosystem Threats at the Sagebrush Biome Scale

The ecoregions and Management Zones within the sagebrush biome have differences and similarities in: (1) resilience and resistance (fig. 32; table 6), (2) persistent ecosystem (e.g., figs. 7, 10) and land use and development threats (figs. 14, 16, 18, 20), and (3) GRSG breeding habitat probabilities (fig. 25) and population indices (fig. 26). An understanding of these differences can help to inform resource needs and budget prioritization at the sagebrush biome scale. A summary of relative resilience and resistance, GRSG breeding habitat probabilities, and GRSG breeding populations is provided for each Management Zone and the PACs within each Management Zone in Appendix 12. In addition, a summary of wildfire area is provided as one example of a widespread persistent ecosystem threat that differs across Management Zones, but that significantly influences management strategies in those Management Zones with high wildfire areas (Appendix 13).

Overlaying breeding habitat probabilities with resilience and resistance categories for the PACs in each Management Zone provides information on the capacity of the Management Zones to support breeding populations and the relative risk of persistent ecosystem threats such as invasive annual grasses and wildfire. In the eastern

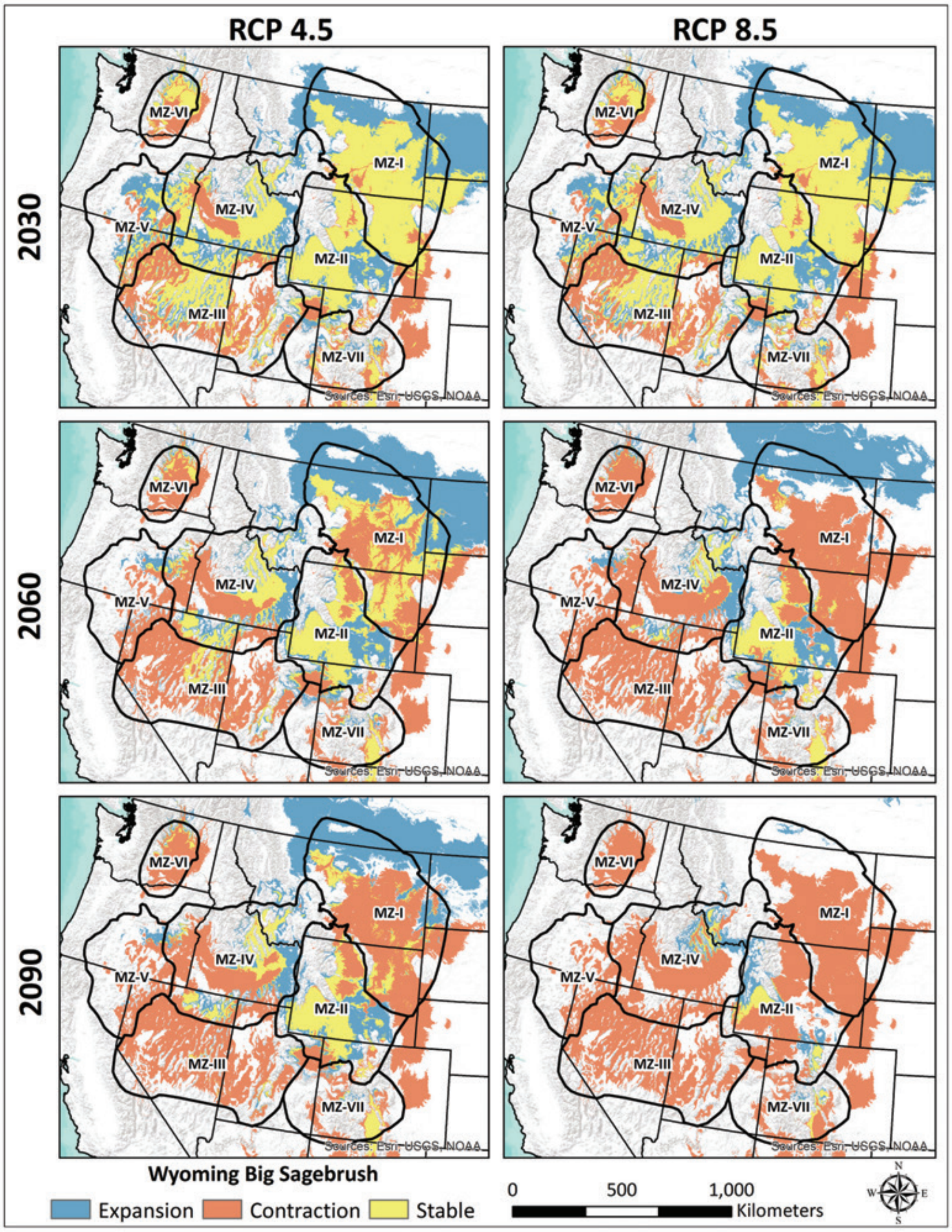


Figure 35—A climatic niche model for Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) projected for three decades and two greenhouse gas emission scenarios (representative concentration pathways, RCP). The columns show scenarios with moderated emissions, RCP 4.5, and unabated emission, RCP 8.5. The rows reflect the decade surrounding 2030, 2060, and 2090. Colors represent areas of expansion, contraction, and stability. The climatic niche model is adapted from Still and Richardson (2015).

part of the range (MZ I, II, VII), a large amount of the area with high to moderate breeding habitat probabilities has high to moderate resilience and resistance indicating that much of this area has the capacity to recover from disturbances given appropriate management (fig. 36; Appendix 12). In the western part of the range (MZ III, IV, V, VI), large areas with high to moderate breeding habitat probabilities are characterized by low resilience and resistance (fig. 36; Appendix 12). The implications of these differences in resilience and resistance are detailed in Sections 6 and 7. In general, areas with low resilience and resistance are more susceptible to invasive annual grasses such as cheatgrass and require longer periods for recovery from either disturbances or management treatments (Chambers et al. 2014a,c; Miller et al. 2013; Pyke et al. 2015a,b). However, invasive annual grasses are an emerging threat in warmer and drier areas of the eastern part of the range (Baker 2011; Brooks et al. 2015; Knight et al. 2014; Mealor et al. 2013) and populations often increase on sites disturbed by development activities (Manier et al. 2011, 2014a,b; Nielson et al. 2011).

Overlaying wildfire area from 1984−1999 and from 2000−2014 with resilience and resistance categories and evaluating differences in fire numbers and size for the PACs in each Management Zone provides information on the differences in the magnitude of the threat among Management Zones. In the western part of the range (MZ III, IV, V, VI), total fire area, numbers of fires, and fire size have generally increased from 1984−1999 to 2000−2015 (Appendix 13). Fire area within the PACs in MZ IV, V, and VI doubled to tripled from 1984−1999 (8, 6, and 4 percent for MZ IV, V, and VI respectively) to 2000−2015 (19, 17, and 13 percent for MZ IV, V, and VI, respectively) (fig. 37; Appendix 13). The exception for the western part of the range was MZ III where fire area remained at about 4 percent from 1984−1999 to 2000−2015.

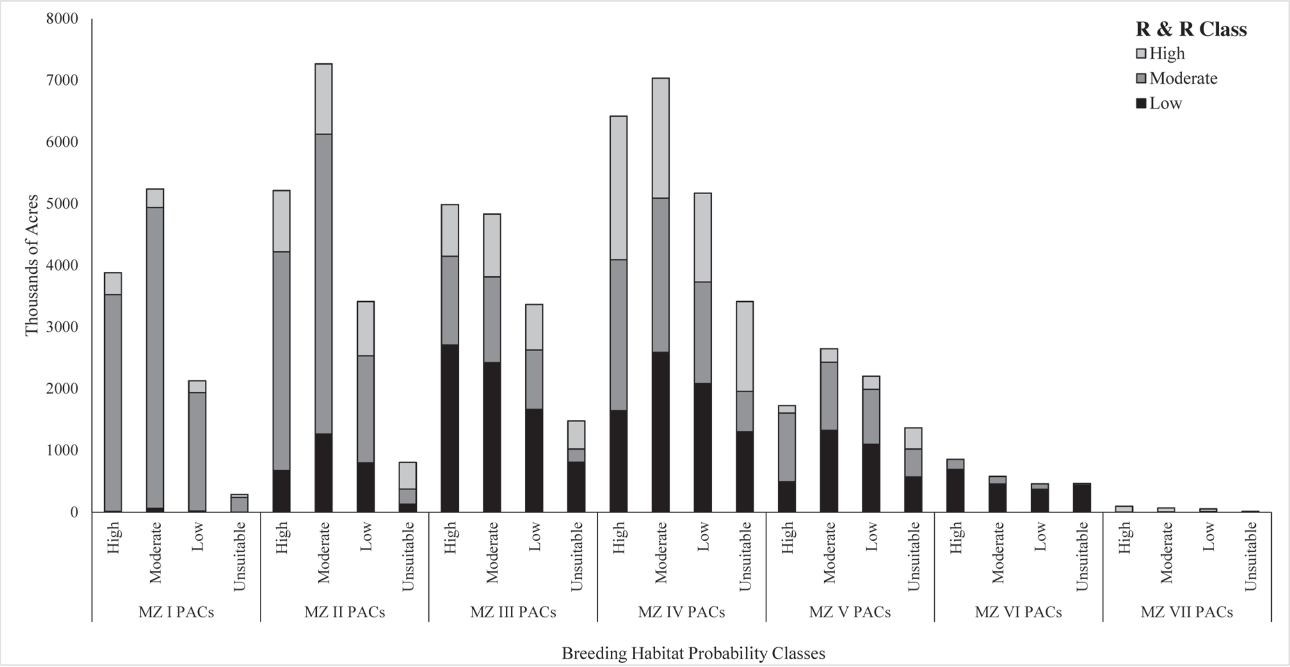


Figure 36—Greater sage-grouse breeding habitat probabilities by resilience and resistance (R&R) class in thousands of acres for Priority Areas for Conservation (PACs; FWS 2015) within the Management Zones (MZs; Stiver et al. 2006). Greater sage-grouse breeding habitat probabilities were based on 2010–2014 lek data (Doherty et al. 2016). The resilience and resistance classes are explained in Appendix 2. In the eastern part of the range (MZ I, II, VII), a large amount of the area with high to moderate breeding habitat probabilities has high to moderate resilience and resistance indicating that much of this area has the capacity to recover from disturbances given appropriate management. In the western part of the range (MZ III, IV, V, VI), large areas with high to moderate breeding habitat probabilities are characterized by low resilience and resistance are more susceptible to invasive annual grasses such as cheatgrass and require longer periods for recovery from either disturbances or management treatments.

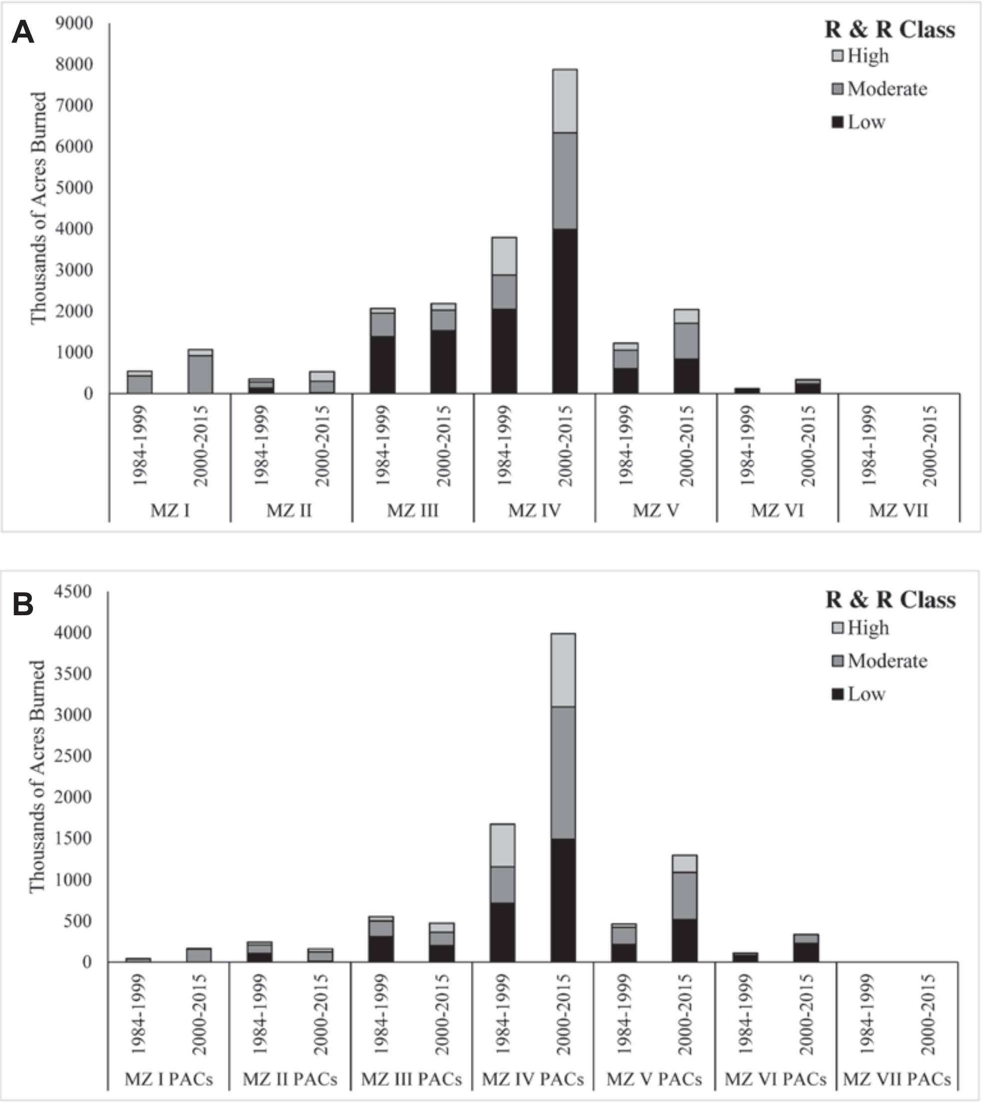


Figure 37—(A) Thousands of acres burned within the occupied range and (B) within Priority Areas for Conservation (PACs; FWS 2015) for Greater sage-grouse within each Management Zone (MZs; Stiver et al. 2006) by resilience and resistance (R&R) class. Data are for fires larger than 1,000 acres (MTBS 2014). The resilience and resistance classes are explained in Appendix 2. Fire area within the PACs in MZ IV, V, and VI doubled to tripled from 1984−1999 (8%, 6%, and 4% for MZ IV, V, and VI respectively) to 2000−2015 (19%, 17%, and 13% for MZ IV, V, and VI, respectively).

In contrast, in the eastern portion of the range (MZ I, II, VII), fire area within the PACs is smaller and has shown little change from 1984−1999 (0.4, 1.5, and 0.3 percent for MZ I, II, VII, respectively) to 2000−2015 (1.6, 1.2, and 0.3 percent for MZ I, II, and VII, respectively) (fig. 37; Appendix 13). Overall, this analysis is largely consistent with fire areas obtained by Brooks et al. (2015) and with their recent analyses showing that the western part of the range is exhibiting more fire than the eastern part of the range.

Climate change and other human-induced factors, including more extreme fire weather, invasive annual grasses, and human-caused fire starts, are resulting not only in increases in burn area, but also in individual fires of unprecedented size (Brooks et al. 2015; McKenzie et al. 2004). Since 1984, 1,021 fires over 1,000 acres

]

(405 ha) burned within PACs in the western portion of the range, but just 12 large fires, 100,000 acres (40,469 ha) to 500,000 acres (202,343 ha) in size, accounted for 27 percent of the area burned (table 10). An additional 187 fires, 10,000 acres (40.5 km^2) to 100,000 acres (40,469 ha) in size accounted for 47 percent of the area burned. The majority of the fire area was concentrated during years of large fires as found elsewhere (Brooks et al. 2015).

A relatively high percentage of total fire area (37 percent or more) in the western portion of the range was in the low resilience and resistance category (fig. 37). Historically, areas with low resilience and resistance typified by Wyoming big sagebrush burned less frequently than higher resilience and resistance areas characterized by mountain big sagebrush and mountain brush due to lower productivity and thus lower fuel loads (Miller et al. 2013). This summary indicates that these low resilience and resistance areas currently appear to be burning at least as frequently as the higher resilience and resistance areas. Similar, recent analyses by Brooks et al. (2015) provide strong evidence for increased fire area for all sagebrush types (based on LANDFIRE biophysical settings; Rollins 2009) combined in the Snake River Plain and Columbia Plateau.

Table 10—The number, area, and percentage of fires greater than 1,000 acres (4 km^2) (MTBS 2014) by fire size within the Priority Areas for Conservation (PACs; FWS 2013).

Fire size (acres)	Number of fires	Fire area (acres)	Fire area (%)
1,000 to 2,000	338	485,696	5
2,000 to 5,000	325	1,022,302	10
5,000 to 10,000	159	1,117,731	11
10,000 to 100,000	187	4,621,893	47
100,000 to 500,000	12	2,576,175	27
Total	1,021	9,823,798	100

8.2.2 Prioritizing Areas for Management at Ecoregion and Management Zone Scales

Assessments of priority areas for management are typically conducted at the scale of ecoregions or Management Zones (fig. 1; table 2) because of similarities in biophysical characteristics and thus management strategies and treatments. 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. The maps and analyses that managers derive from this process are an essential component of prioritizing areas for management actions and developing management strategies. The steps in the geospatial analysis are based on those identified in table 1 and are described below. The maps used to illustrate the steps are from the GRSG range.

1. First, determine focal species and resources and delineate their distribution and area using the best information available. For GRSG, this includes PACs, breeding habitat probabilities, the population index (Doherty et al. 2016), and breeding bird densities (figs. 25, 26).

Second, determine the probability of suitable habitat. For GRSG, this is the breeding habitat probability (table 7; low = 0.25 to <0.50, moderate = 0.50 to <0.75, high = 0.75 to 1.0). For other species (e.g., mule deer, localized pygmy rabbit populations), available species distribution data and habitat selection modeling can be used. For many sagebrush-obligate species, the probability of suitable habitat will likely be based on landscape cover of sagebrush until models similar to the breeding habitat model for GRSG are developed (Doherty et al. 2016).

2. Create the resilience and resistance layer using categorized soil temperature and moisture regimes (figs. 6, 32; Appendix 2; Maestas et al. 2016a).

   First, overlay resilience and resistance categories with the probability of suitable breeding habitat (Doherty et al. 2016) for the assessment area (fig. 38).

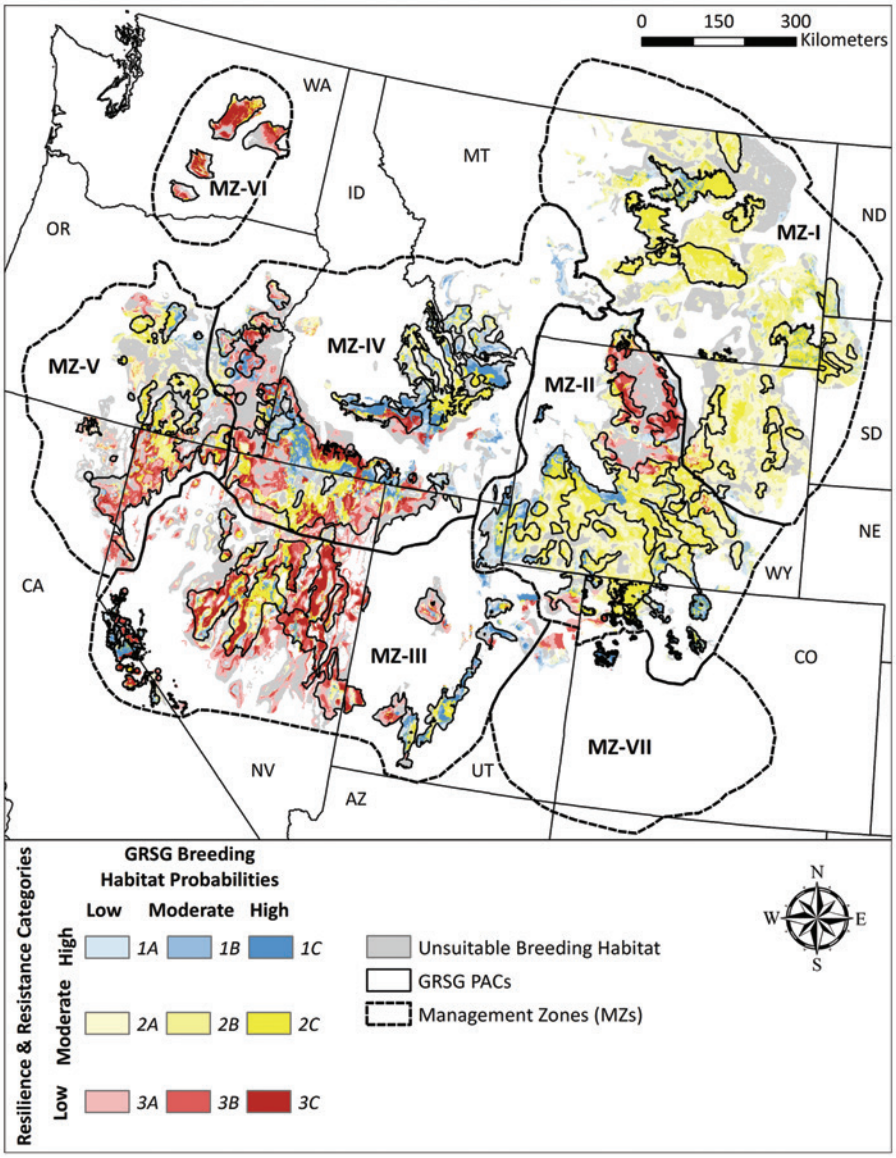


Figure 38— Greater sage-grouse (GRSG) breeding habitat probabilities based on 2010–2014 lek data (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes. The soil temperature and moisture regime data used in this report and the resilience and resistance categories are explained in Appendix 2. This map provides a spatial depiction of the sage-grouse habitat resilience and resistance matrix.

This layer provides information on how areas that can support focal species and resources will respond to both disturbance and management treatments, specifically, the likelihood of recovery and risk of conversion to undesirable states. It can be related directly to the sage-grouse habitat resilience and resistance matrix (fig. 38; table 8) and management strategies (table 9). Calculating the areas in the different categories by ecoregion, or PACs within Management Zones, can help identify target areas for management of GRSG. Weighted or scaled measures of suitable habitat probabilities for ecoregions, or PACs within Management Zones, can be used to help ensure range wide consistency in determining target areas for management.

Second, overlay resilience and resistance with species population abundance measures. For GRSG, this is the population index model (fig. 39). For the purposes of this report, the population index model was classified into two categories (high = 80 percent of the breeding population; low = the remaining 20 percent of the breeding population). These categories can be based on assessment objectives and identified by stakeholders. This layer provides information on areas that currently support large populations, have potential to increase connectivity between populations, and are close enough to population centers so that the species can recolonize reclaimed habitats. It can be related directly to the sage-grouse habitat resilience and resistance matrix (fig. 39; table 8) and management strategies (table 9). Calculating the areas in the different categories by ecoregion, or PACs within Management Zones for GRSG, can further refine areas for management of GRSG habitat.

4. Assess the extent and magnitude of the predominant threat(s). This will typically involve overlaying the resilience and resistance layer with the areas supporting high breeding habitat probabilities and the predominant threat(s). Threats vary by ecoregion and Management Zone. Developing thresholds (ecological minimums) for the extent and magnitude of the threat (e.g., land cover of juniper and piñon and invasive annual grasses, density of oil and gas wells, active mineral claims, road density, etc.) above which the habitat can no longer support a focal species or resource and incorporating these into the geospatial analyses can further inform prioritization of areas for management. For example, ability of GRSG to maintain active leks decreases significantly when conifer canopy exceeds 2 percent and extirpation occurs with canopy cover above 4 percent in the immediate vicinity (within 1000 m) of the lek (Baruch-Mordo et al. 2013).
5. Prioritize areas for management. The maps and data derived from the prior steps and the sage-grouse habitat matrix (table 8) are used to determine target areas for management within the assessment area. Key considerations follow.
    a. Does the area provide suitable habitat and support species populations? For GRSG, this is the breeding habitat probability and breeding bird density (table 8 cells 1B, 2B, 3B, 1C, 2C, 3C).
    b. If the area has reduced habitat suitability, can it be improved by active management? These areas may be at higher risk of becoming unsuitable with additional disturbances that degrade habitat (table 8 cells 1B, 2B, 3B).

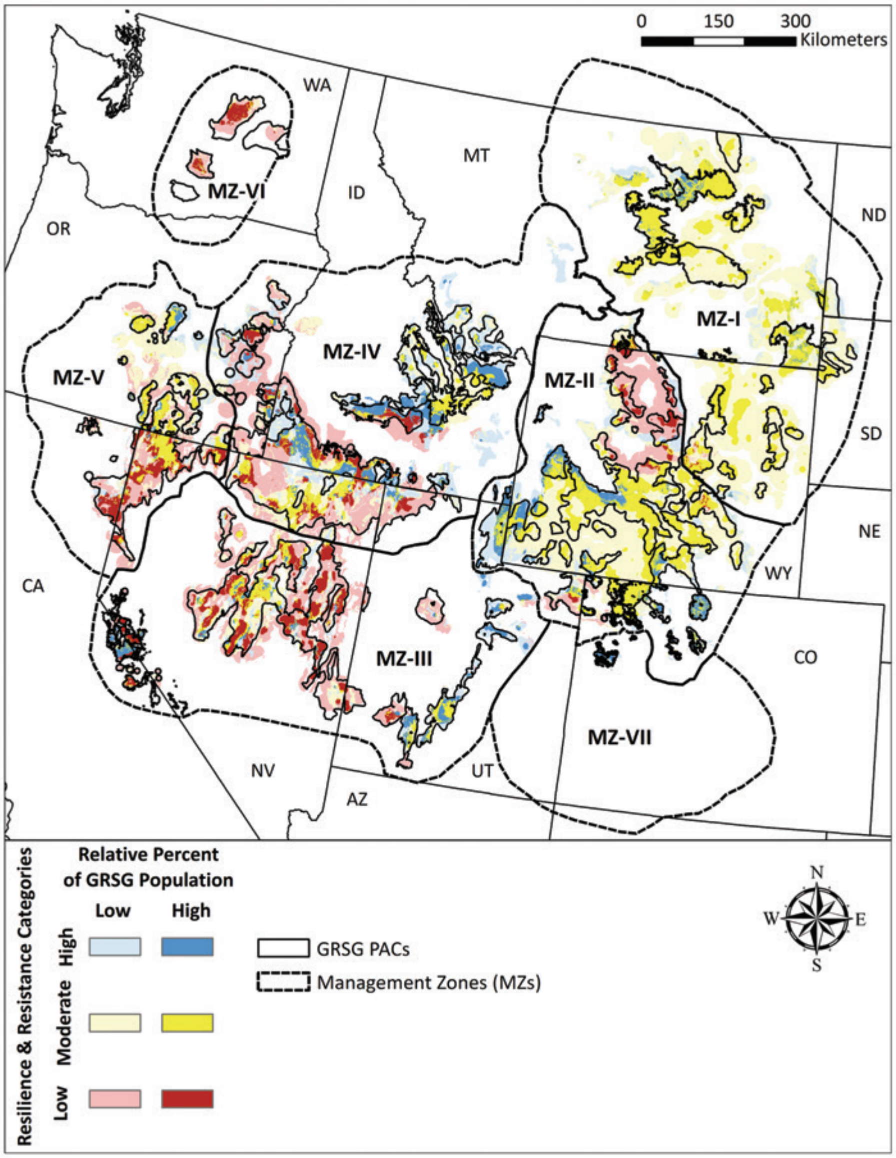


Figure 39—Relative percent of Greater sage-grouse (GRSG) population based on breeding abundance during 2010–2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes. The soil temperature and moisture regime data used in this report and the resilience and resistance categories are explained in Appendix 2. The high value represents 80 percent of the GRSG breeding population; the low value represents the remaining 20 percent of the breeding population. This map provides information on areas that currently support large populations of breeding birds, have potential to increase connectivity between populations, and are close enough to population centers so that the birds can recolonize reclaimed habitats.

c. If the area is at risk due to low resilience and resistance but has high conservation value for the focal species, can it be maintained or improved through protective management (table 8 cells 3B, 3C)? These areas have the potential for rapid conversion to invasive annual grasses, but could be maintained or improved by aggressive weed management, fire suppression, and passive management activities such as improved livestock management.

6. Determine the most appropriate management strategies. The maps and data derived from the prior steps and the sage-grouse habitat matrix (table 8) are also used to determine management strategies. At the scale of the ecoregion, or PACs within Management Zones for GRSG, management strategies are developed that require interagency coordination at the mid-scale, e.g., State, National Forest, etc. Examples of these types of strategies include: (1) prepositioning firefighting resources within fire-prone areas that provide suitable habitat and support species populations as is being done for areas in the Great Basin with high fire risk (BLM 2015a); (2) coordinating efforts to use EDRR to prevent expansion of invasive annual grasses and other invasive plants; (3) assessing habitat connectivity among PACs and species populations to develop coordinated approaches to management strategies, such as conifer removal and other habitat improvements, to decrease fragmentation (e.g., Coates et al. 2016b); (4) refining livestock management strategies and offering flexibility to promote or perpetuate perennial grass and forb establishment and promote recovery of soil biotic crusts; and (5) evaluating climate change projections and developing effective adaptation strategies.

9. Determining Appropriate Management Treatments at Local Scales

Once priority areas and overarching strategies are identified, higher resolution spatial data are combined with local information and knowledge to help managers and stakeholders determine the most appropriate management strategies and identify project areas. The sage-grouse habitat matrix (table 8) and the general criteria for prioritizing areas for management in Step 6 of the prior section can aid in selecting areas for treatment that will benefit sagebrush ecosystems and species populations. Also, information on the resilience and resistance of the area and the predominant threats can help in determining appropriate management strategies and treatments (table 9).

9.1 Steps in the Process

Steps in the process of determining the suitability of an area for treatment and the most appropriate treatment(s) include: (1) identify the different ecological sites that occur across the area and determine their relative resilience to disturbance and resistance to invasive annual grasses; (2) evaluate the current ecological dynamics of the ecological sites and, where possible, their restoration pathways; and (3) select actions with the potential to increase ecosystem functioning and habitat connectivity (see Miller et al. 2014, 2015 and Pyke et al. 2015a,b for detailed descriptions of this process). Anticipating changes like climate warming and monitoring management outcomes can be used to adapt management over time. A general approach that uses questions to identify the information required in each step is described in table 11. These questions can be modified to include the specific information needed for each project area and for treating different ecological site types. This format is used in Miller et al. 2014, 2015.

Table 11—Questions and considerations for conducting fuels management, fire rehabilitation, and restoration treatments (modified from Miller et al. 2014, 2015).

Steps in the process	Questions and considerations
I. Assess potential treatment area and identify ecological sites	1. Where are priority areas for fuels management, fire rehabilitation or restoration within the focal area? Consider sage-grouse habitat needs and resilience and resistance. 2. What are the topographic characteristics and soils of the area? Verify soils mapped to the location and determine soil temperature and moisture regimes. Collect information on soil texture, depth, and basic chemistry for restoration projects. 3. How will topographic characteristics and soils affect vegetation recovery, plant establishment, and erosion? Evaluate erosion risk based on topography and soil characteristics. 4. What are the potential native plant communities for the area? Match soil components to their correlated ESDs. This provides a list of potential species for the site(s).
II. Determine current state of the site	5. Is the area still within the reference state for the ecological site(s)?
III. Select appropriate action	6. How far do sites deviate from the reference state? How will treatment success be measured? 7. Do sufficient perennial shrubs and perennial grasses and forbs exist to facilitate recovery? 8. Are invasive species a minor component? 9. Do invasive species dominate the sites while native life forms are missing or severely under represented? If so, active restoration is required to restore habitat. 10. Are species from drier or warmer ecological sites present? Restoration with species from the drier or warmer sites should be considered. 11. Have soils or other aspects of the physical environment been altered? Sites may have crossed a threshold and represent a new ecological site type requiring new site-specific treatment/restoration approaches.
IV. Determine post-treatment management	12. How long should the sites be protected before land uses begin? In general, sites with lower resilience and resistance should be protected for longer periods. 13. How will monitoring be performed? Treatment effectiveness monitoring includes a complete set of measurements, analyses, and a report. 14. Are adjustments to the approach needed? Adaptive management is applied to future projects based on consistent findings from multiple locations.

9.1.1 Ecological Site Descriptions

Ecological site descriptions and their associated state-and-transition models 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). The Natural Resource Conservation Service (NRCS) soil survey data (http://soils.usda.gov/survey/), including soil temperature/moisture regimes and other soil characteristics, are integral to ecological site description development. Ecological site descriptions have been developed by the NRCS and their partners to assist land management agencies and private landowners with making resource decisions, and are often available for the Management Zones. 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/. Ecological site descriptions assist managers to step-down generalized vegetation dynamics, including the concepts of resilience and resistance, to local scales. For example, variability in soil characteristics and the local environment (e.g., average annual precipitation as indicated by soil moisture regime) can strongly influence plant community resilience to disturbance and resistance to nonnative invasive species (table 6). The relative resilience and resistance of an ecological site can be used to help determine the most appropriate management actions.

A tool has recently been developed through the Web Soil Survey that produces a "Sagebrush Ecosystem Resilience and Resistance Soils Report" based on the approach developed in Miller et al. (2014, 2015) (http://websoilsurvey.nrcs.usda.gov/app/). It provides managers with necessary information to assess the soil characteristics of a project area and determine the area's relative resilience to disturbance and management treatments and resistance to nonnative invasive annual grasses.

9.1.2 State-and-Transition Models

State-and-transition models 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; NRCS 2015; Stringham et al. 2003) including in sagebrush ecosystems (Barbour et al. 2007; Boyd and Svejcar 2009; Chambers et al. 2014c; Forbis et al. 2006; Holmes and Miller 2010). These models describe the alternative states, ranges of variability within states, and processes that cause plant community shifts within states as well as transitions among states within ecological types or sites (Caudle et al. 2013). State-and-transition models 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 inappropriate 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.

Generalized state-and-transition models that follow current interagency guidelines (Caudle et al. 2013) and that are aligned with the dominant ecological types in table 6 are provided in Appendices 5 and 6. These state-and-transition models are generally applicable to MZ I (West-Central Semiarid Prairies), MZs II and VII (Wyoming Basin and Central Middle Rockies; Colorado Plateau and Southern Rockies), and MZs III, IV, and V (Central Basin and Range, Northern Basin and Range, and Snake River Plain).

9.2 Examples of How to Apply the Concepts and Tools

Examples of the approach discussed in the Science Framework are provided below for three areas that support GRSG populations but differ in relative resilience and resistance as indicated by soil temperature and moisture regimes and the dominant habitat threat.

9.2.1 Example 1: East-Central Montana

This area is characterized primarily by cool and summer moist bordering on dry soil temperature and moisture regimes (fig. 40) with moderate resilience and resistance (table 8 cells 2A, 2B, 2C). Most of the area is privately owned (fig. 41), and large cropland areas exist adjacent to PACs with moderate to high GRSG

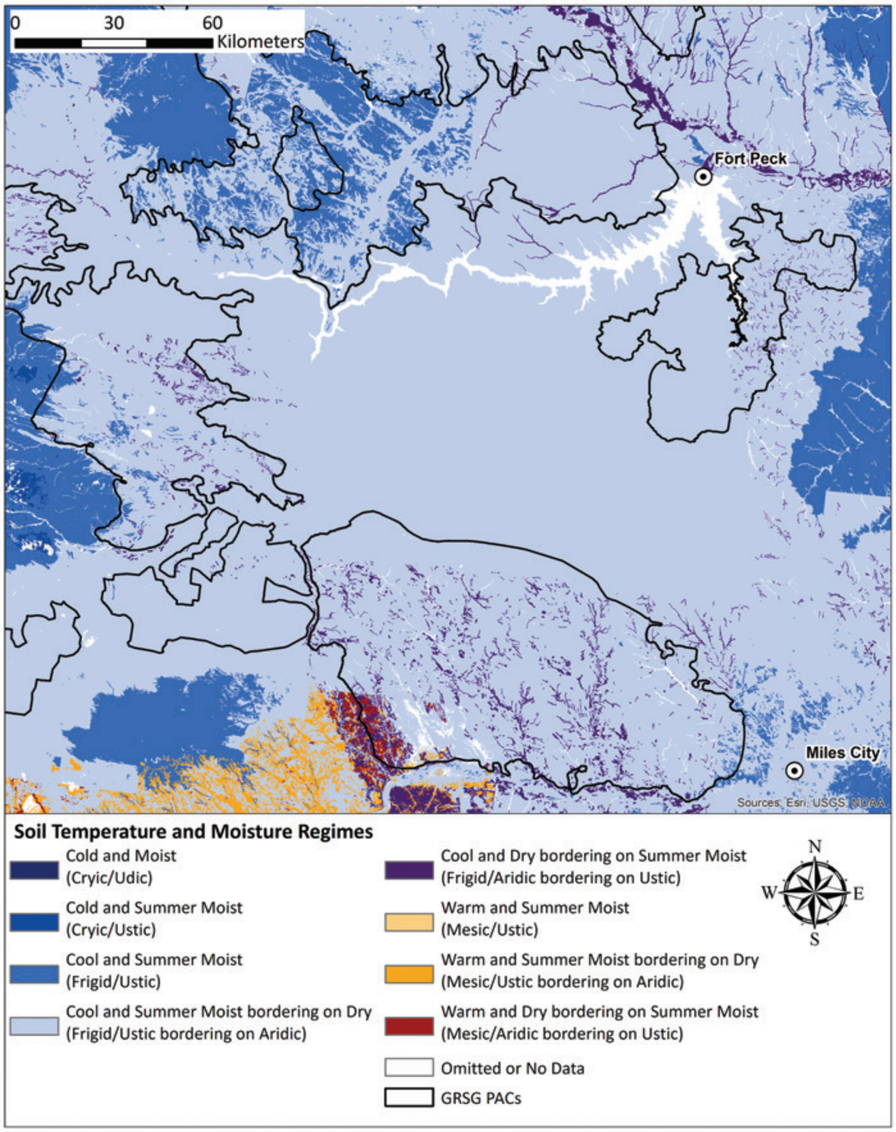


Figure 40—Soil temperature and moisture regimes by soil moisture subclass for an area with agricultural conversion in eastern Montana that is in the Northwestern Great Plains (EPA 2016) and Management Zone I (Stiver et al. 2006). The soil temperature and moisture regime data used in this report is explained in Appendix 2. This area is characterized largely by cool and summer moist bordering on dry soil temperature and moisture regimes with moderate resilience and resistance.

populations (figs. 42a, 43). Ensemble means from climate models project temperature increases in this area of 3.2 to 3.6 °F (1.8 and 2.0 °C; RCP 4.5 and RCP 8.5, respectively) by 2020–2050, and 5.4 to 9.7 °F (3.0 to 5.4 °C) by the end of the 21st century (see Appendix 3). These temperature increases are projected to be slightly greater in both winter and summer than in spring. Most climate models project increasing precipitation over this landscape, and average changes range from 5 to 15 percent increases (about 0.6 to 2.0 in yr^{-1} [15 to 50 mm yr^{-1}]) with the greatest increases towards the end of the century (see Appendix 3). Most of the increase in precipitation is projected for winter and spring. Summer, by contrast, is likely to become slightly drier across most of this area with the exception of the north-central portion; this decline is projected in almost all climate models and for both emissions scenarios.

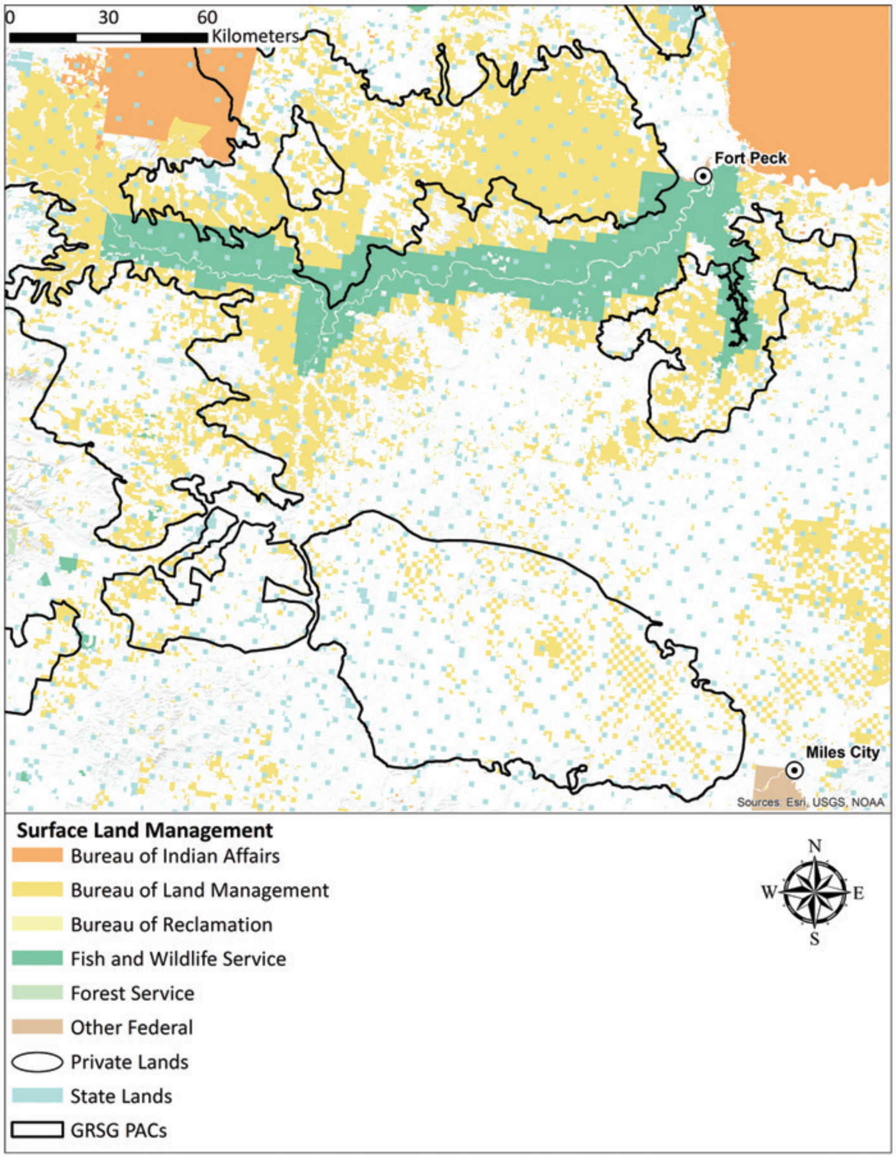


Figure 41—Surface land management for an area with agricultural conversion in eastern Montana that is in the Northwestern Great Plains (EPA 2016) and Management Zone I (Stiver et al. 2006); (see Appendix 8 for data source). Most of the area is privately owned.

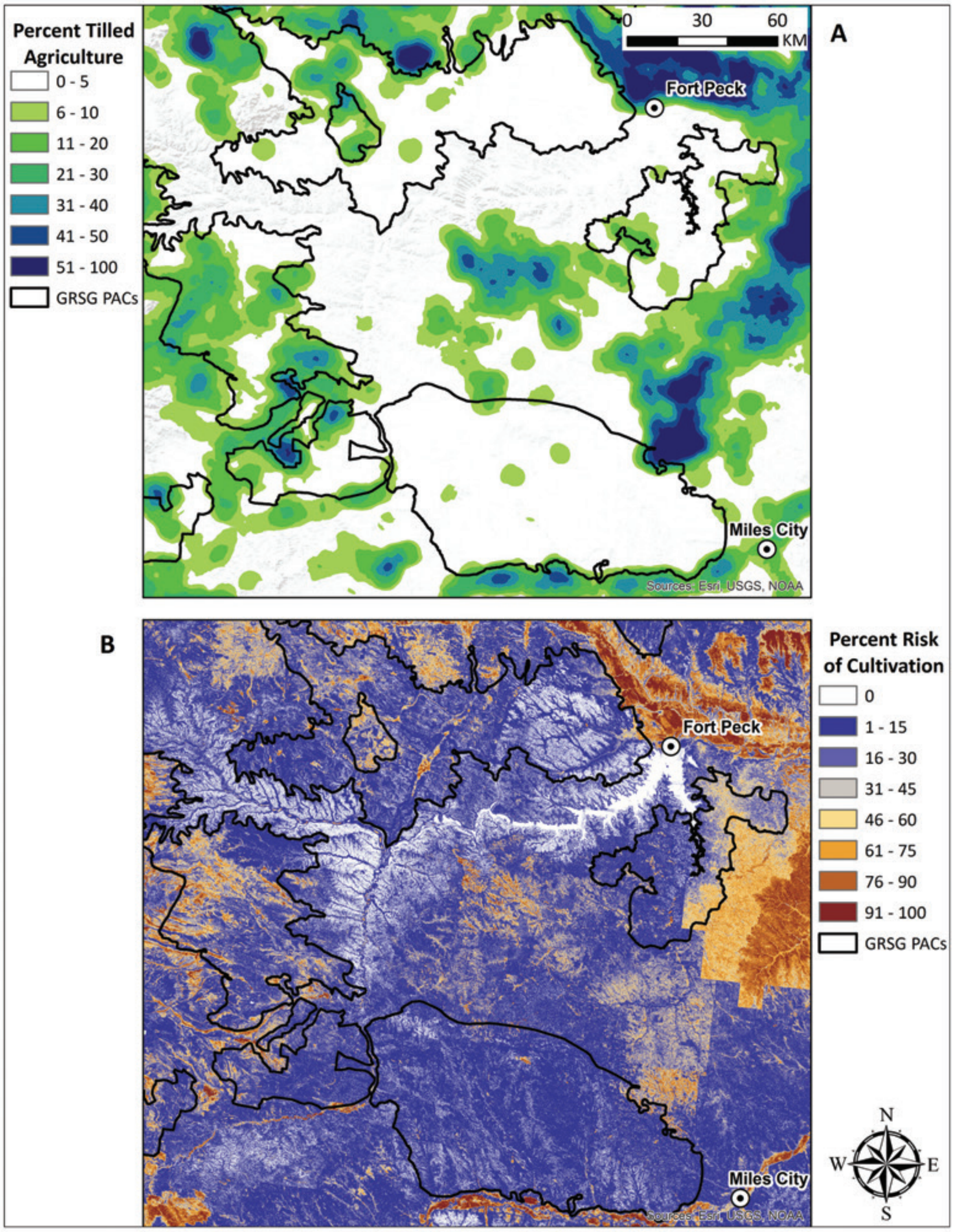


Figure 42—(A) Percent annually tilled agricultural land (NASS 2014) within 5.0 km of each pixel for an area in eastern Montana that is in the Northwestern Great Plains (EPA 2016) and Management Zone I (Stiver et al. 2006). (B) Percent risk of cultivation for the same area derived from the Sage-Grouse Initiative (SGI) cultivation risk mapping tool (http://map.sagegrouseinitiative.com/), which is based on climate, soils, and topography.

Longer-term management strategies in this area focus on reducing the impacts of land use and development stressors and promoting landscape connectivity. Areas on private lands that support high probabilities of suitable habitat and encompass or are adjacent to populations of GRSG or other at-risk species could be targeted for conservation easements, term easements, or other conservation tools to keep native rangelands intact. USDA and State-based initiatives may provide incentives for transitioning expiring Conservation Reserve Program or other cultivated lands to rangelands that support perennial plant communities. The Sage-Grouse Initiative

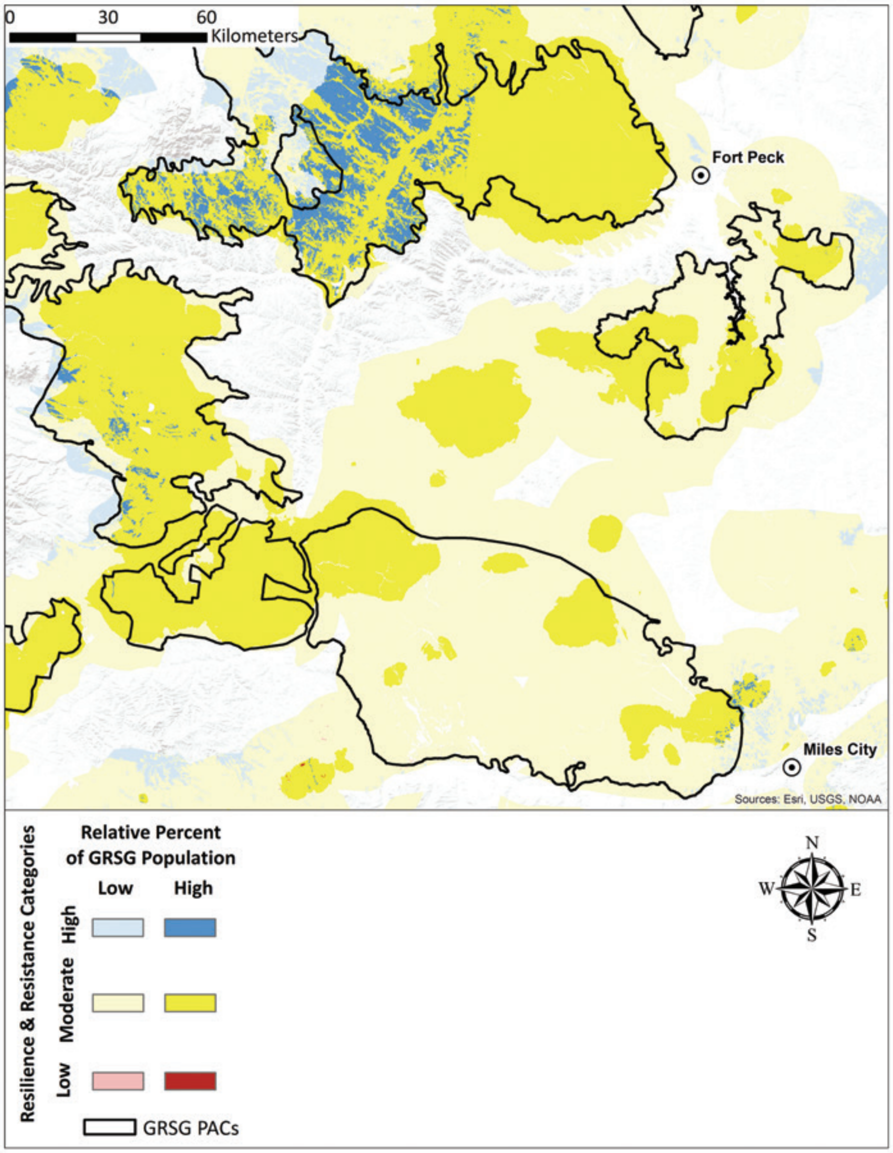


Figure 43—Relative percent of the Greater sage-grouse population based on breeding abundance during 2010–2014 (Doherty et al. 2016) intersected with the resilience and resistance categories developed from soil temperature and moisture regimes for an area (Appendix 2) with agricultural conversion in eastern Montana that is in the Northwestern Great Plains (EPA 2016) and Management Zone I (Stiver et al. 2006). The high value represents 80 percent of the Greater sage-grouse breeding population; the low value represents the remaining 20 percent of the breeding population. Large cropland areas exist adjacent to PACs with moderate to high GRSG populations (see fig. 42).

Cultivation Risk layer (Smith et al. 2016; http://map.sagegrouseinitiative.com/) along with existing cropland cover maps can be used to help identify areas that have not yet been plowed but may be at high risk of future conversion due to suitable climate, soils, and topography (fig. 42b; Lipsey et al. 2015; Smith et al. 2016).

State-and-transition models provide information that can help managers determine effective strategies for managing threats. The alternative states and transitions for the dominant ecological type in this area are identified in a generalized state-and-transition model (Appendix 5 fig. A5.3). Following prolonged drought, improper grazing, and frequent sagebrush control treatments, the site can transition to an alternative state that is dominated by low statured, cool season and sod-forming grasses (Appendix 5 fig. A5.3). In the absence of fire and sagebrush control treatments, the site can transition to heavy sagebrush dominance with few grasses and forbs. These altered states are susceptible to a variety of nonnative invasive plants such as Russian knapweed (*Centaurea repens*), field brome, and cheatgrass (see http://invader.dbs.umt.edu/queryarea.asp for a complete county list), and EDRR can be used in all areas with high to moderate habitat probabilities and breeding bird concentrations to limit establishment of these invasive species (see table 9). Livestock management that maintains a balance of native perennial grasses (cool and warm season species) and forbs allows natural regeneration of sagebrush and increases competitive ability with nonnative invasive plants. Where introduced perennial grasses such as crested wheatgrass were seeded onto former croplands an altered or seeded state exists. These introduced perennial grasses can prevent establishment of sagebrush and other native species and spread into and dominate sagebrush ecosystems (Lesica and Deluca 1996). Thus further seeding of these species following disturbances is not recommended.

Monitoring of ecosystem status and trends (e.g., cover of native and invasive species, disturbance factors, soil and site stability) can provide the necessary information to track landscape change due to climate change and other stressors, evaluate the effectiveness of management strategies, and adapt management. Programs such as the Bureau of Land Management Assessment, Inventory, and Monitoring Program provide the mechanism for this type of comprehensive monitoring.

9.2.2 Example 2: Southwestern Wyoming

This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and summer moist to warm and dry bordering on summer moist and thus high to low resilience and resistance (fig. 44). Surface land management is primarily USFS, BLM, and private (fig. 45). The area has widespread oil and gas development along with high GRSG concentration areas (figs. 46, 47). Ensemble mean climate change projections suggest average temperature increases of 3.2 to 3.6 °F (1.8 and 2.0 °C; RCP 4.5 and RCP 8.5, respectively) by 2020−2050, and 5.7 to 10 °F (3.2 to 5.6 °C) by the end of the 21st century (Appendix 3). These temperature projections are relatively consistent throughout the year but are most pronounced in the southwestern portion of the area. Most models suggest precipitation increases between 5 and 15 percent in this area, although spatial patterns in precipitation change vary dramatically within this landscape due to the steep topography. Although most areas are likely to experience increases in precipitation of 5 to 10 percent (0.8 to 1.2 in yr^{-1} [20 to 30 mm yr^{-1}]), mountainous areas may receive increases of 20 to 30 percent (7.9 in yr^{-1} [>200 mm yr^{-1}]) (Appendix 3). While climate models are evenly split between increases and decreases in summer precipitation, most models indicate modest increases in precipitation during winter and spring and all models suggest a decrease in the proportion of annual precipitation coming between May and October.

Minimizing the impacts of land use and development stressors and promoting landscape connectivity is a key management strategy. In areas with high GRSG breeding habitat probabilities and breeding concentration centers, avoiding development and fragmentation where feasible and consistent with existing State and Federal conservation plans can help prevent habitat loss regardless of resilience and

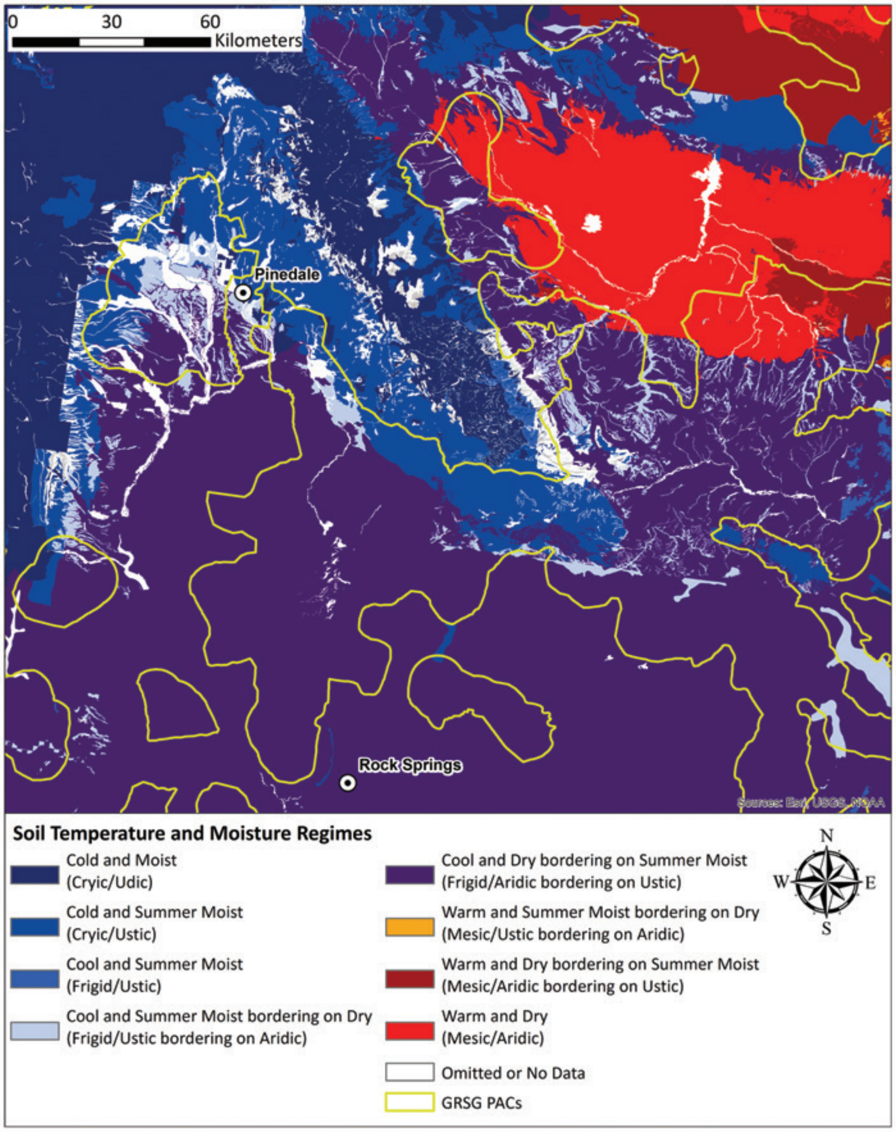


Figure 44—Soil temperature and moisture regimes by soil moisture subclass for an area with oil and gas development in southwest Wyoming that is in the Wyoming Basin and Northern & Middle Rockies (EPA 2016) and Management Zone II (Stiver et al. 2006). The soil temperature and moisture regime data used in this report and the resilience and resistance categories are explained in Appendix 2. This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and summer moist to warm and dry bordering on summer moist and thus high to low resilience and resistance.

resistance category (table 8 cells 1C, 2C, 3C). Reducing energy and other transport corridors as well as vehicle access where consistent with the above mentioned plans can minimize fragmentation. Also, conservation easements can be an important tool where exurban residential development is fragmenting habitats (fig. 48).

The ecological types and state-and transition models for this area provide information to help manage key threats. Because of the wide range of soil temperature and moisture regimes, the area supports several ecological types. Relevant state-and-transition models for these types are in Appendix 5 (figs. A5.5, A5.6, A5.7, A5.9, A5.10). In general, continuous heavy grazing of cool season grasses during the critical growth period can result in an alternative state dominated by

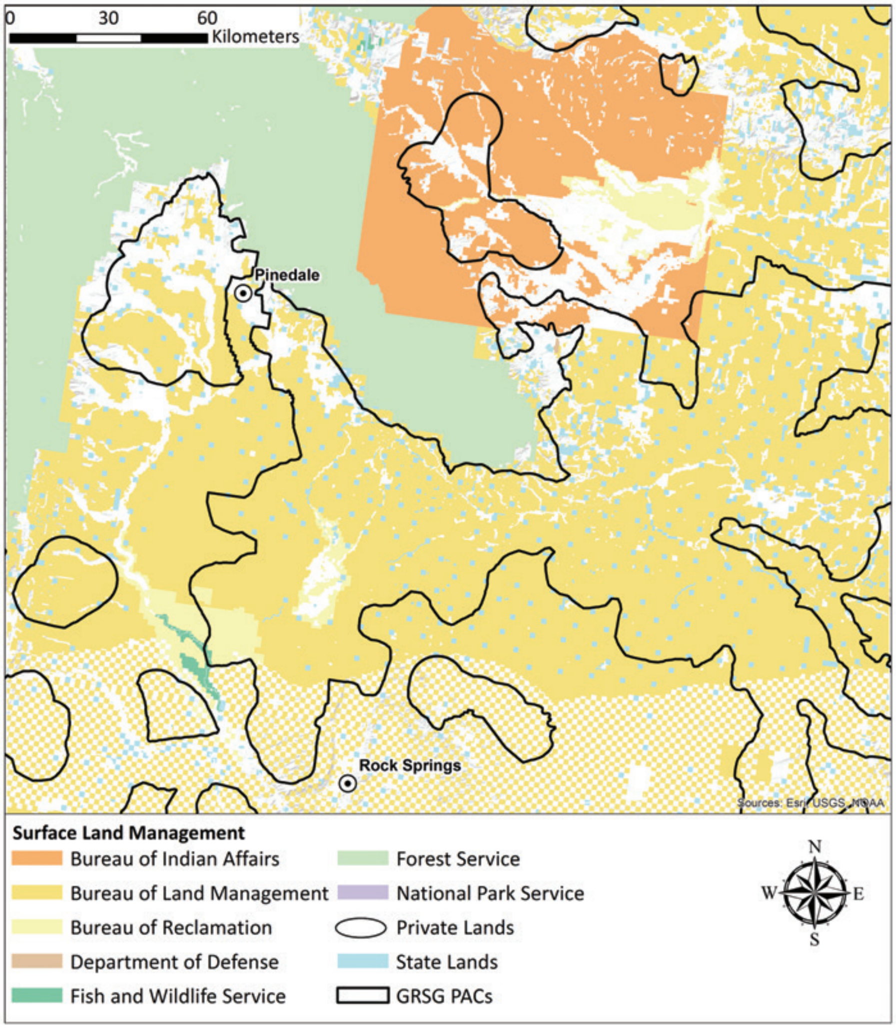


Figure 45—Surface land management for an area with oil and gas development in southwest Wyoming that is in the Wyoming Basin and Northern & Middle Rockies (EPA 2016) and Management Zone II (Stiver et al. 2006); (see Appendix 8 for data source). Surface land management is primarily USFS, BLM, and private.

grazing-tolerant species. Further grazing can result in an eroded state which is highly susceptible to nonnative invasive species. Fire is rare, but multiple chemical or mechanical treatments or biological disturbances that reduce sagebrush can result in a sprouting shrub state. For these states, livestock grazing strategies can be designed to improve the condition of native plant communities and decrease nonnative invasive plant species. Strategies that include periodic deferment from use during the critical growth period, especially for cool season grasses, can increase native species and minimize invasion. This strategy is particularly important in areas with low resilience and resistance. Given climate warming, management aimed at restoring and maintaining perennial grasses and forbs has the potential to increase resilience to both drought and fire and resistance to invasive plant species.

The area is susceptible to numerous nonnative invasive plants and proactive weed management strategies can help prevent their establishment and spread in all areas with high habitat suitability and breeding concentration centers (see table 9). Nonnative invasives include several *Bromus* species such as cheatgrass and field brome, *Poa* species such as bulbous bluegrass (*P. bulbosa*) and Kentucky bluegrass

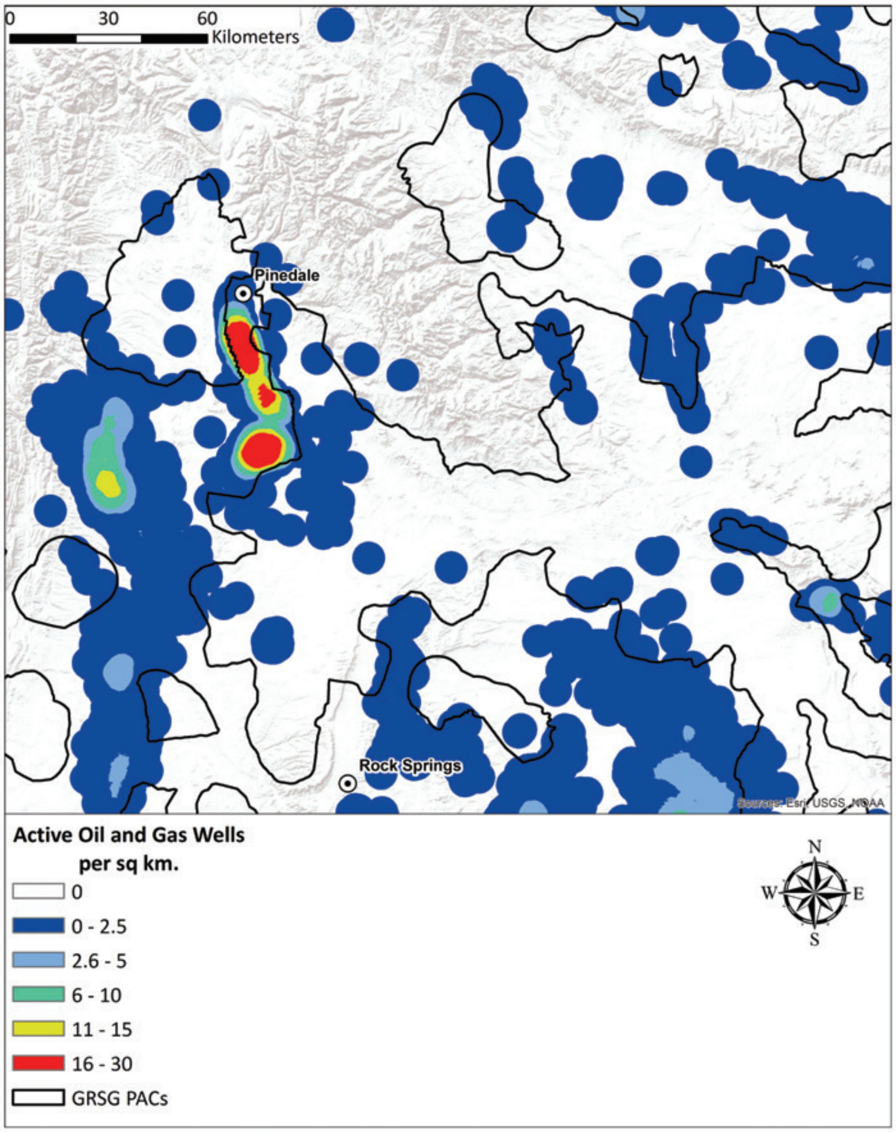


Figure 46—Number of active oil and gas wells per square kilometer for an area in southwest Wyoming that is in the Wyoming Basin and Northern & Middle Rockies (EPA 2016) and Management Zone II (Stiver et al. 2006); (see Appendix 8 for data source). The area has widespread oil and gas development.

(*P. pratense*), spotted and Russian knapweed, diffuse knapweed (*Centauria diffusa*), Canada thistle (*Cirsium arvense*), and bull thistle (*Cirsium vulgare*) among others (http://invader.dbs.umt.edu/queryarea.asp). Preventing the spread of large weed infestations from areas with lower habitat probabilities can help protect higher quality habitat.

For disturbances that remove vegetation and cause soil disturbance such as well pads and roads, impacts can be minimized through best management practices identified in State and Federal conservation plans, such as top soil banking, using certified weed-free (including annual bromes) seed mixes, appropriate seeding technologies, and monitoring. Numerous introduced plant species including crested wheatgrass, and several *Medicago* species such as alfalfa and *Trifolium* species (clovers) occur in this area. Seeding these species for reclamation purposes or restoration of sagebrush habitat can be avoided, especially in cooler and moister

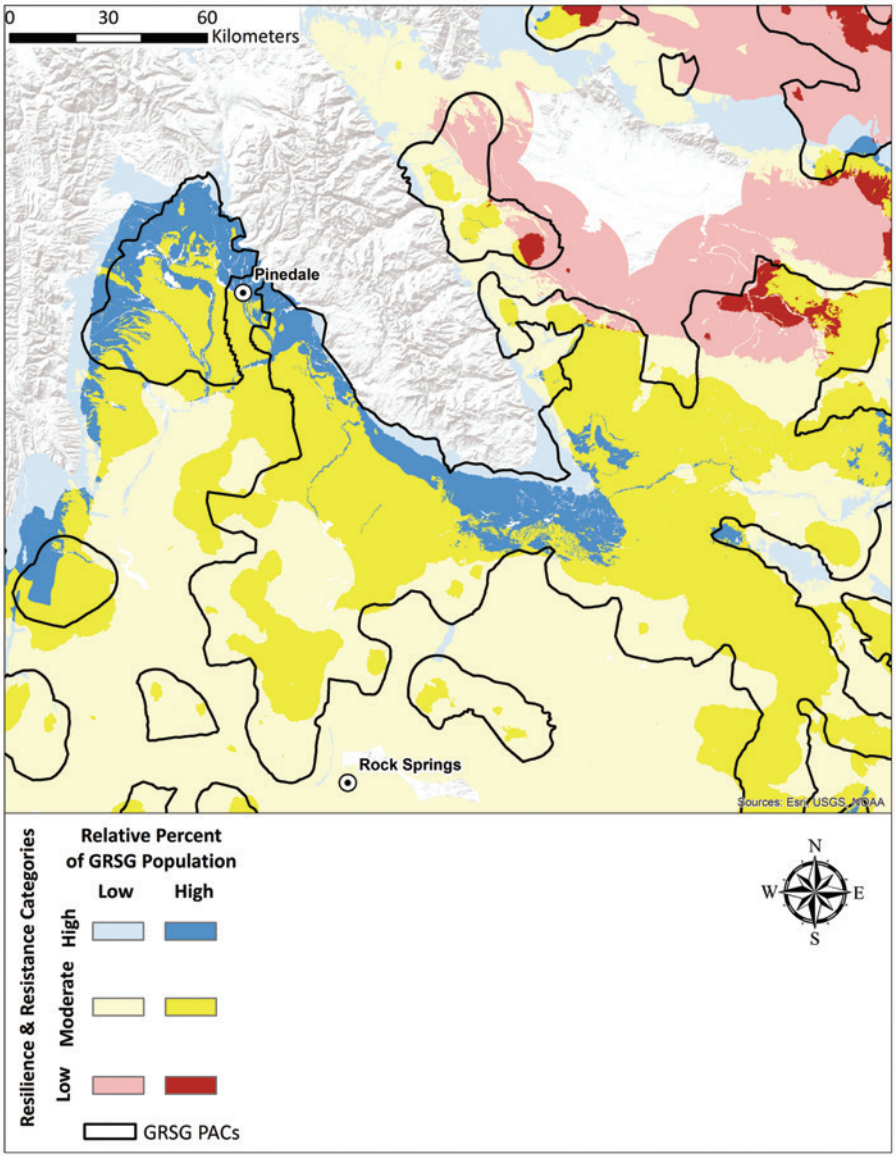


Figure 47—Relative percent of the Greater sage-grouse population based on breeding abundance during 2010–2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes (Appendix 2) for an area with oil and gas development in southwest Wyoming that is in the Wyoming Basin and Northern & Middle Rockies (EPA 2016) and Management Zone II (Stiver et al. 2006). The high value represents 80 percent of the Greater sage-grouse breeding population; the low value represents the remaining 20 percent of the breeding population. The area has high GRSG concentration areas within and adjacent to areas with oil and gas development (see fig. 46).

areas where native species establish well. In low resilience and resistance areas, multiple interventions may be required to restore sagebrush habitat, and restoration to the original ecological site may not be possible in areas undergoing rapid climate change. Favoring existing genotypes for seeding and outplanting that are better adapted to future conditions because of pest resistance, broad tolerances, or other characteristics may help increase the success of restoration and rehabilitation efforts. Monitoring of ecosystem status and trends can provide the necessary information to track landscape change due to climate change and the interacting effects of other landscape stressors, and to adjust management where needed.

Figure 48—A conservation easement near Pinedale, Wyoming. Photo by Jeremy Roberts, Conservation Media; used with permission. Conservation easements can be an important tool where development is fragmenting habitats.

9.2.3 Example 3: Northeastern Nevada

This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and moist to warm and dry (fig. 49) and thus from high to low resilience and resistance. Surface land management is primarily BLM, USFS, and private (fig. 50). Mid- to high- elevation areas are exhibiting localized conifer expansion, primarily Utah juniper, and low- to mid-elevation areas are exhibiting cheatgrass invasion and spread (fig. 51). Since 2000, a relatively large portion of the area has burned in wildfires (fig. 51) in and around areas with high concentrations of breeding birds (fig. 52). Since 1984 about 30 percent of the total area burned; 20 percent of the total area burned since 2000. Ensemble mean climate change projections suggest average temperature increases of 3.2 to 3.6 °F (1.8 and 2.0 °C; RCP 4.5 and RCP 8.5, respectively) by 2020−2050, and 5.7 to 9.9 °F (3.2 to 5.5 °C) by the end of the 21st century (Appendix 3). The largest temperature increases are projected for the summer (July to September). Average precipitation forecasts over this area range from decreases of about 10 percent (0.8 to 1.2 in yr^{-1} [20-30 mm yr^{-1}] to increases of more than 50 percent (7.9 in yr^{-1} [>200 mm yr^{-1}]) (Appendix 3). The largest increases are projected consistently for the winter and the cooler, mountainous areas.

The state-and-transition models for the predominant ecological types provide information to help manage the primary threats (Appendix 6). In general, improper livestock use, such as heavy grazing during the critical growth period, can decrease perennial grasses and forbs and result in increases in woody species and fuel loads. Increases in woody species can result in a shrub or tree dominated state and the potential for higher fire severity. Progressive conifer expansion can result in an alternative state dominated by trees, and depending on soils, slope, and understory

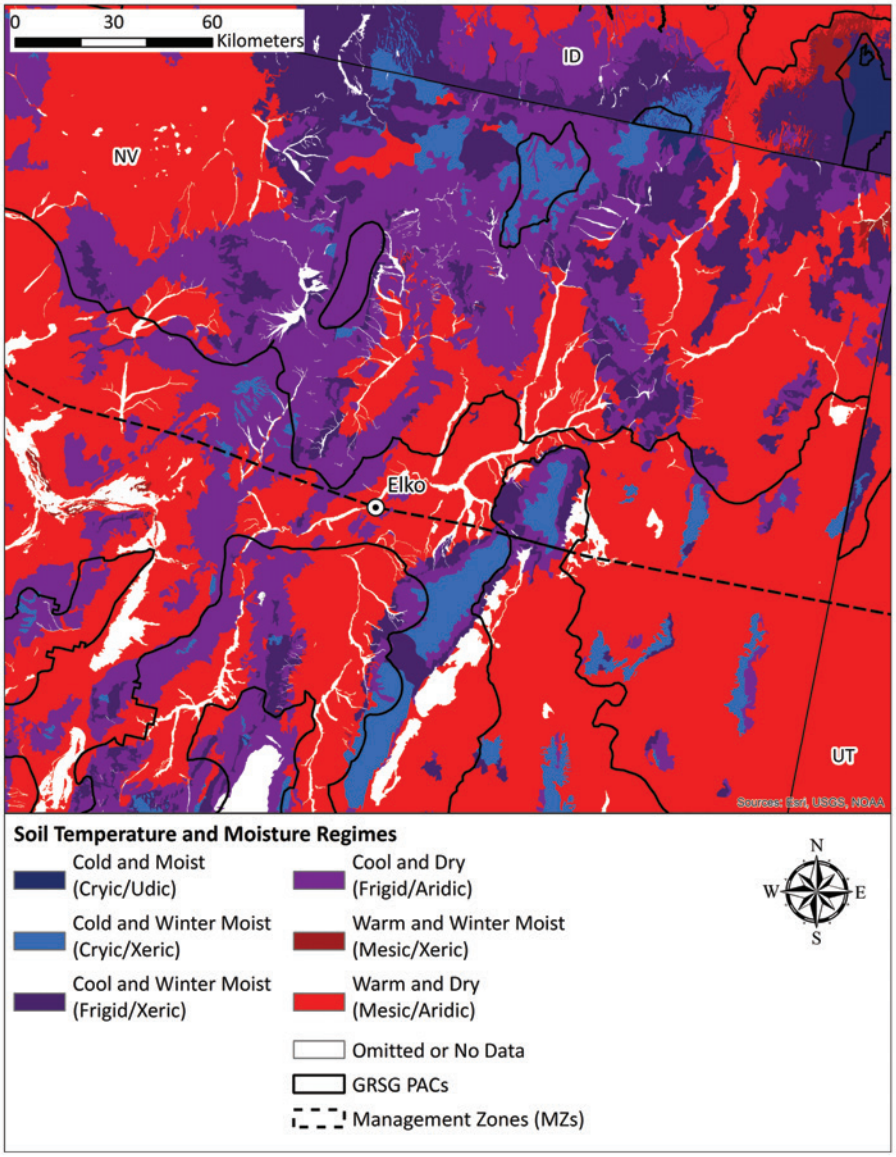


Figure 49—Soil temperature and moisture regimes by soil moisture subclass for an area with cheatgrass invasion and conifer expansion in northeast Nevada that is in the Northern Basin and Range (EPA 2016) and Management Zone IV (Stiver et al. 2006). The soil temperature and moisture regime data used in this report are explained in Appendix 2. This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and moist to warm and dry and thus from high to low resilience and resistance.

species, an eroded state. On relatively warm and dry sites, improper livestock use that depletes perennial grasses and forbs can decrease resistance to invasive annual grasses. Increases in invasive annual grasses may cause more frequent and continuous fires and result in conversion to alternative states dominated by annuals (Miller et al. 2013). Proper management of livestock and wild horse and burro grazing can promote native perennial grass and forb growth and reproduction and maintain or enhance resilience to wildfires and resistance to invasive annual grasses.

Various fire management strategies can be used to help maintain connected and functioning sagebrush ecosystems (table 9). Fuel loads and fuel continuity can be reduced to: (1) decrease fire size, alter burn patterns, decrease perennial grass

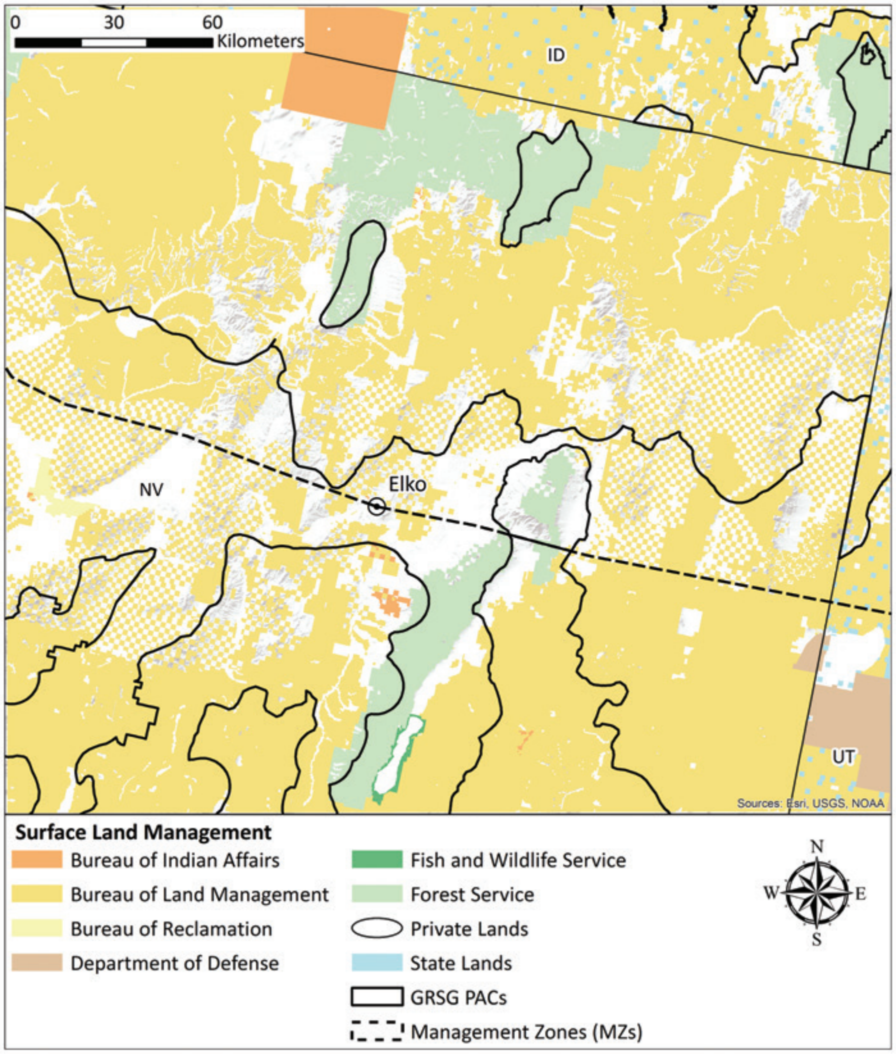


Figure 50—Surface land management for an area with cheatgrass invasion and conifer expansion in northeast Nevada that is in the Northern Basin and Range (EPA 2016) and Management Zone IV (Stiver et al. 2006); (see Appendix 8 for data sources). Surface land management is primarily BLM, FS, and private.

mortality, and maintain landscape connectivity; (2) decrease competitive suppression of native perennial grasses and forbs by woody species; and thus (3) lower the longer-term risk of dominance by invasive annual grasses and other invaders. Wildfires can be suppressed in low to moderate resilience and resistance sagebrush-dominated areas to prevent conversion to invasive annual grass states and maintain both ecological processes and ecosystem services. Wildfires can be suppressed adjacent to or within recently restored ecosystems to promote recovery and increase capacity to absorb future change. Finally, fuel breaks can be used in carefully targeted locations along existing roads where they have minimal effects on ecosystem processes and can aid fire suppression efforts (Maestas et al. 2016b)

Targeted tree removal in early- to mid-phase (Phase I and II), postsettlement piñon and juniper expansion areas can be used to maintain shrub/herbaceous cover and prevent conversion to a tree dominated state as well as reduce fuel loads (table 9). The ability of GRSG to maintain active leks decreases significantly when conifer canopy exceeds 2 percent in the immediate vicinity (within 1,000 m) of the lek

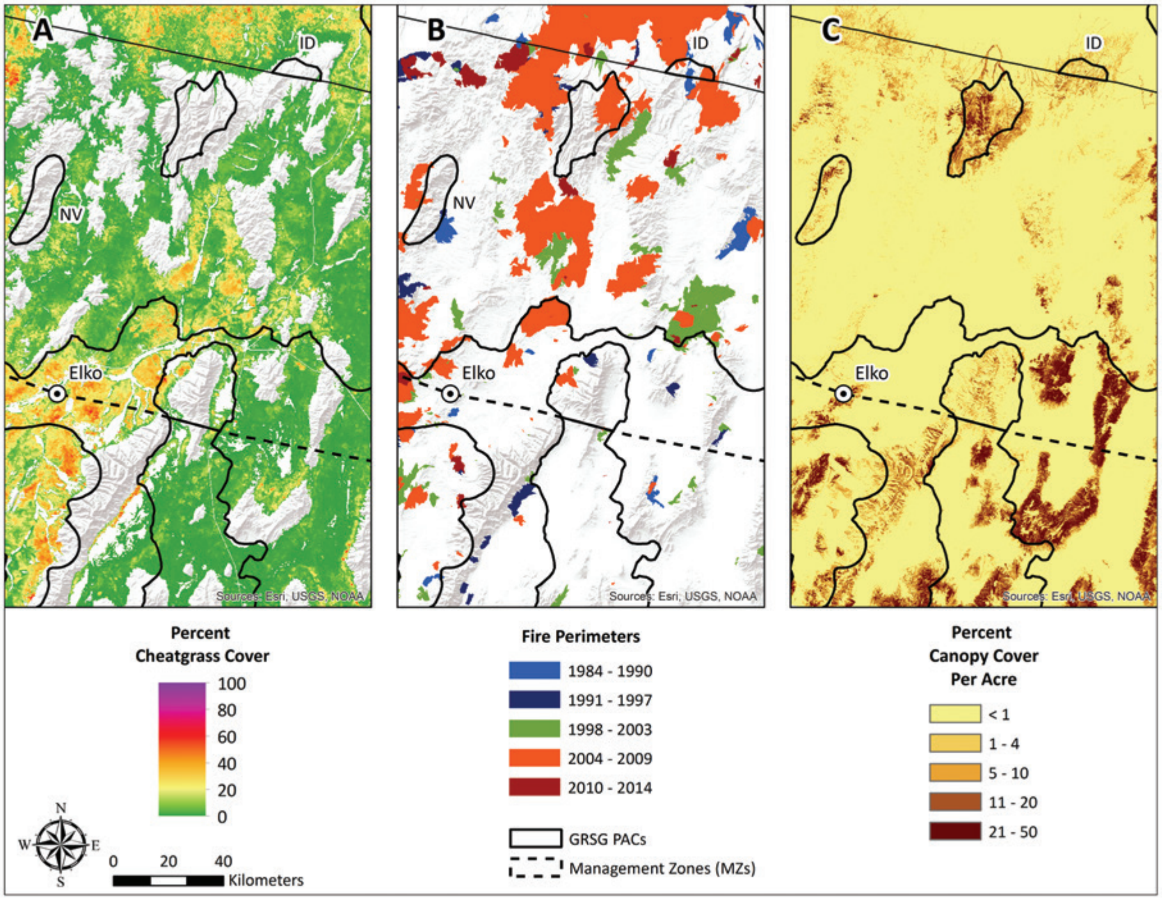


Figure 51—(A) Percent cheatgrass cover in northeast Nevada in 2015 at a 250 meter resolution (Boyte et al. 2015). (B) Perimeters of fires that occurred from 1984–2014 in an area in northeast Nevada. Data for fires larger than 1,000 acres are from MTBS (2014) and data for fires smaller than 1,000 acres are from GeoMAC (2015). (C) Estimate of tree canopy cover per acre in northeast Nevada at a 30 meter resolution (Falkowski et al. 2017). The area is in the Northern Basin and Range (EPA 2016) and Management Zone IV (Stiver et al. 2006). Priority Areas for Conservations (PACs; FWS 2013) are overlaid. Mid- to high- elevation areas are exhibiting localized conifer expansion, primarily Utah juniper, and low- to mid-elevation areas are exhibiting cheatgrass invasion and spread. Since 2000, a relatively large portion of the area has burned in wildfires.

(Baruch-Mordo et al. 2013) and targeted tree removal can effectively increase habitat availability for nesting and brooding sage-grouse (Sandford et al. 2017; Severson et al. 2017). Guidance for selecting sites for conifer removal treatments and evaluating treatment types is in Miller et al. 2014.

Following fire in either sagebrush or conifer dominated areas, postfire rehabilitation can be used to accelerate sagebrush establishment and recovery of perennial native herbaceous species. Areas with moderate to high resilience and resistance are often capable of unassisted recovery and seeding is typically needed only in areas where perennial native grasses and forbs have been depleted (Miller et al. 2013, 2015). Seeding introduced species like crested wheatgrass or forage kochia (*Bassia prostrata*) can retard recovery of native perennial grasses and forbs that are important to GRSG and is not recommended (Knutson et al. 2014). However, seeding or transplanting of sagebrush may be needed to accelerate establishment in target areas and increase connectivity. Guidance for determining when a site will recover on its own and when it would benefit from management intervention is in Miller et al. 2015. Information on seed transfer guideline is in Appendix 11.

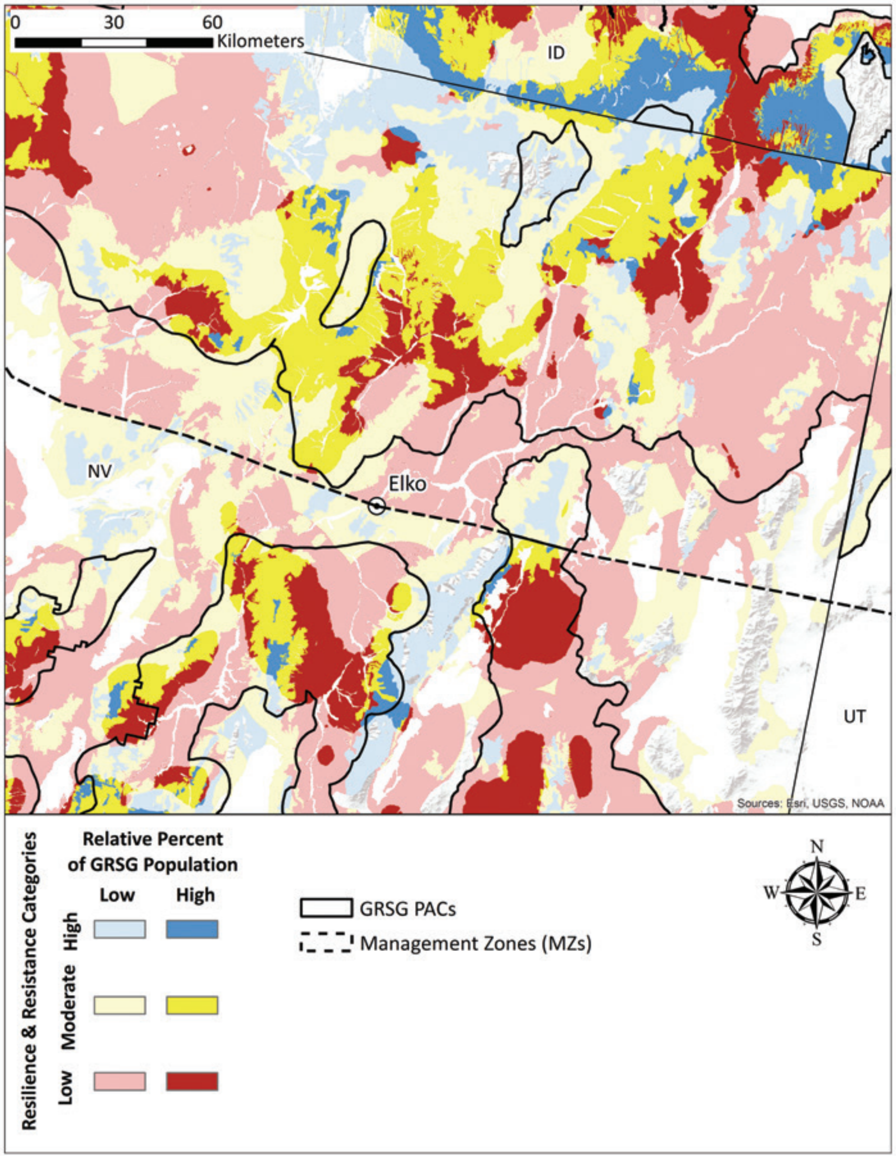


Figure 52—Relative percent of the Greater sage-grouse population based on breeding abundance during 2010–2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes (Appendix 2) for an area with cheatgrass invasion and conifer expansion in northeast Nevada that is in the Northern Basin and Range (EPA 2016) and Management Zone IV (Stiver et al. 2006). The high value represents 80 percent of the Greater sage-grouse breeding population; the low value represents the remaining 20 percent of the breeding population. Wildfires have burned in and around areas with high concentrations of breeding birds in recent decades resulting in spread of cheatgrass (see fig. 51).

In areas with lower resilience and resistance and high breeding bird densities, large, contiguous areas of sagebrush with intact understories are a high priority for protective management (table 8 cell C3). In these areas, emphasis is on maintaining or increasing habitat conditions by minimizing stressors and disturbance (table 9). Following fires or surface disturbances, multiple interventions may be required to restore sagebrush habitat. Restoration may not be possible in areas undergoing rapid climate change, and favoring or restoring genotypes of native species that are expected to be better adapted to the future range of climatic and site conditions may help increase the success of restoration and rehabilitation efforts. Monitoring can provide information on landscape change in response to climate change and on the interacting effects of other landscape stressors like wildfire and invasive annual grasses. Monitoring can also provide information on the effectiveness of current management activities aimed at addressing these threats and on the need to adjust management.

9.3 Sources of Management Information

Several resources exist to assist in developing effective management strategies for persistent ecosystem threats. Archived information from the Center for Invasive Species Management website provides a variety of resources for managing nonnative invasive species, including information on individual species, inventory and monitoring, ecologically based invasive plant management, control methods, prevention, restoration and revegetation (http://www.weedcenter.org/). Also, a recent handbook on cheatgrass management is broadly applicable across the eastern portion of the range (Mealor et al. 2013). To address wildfire, invasive annual grasses, and conifer expansion in sagebrush ecosystems in the western portion of the range, field guides (Miller et al. 2014, 2015) and handbooks (Pyke et al. 2015 a,b) have recently been developed that explicitly incorporate resilience and resistance concepts. These resources can be adapted to MZs II and VII to help guide managers through the process of determining both the suitability of an area for treatment and the most appropriate treatment. Three treatment types are emphasized: (1) conifer removal (Miller et al. 2014), (2) postfire rehabilitation (Miller et al. 2015), and (3) rehabilitation and restoration (Pyke et al. 2015a,b). Additional information on implementing these types of management treatments is synthesized in Monsen et al. (2004) and Pyke (2011); additional information on treatment response is synthesized in Miller et al. (2013).

General information on rangeland ecosystems is available through the Range Science Information System (http://arc.lib.montana.edu/range-science/), which includes a searchable bibliography and general information on MLRA Ecoregions and associated vegetation types. Information is available on grazing management from university extension services at Montana State University (http://animalrangeextension.montana.edu/range/grazing-management.html), the University of Wyoming (Cagney et al. 2010), and Colorado State University (http://extension.colostate.edu/topic-areas/natural-resources/). Additional information on livestock management can be found on websites such as http://www.grazinglands.org/ and Grass: The Stockman's Crop. Also, the different agencies have guidelines for livestock grazing (e.g., BLM Standards for Rangeland Health and Guidelines for Grazing Management; http://www.blm.gov/style/medialib/blm/mt/blm_programs/grazing.Par.83445.File.dat/MCSG.pdf).

A variety of programs exist to help support ranchers and other private landowners and enhance their ability to maintain and enhance sagebrush habitat. Financial and technical assistance is available for planning and implementing conservation practices that can improve ecological conditions and natural resources on rangelands through the Environmental Quality Incentives Program (EQIP; http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/) and the FWS Partners for Fish and Wildlife Program (PFW). The FWS Ecological Services branch offers recovery funding to implement restoration actions, conduct research, and assist in the implementation of other conservation actions designed to restore and protect sagebrush habitat. State wildlife agencies also have private lands programs that vary by State, but that offer seed cost share for Conservation Reserve Program plantings and restoration projects, and technical assistance and infrastructure for wetland enhancement and range management systems. And non-governmental organizations, such as The Nature Conservancy and Wetlands Conservancy, offer community-based landowner programs, such as grassbanks, and provide technical assistance to landowners interested in enhancing sagebrush range conditions.

Resources also exist to assist in addressing land use and development threats. Long-term conservation easements are available through the Agricultural Conservation Easement Program that can help maintain large and intact sagebrush ecosystems by preventing cropland conversion and residential development (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/acep/). In addition, State wildlife agencies private lands programs can include conservation easements and 30-year conservation leases, and non-governmental organizations such as The Nature Conservancy and Wetlands Conservancy, can hold conservation easements.

Information is available to help develop adaptation strategies for climate change. The Climate Change Resources Center (http://www.fs.usda.gov/ccrc/home), a USFS sponsored portal, is a web-based, national resource that connects land managers and decision makers with useable science to address climate change in planning and application (USFS 2011). The website contains links to numerous reports, papers, tools, and data for assessing climate change and climate change impacts. The FWS has worked with the National Oceanic and Atmospheric Administration, the States, and tribal partners to co-lead the National Fish, Wildlife and Plants Climate Adaptation Strategy (www.wildlifeadaptationstrategy.gov), and has also developed an internal Climate Change Strategic Plan. The FWS supports integration of climate change considerations into all aspects of agency work (https://www.fws.gov/home/climatechange/). The FWS national training center offers interagency courses, both classroom and web-based, on climate change, climate change adaptation, vulnerability assessment, scenario planning, and communications. It offers a regular web conference on safeguarding wildlife from climate change and has produced several reports and guidance documents on potential impacts and responses to protect wildlife and wildlife habitat from climate change.

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Appendix 1—Definitions of Terms Used in This Document

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).

Community phase—A unique assemblage of plants and associated soil properties that can occur within a state (Caudle et al. 2013).

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 descriptions (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, 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 (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 Appendix 3.

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: (1) at-risk, (2) influencing management actions and regional economies, (3) potentially being negatively influenced by management actions, and/or (4) serving as indicators of habitat quality or habitat niches such as riparian areas in sagebrush ecosystems.

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).

Land use and development threats—Threats that include cropland conversion, energy development, mining, roads and other infrastructure, urban and exurban development, and recreation and can be regulated (FWS 2013).

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).

Persistent ecosystem threats—Threats that include invasion of nonnative invasive plant species, altered fire regimes, and conifer expansion (Knick et al. 2011: Miller et al. 2011), are difficult to regulate, and are managed using ecologically based approaches (Boyd et al. 2014a; Evans et al. 2013).

Projects—Projects are comprised of multiple 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 (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 (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).

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).

Thresholds—Conditions sufficient to modify ecosystem structure and function beyond the limits of ecological resilience, resulting in transition 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/or 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).

Woodland (Piñon and Juniper) 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).

Appendix 2—Explanation of Soil Temperature and Moisture Regimes Data and the Resilience and Resistance Categories

Soil climate regimes (temperature and moisture) are used in soil taxonomy to classify soils. They are important to consider in land management decisions because of their influence on (1) amounts and kinds of vegetation and (2) response to disturbance and management actions. Soil temperature and moisture regimes are assigned to soil map unit components as part of the National Cooperative Soil Survey program. Abbreviated definitions of predominant soil temperature and moisture regime classes are listed below (table A2.1). Complete descriptions can be found in the 12th edition of the *Keys to Soil Taxonomy* (Soil Survey Staff 2014) https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/taxonomy/?cid=nrcs142p2_053580.

Table A2.1—Definitions of the dominant soil temperature and moisture regimes.

Soil Temperature Regimes

Cryic (cold): Soils that have a mean annual soil temperature between 0 and 8 ºC and do not have permafrost at a depth of 50 cm below the surface or at a restrictive feature, whichever is shallower.

Frigid (cool): Soils that have a mean annual soil temperature between 0 and 8 ºC and the difference between mean summer and mean winter soil temperatures is greater than 6 ºC at a depth of 50 cm below the surface or at a restrictive feature, whichever is shallower.

Mesic (warm): Soils that have a mean annual soil temperature of 8−15 ºC and the difference between mean summer and mean winter soil temperatures is greater than 6 ºC at a depth of 50 cm below the surface or at a restrictive feature, whichever is shallower.

Soil Moisture Regimes

Udic (moist): Characteristic of high elevation areas with winter snowfall and/or summer precipitation. The soil is dry for less than 90 consecutive days in normal years.

Ustic (summer moist): Generally there is some plant-available moisture during the growing season, although significant periods of drought may occur. Summer precipitation allows presence of warm season plant species. The soil is dry for 90 or more cumulative days in normal years.

Xeric (winter moist; generally mapped at >12 inches mean annual precipitation): Characteristic of areas where winters are moist and cool and summers are warm and dry. The soil is dry for 45 or more consecutive days in the 4 months following the summer solstice but moist in some part for 90 or more consecutive days during the growing season.

Aridic (dry; generally mapped at <12 inches mean annual precipitation): Characteristic of arid regions. The soil is dry for at least half the growing season and moist for less than 90 consecutive days.

Soil moisture regimes are further divided into moisture subclasses, which are often used to indicate soils that are transitional between moisture regimes. For example, a soil with an aridic moisture regime and a xeric moisture subclass may be described as “Aridic bordering on Xeric.” Understanding these gradients becomes increasingly important when making interpretations and decisions at the project scale where aspect, slope, and soils affect the actual moisture regime. More information on taxonomic moisture subclasses is available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053576.

We used soil survey spatial and tabular data aggregated in October 2013 to facilitate broad scale analyses of resilience and resistance across the range of sage-grouse (all Management Zones; Maestas et al. 2016a). Soils data were derived from two primary sources: (1) completed and interim soil surveys available through the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff a), and (2) the State Soils Geographic Database (STATSGO2) (Soil Survey Staff b). Data for the eastern range were updated in January 2016 to reflect the most current soil survey information available (fig. 6). In some cases, abrupt changes in soil temperature and moisture regimes are apparent when merging together STATSGO2 and SSURGO soil survey areas due to differences in data collection and publication, scale of interpretation, or changes in application of regime concepts. For example, the area near the border between southeastern Montana and northeastern Wyoming is in a transition zone between the frigid and mesic soil temperature regimes, which has resulted in an apparent abrupt change in temperature regime at the state border. Future updates to soil survey information will resolve these boundary issues along state lines, using current climate datasets and additional field data.

We used soil temperature regime and moisture regime subclass data to generate a simplified index of relative resilience and resistance that has three categories: high, moderate, and low (table A2.2). We used the relationships among the predominant ecological types, soil temperature and moisture regimes, and relative resilience and resistance (table 6) to inform these categories. Soils with high water tables, wetlands, or frequent ponding or uncommon regimes that would not typically support sagebrush were excluded.

In the three cases where the primary rating for resilience and resistance of a soil temperature and moisture regime differed (Mesic/Ustic bordering on Aridic, Mesic/Aridic bordering on Ustic, and Frigid/Aridic-Typic) in table 6, the final rating was based on expert opinion of ecosystem response to disturbance and resistance to invasive annual grasses. Also, because of the distinct climatic regimes and vegetation responses in the West-Central Semiarid Prairies in MZ I and Cold Deserts in MZ II and VII, and Cold Deserts in MZ III, IV, V, and VI, the rankings for these ecoregions were performed separately. The Mesic/Ustic bordering on Aridic and Mesic/Aridic bordering on Ustic regimes were ranked as moderate in the West-Central Semiarid Prairies in MZ I (Prairies) and as low in the Cold Deserts in MZ II and VII (Cold Deserts). The rankings for the Cold Deserts in MZ II and VII, and Cold Deserts in MZ III, IV, V, and VI were similar.

Soils geodatabases and categorized resilience and resistance layers can be accessed at: https://www.sciencebase.gov/catalog/item/538e5aa9e4b09202b547e56c.

This appendix was prepared by Steve Campbell and Jeremy Maestas. Karen Clause, Jeanne Chambers, Dave Pyke, and Mary Manning contributed to its development.

Table A2.2—Resilience and resistance (R&R) rating for the soil temperature and moisture regimes in the West-Central Semiarid Prairies in MZ I, Cold Deserts in MZ II and VII, and Cold Deserts in MZ III, IV, V, and VI. The information contained in the table is based on a sagebrush biome scale analysis that used data from the National Soil Information System (NASIS) to summarize soil temperature and soil moisture regimes (to soil moisture subclass) capable of supporting big sagebrush and to assign R&R categories.

Soil taxonomic name	**Common name**	**R&R rating**
Cryic/Udic-Typic	Cold/moist	High
Cryic/Ustic-Typic	Cold/summer moist	High
Cryic/Xeric-Typic	Cold/winter moist	High
Cryic/Xeric bordering on Aridic	Cold/winter moist bordering on dry	High
Cryic/Aridic bordering on Xeric	Cold/dry bordering on winter moist	Moderate
Frigid/Ustic-Typic	Cool/summer moist	High
Frigid/Xeric-Typic	Cool/winter moist	High
Frigid/Ustic bordering on Aridic	Cool/summer moist bordering on dry	Moderate
Frigid/Xeric bordering on Aridic	Cool/winter moist bordering on dry	Moderate
Frigid/Aridic bordering on Ustic	Cool/dry bordering on summer moist	Moderate
Frigid/Aridic-Typic	Cool and dry	Moderate
Frigid/Aridic bordering on Xeric	Cool/dry bordering on winter moist	Moderate
Mesic/Ustic-Typic	Warm/summer moist	Moderate
Mesic/Xeric-Typic	Warm/winter moist	Moderate
Mesic/Ustic bordering on Aridic	Warm/summer moist bordering on dry	Moderate (Prairies) Low (Cold Deserts)
Mesic/Aridic bordering on Ustic	Warm/dry bordering on summer moist	Moderate (Prairies) Low (Cold Deserts)
Mesic/Aridic bordering on Xeric	Warm/dry bordering on moist	Low
Mesic/Aridic-Typic	Warm/dry	Low

Appendix 3—Climate Change Projections for the Sagebrush Biome: Data, Methods, and Maps

Climate projections for key climate variables were developed for the sagebrush biome for this document. A summary of the climate projections for the sagebrush biome as a whole and the different ecoregions is in Section 5.2, "Persistent Ecosystem Threats: Climate Change." The magnitude of change projected is illustrated in the maps and graphs in this appendix. These data layers can be used similarly to the data layers for other persistent ecosystem threats.

Data Sources

The climate data layers developed for the Science Framework include both current and future climatic conditions developed for a 10 km resolution grid across western North America. The U.S. National Centers for Environmental Prediction, Climate Forecast System Reanalysis products (Saha et al. 2011) for current climate conditions (1980−2010), were used to extract daily maximum and minimum temperatures (2 m above-ground). The 6-hourly T382 products (Saha et al. 2010) were used to extract daily maximum and minimum precipitation. For future conditions, bias-corrected and spatially downscaled (BCSD) climate projections were downloaded as monthly time-series for two time periods, 2020−2050 and 2070−2100, from the fifth phase of the Climate Model Intercomparison Project (CMIP5) (Taylor et al. 2012). Output from 11 climate models and two representative concentration pathways (RCPs) (Moss et al. 2010), RCP 4.5 and RCP 8.5, were extracted from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive (Maurer et al. 2007) at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/. Historical daily data (NCEP/NFSR) were combined with monthly General Circulation Model (GCM) predictions of historical and future conditions with a hybrid-delta downscaling approach to obtain future daily forcing (Hamlet et al. 2010; Tohver et al. 2014). Climate models selected for this analysis from the large set of models in CMIP5 included the most independent models in terms of model design (Knutti et al. 2013) and the best performing models over the historical period for the northwestern United States (Rupp et al. 2013) and southwestern United States (Rupp, personal communication). The models used were CanESM2, CESM1-CAM5, CNRM-CM5, CSIRO-Mk3-6-0, FGOALS-g2, FGOALS-s2, GISS-E2-R, HadGEM2-ES, inmcm4, IPSL-CM5A-MR, and MIROC-ESM.

Methods

Variables Examined

From the 30-year time-series of daily precipitation and temperature data for each time period, we calculated 12 variables as general predictors of important climatic conditions for sagebrush ecosystems. In general, mean daily temperatures were calculated as the average of daily minimum and maximum, and total precipitation was calculated as the sum of daily precipitation. These temperature and precipitation variables were calculated for four time periods: annual (mean annual temperature and precipitation), winter (December through March), spring (April through June), and summer (July through September). We also quantified average daily maximum temperature in July (a metric of summer heat stress), average daily minimum temperature in January (a metric of winter frost exposure), and the annual mean proportion of precipitation that occurs between May and October (a measure of warm-season precipitation), and between July and September (a measure of mid-summer monsoon season precipitation).

Ensemble Calculations

Future climatic conditions were represented by 44 projections derived from 11 climate models simulating climate under two RCP scenarios over two time periods. For each RCP scenario and time period, we developed cell-specific ensemble grids of minimum, mean, and maximum values. These ensemble determinations are performed for each 10 km x 10 km grid cell. The minimum, mean, and maximum values are determined for each cell from the 11 values for that cell relating to the set of 11 climate models. Data for all ensemble levels are available through the U.S. Geological Survey ScienceBase (https://www.sciencebase.gov/catalog/item/5850549ae4b0f24ebfd9368f).

Maps and Summaries of Climate Change Projections for the Ecoregions in the Sagebrush Biome

Climate change projections were developed for the entire sagebrush biome. To evaluate differences among EPA level III ecoregions or groups of ecoregions with similar topography and climate, data were summarized by the following ecoregions or ecoregion group: (1) Northwestern Glaciated Plains and Northwestern Great Plains; (2) Wyoming Basin (3) Colorado Plateau and AZ-NM Plateau; (4) Central Basin and Range; (5) Northern Basin and Range, Snake River Plain, and Columbia Plateau; (6) Wasatch and Uinta Mountains and Southern Rockies; (7) Sierra Nevada; (8) Eastern Cascades Slopes and Foothills and Blue Mountains; and (9) Idaho Batholith and Middle Rockies.

This appendix includes two pages for each climate variable. The first page shows current and projected climate conditions for a variable. The boxplots in the graph at the top of the page illustrate variability between current conditions (1980−2010, left box) and the 12 future climate projections for the sagebrush biome. For the future climate projections, the minimum, mean, and maximum values from the 11 climate models are shown for two RCPs and two future time periods. This graph allows comparison of current conditions with future projections, and provides perspective on the magnitude of uncertainty in the climate models for the different RCPs and time periods. For example, by contrasting the min, mean and max boxplots within a group, it is evident that climate model uncertainty is greater for the longer-term time period.

This graph also allows assessment of the magnitude of difference between time periods and RCPs by comparing groups. For example, mean annual temperatures are projected to be greater under RCP 8.5 than RCP 4.5 and greater at the end of the 21st century than in the middle of the century. In contrast, although uncertainty in mean annual precipitation (variability among min, mean, and max) is higher at the end of the century, the amount of precipitation expected does not show a consistent trend for either RCP or time period.

Maps on the first page show mean conditions for 1980−2010 (center left), mean conditions for RCP 4.5 in 2020−2050 and 2070−2100 (upper center and right, respectively), and mean conditions for RCP 8.5 in 2020−2050 and 2070−2100 (lower center, and center right, respectively). These maps provide perspective on the geographic patterns of potential climate change and facilitate examination of specific locations within the sagebrush biome.

The second page for a variable shows changes in climate between current conditions and the 12 future climate projections for the sagebrush biome. The graph at the top of the page is structured similarly to the one on the first page. However, the 12 boxplots show the differences between current conditions and future projections for the two RCPs and time periods. Positive values indicate projected increases in temperature or precipitation, and negative values indicate projections of decreases. Similar to the boxplots in the graph on the first page, the uncertainty in climate forecasts can be assessed by contrasting the min, mean, and max values within groups. The impact of concentration pathways and future time periods can also be evaluated by contrasting groups.

Ranges for each boxplot in this graph are generally smaller than ranges from the graph on the first page, because the spatial variation in projected changes is smaller than the spatial variation in climate across the entire sagebrush biome. Also, while mean annual temperature is projected to increase everywhere, projected changes in mean annual precipitation include increases and decreases depending on location.

The maps on the second page show the projected change in mean conditions between 1980−2010 and 2070−2100 for RCP 4.5 and RCP 8.5. At the bottom of the page, a map illustrating the nine ecoregion groups used in this analysis is shown. The graph beside the ecoregion map shows a boxplot of the change for each ecoregion group under RCP 8.5 between 1980−2010 and 2070−2100. This graph provides perspective on how the magnitude of change is projected to vary among ecoregions.

The projected change in climate is particularly useful in evaluating management scenarios (see table 9). For example, in areas where climate change and its interactions with other stressors are projected to be relatively small, it may be possible to continue existing management practices, monitor outcomes, and adapt management as needed. However, where climate change and its interactions are expected to be severe, proactive management may be necessary to facilitate transition to a new site potential.

This appendix was prepared by John B. Bradford. Linda Joyce, Jeanne Chambers, Marian Talbert, Bryce Richardson, John Kim, and Steve Hanser contributed to its development.

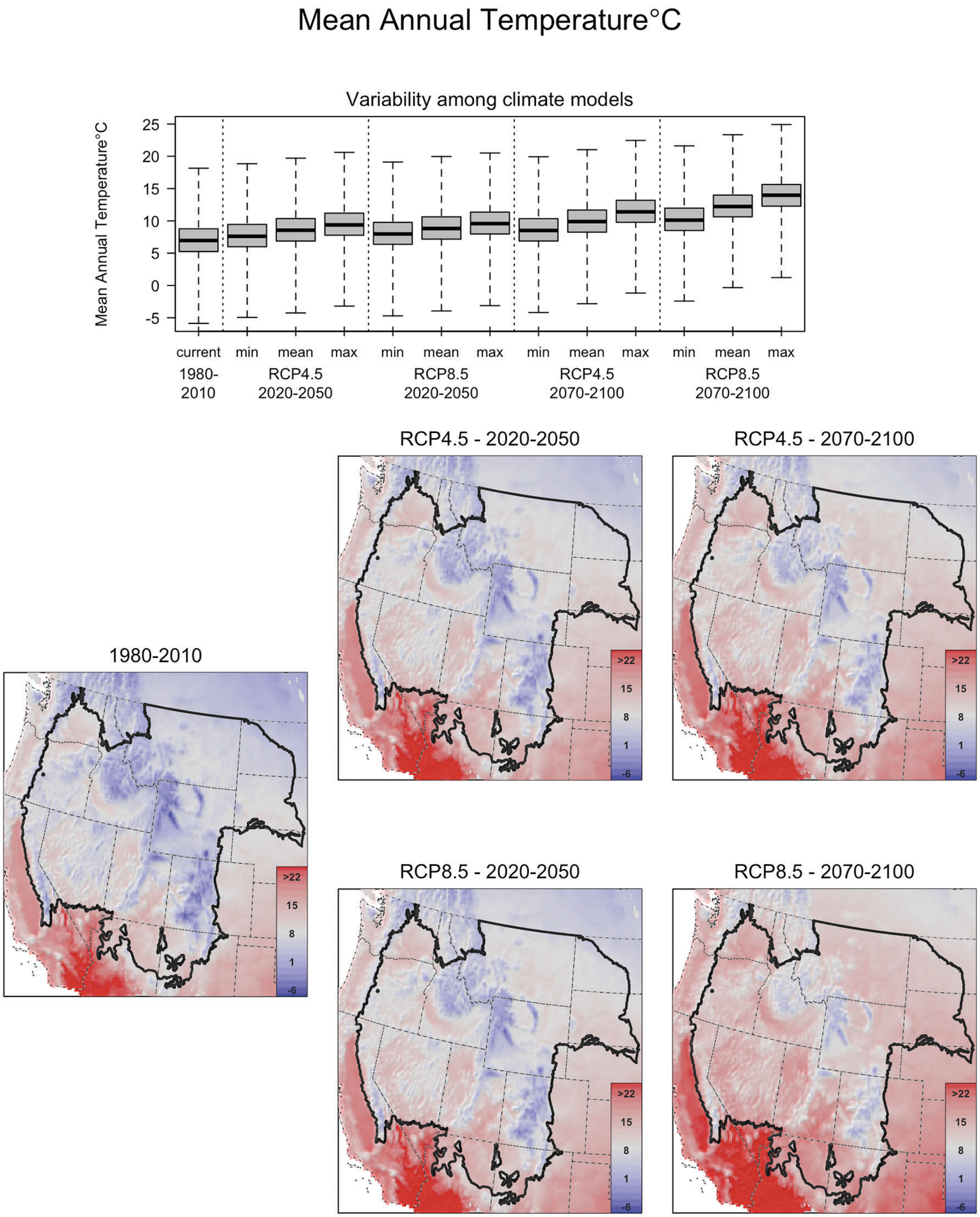

Mean Annual Temperature°C
Variability among climate models
Mean Annual Temperature°C
25
20
15
10
5
0
-5
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
1980-2010
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>22
15
8
1
-6

Figure A3.1a.

Change in Mean Annual Temperature°C

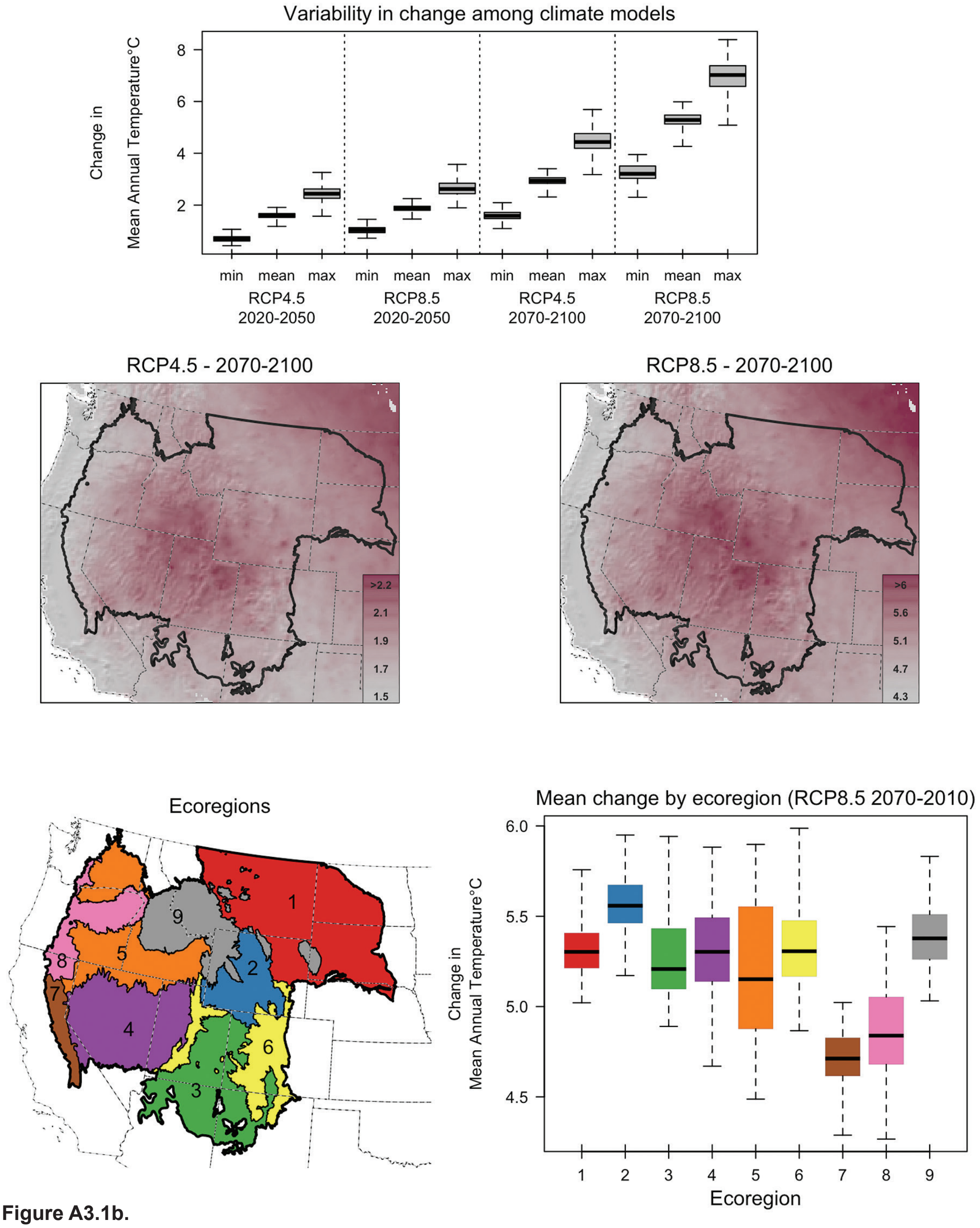


Figure A3.1b.

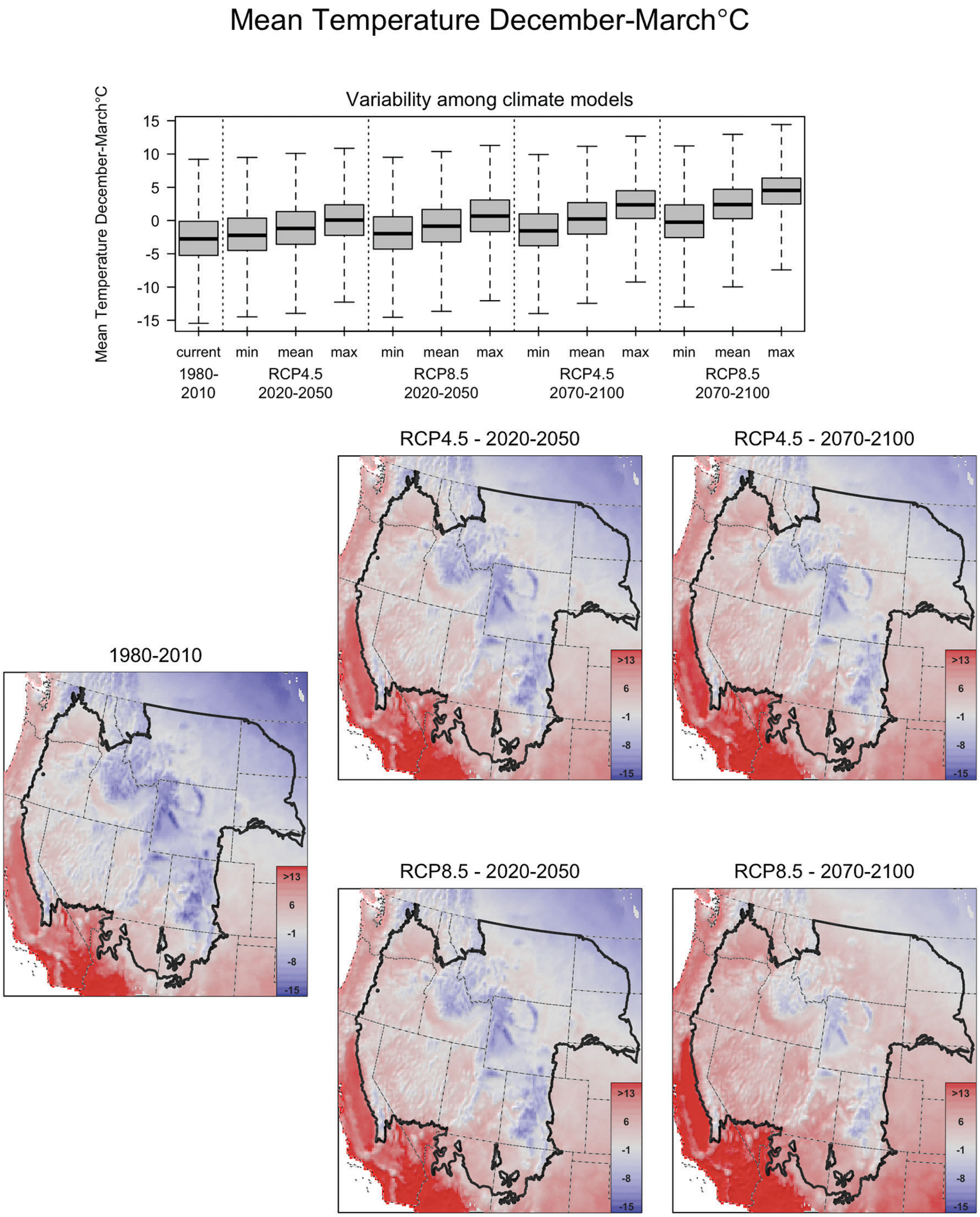

Mean Temperature December-March°C
Variability among climate models
Mean Temperature December-March°C
15
10
5
0
-5
-10
-15
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
1980-2010
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>13
6
-1
-8
-15

Figure A3.2a.

Change in Mean Temperature December-March°C

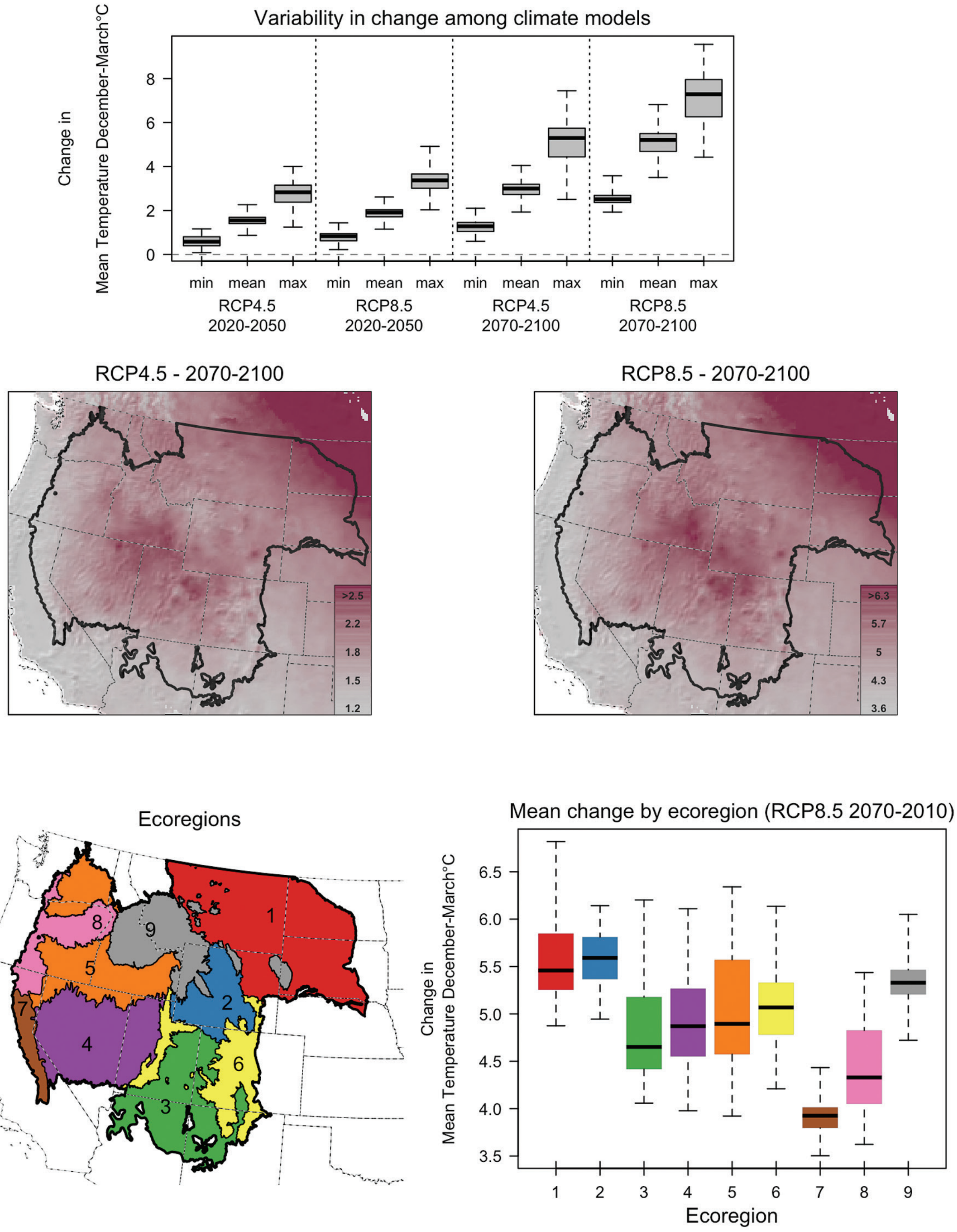


Figure A3.2b.

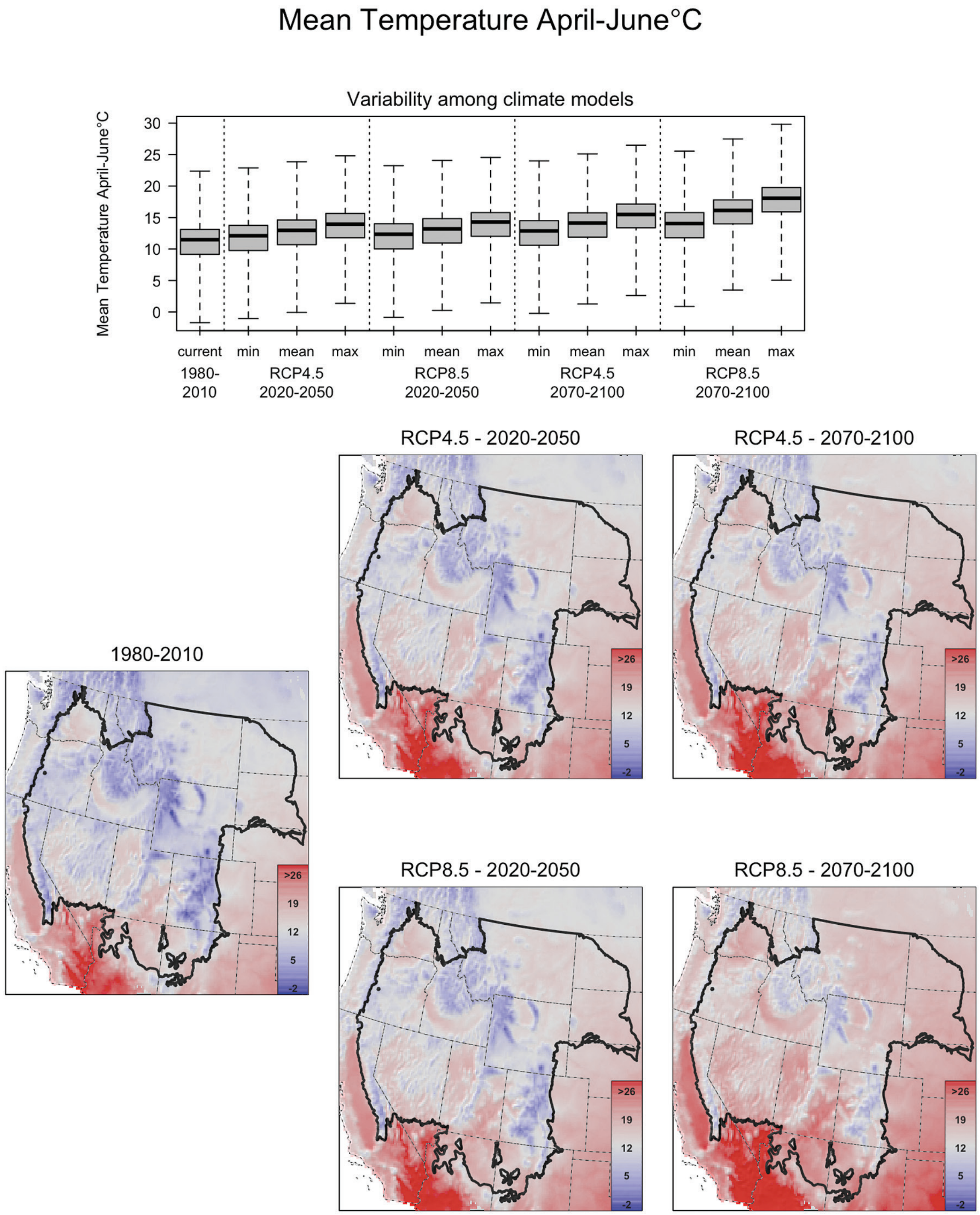
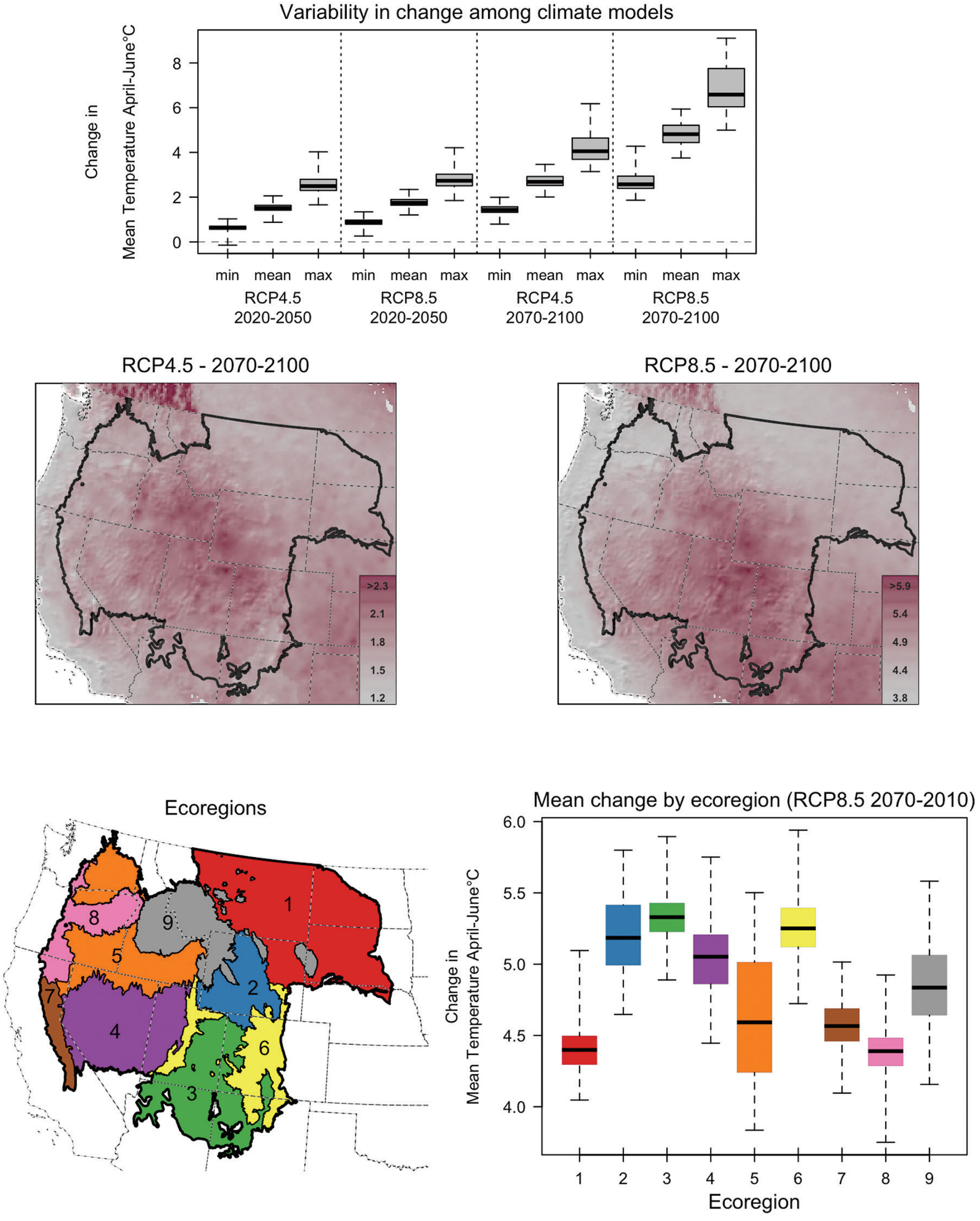

Mean Temperature April-June°C
Variability among climate models
Mean Temperature April-June°C
30
25
20
15
10
5
0
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-2010
RCP4.5 2020-2050
RCP8.5 2020-2050
RCP4.5 2070-2100
RCP8.5 2070-2100
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
1980-2010
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>26
19
12
5
-2

Figure A3.3a.

Change in
Mean Temperature April-June°C


Variability in change among climate models

RCP4.5 - 2070-2100

RCP8.5 - 2070-2100

Ecoregions

Mean change by ecoregion (RCP8.5 2070-2010)

Figure A3.3b.

Mean Temperature July-September°C

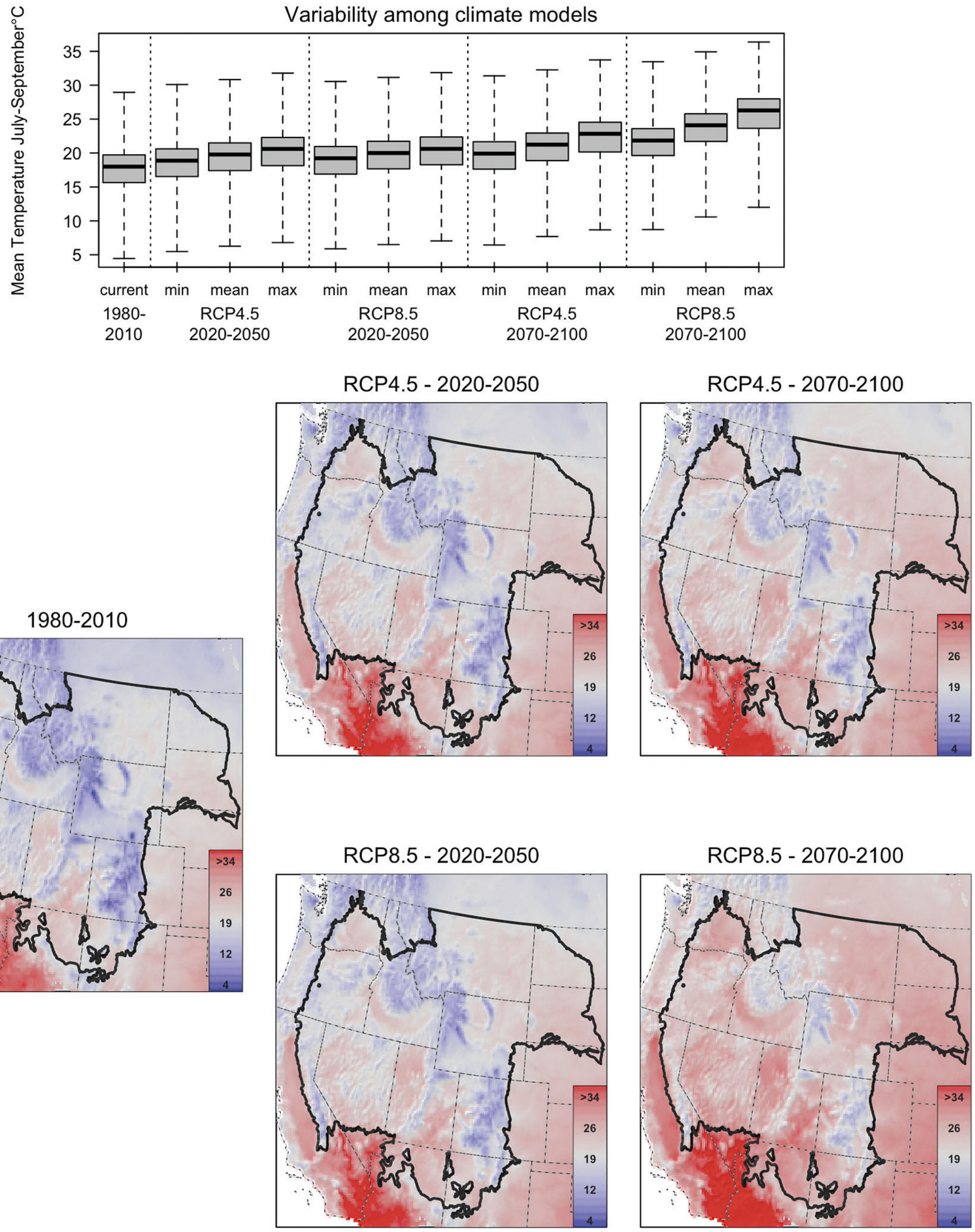


Figure A3.4a.

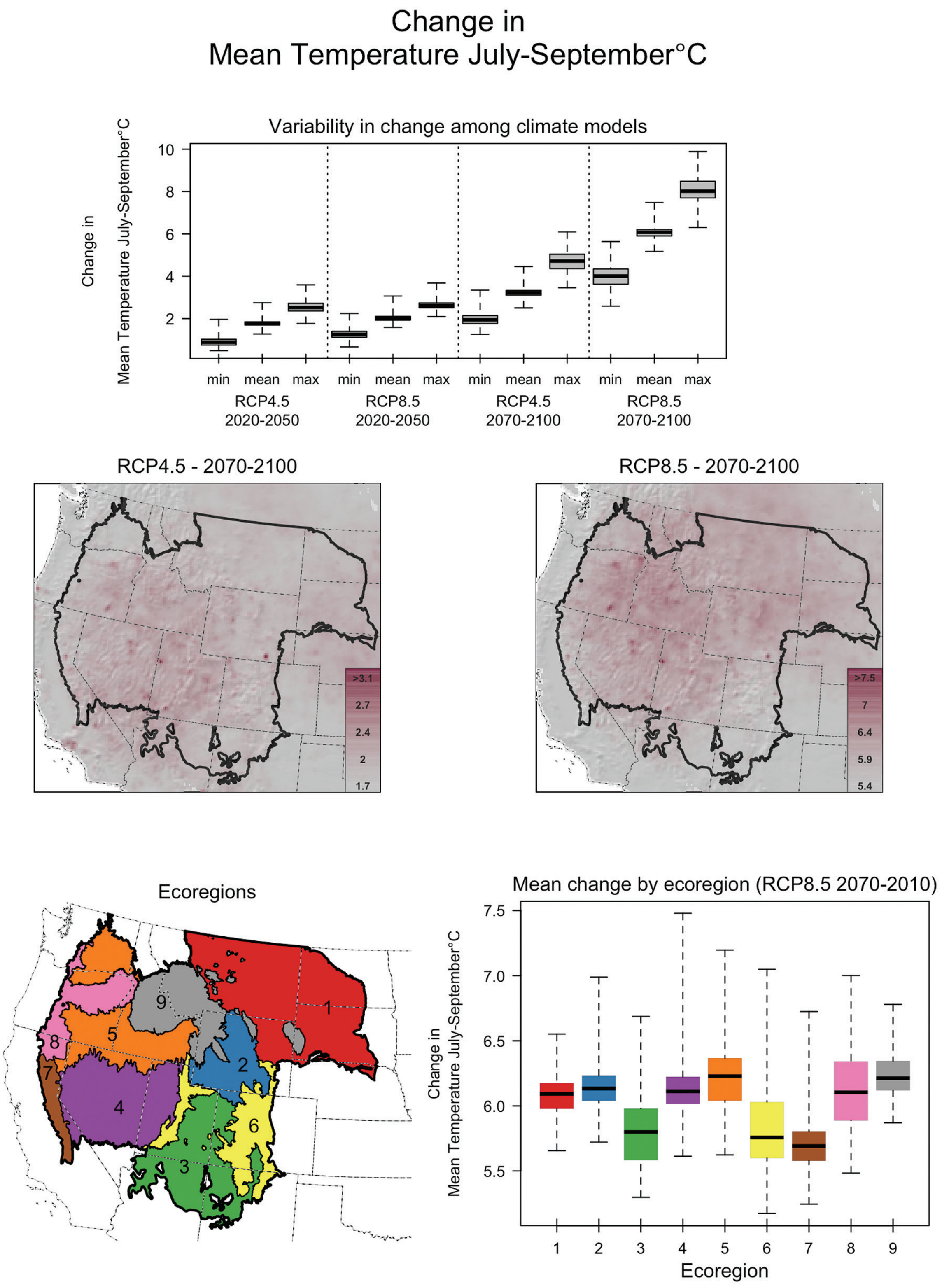

Change in
Mean Temperature July-September°C
Variability in change among climate models
Change in
Mean Temperature July-September°C
10
8
6
4
2
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>3.1
2.7
2.4
2
1.7
RCP8.5 - 2070-2100
>7.5
7
6.4
5.9
5.4
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Change in
Mean Temperature July-September°C
7.5
7.0
6.5
6.0
5.5
Ecoregion

Figure A3.4b.

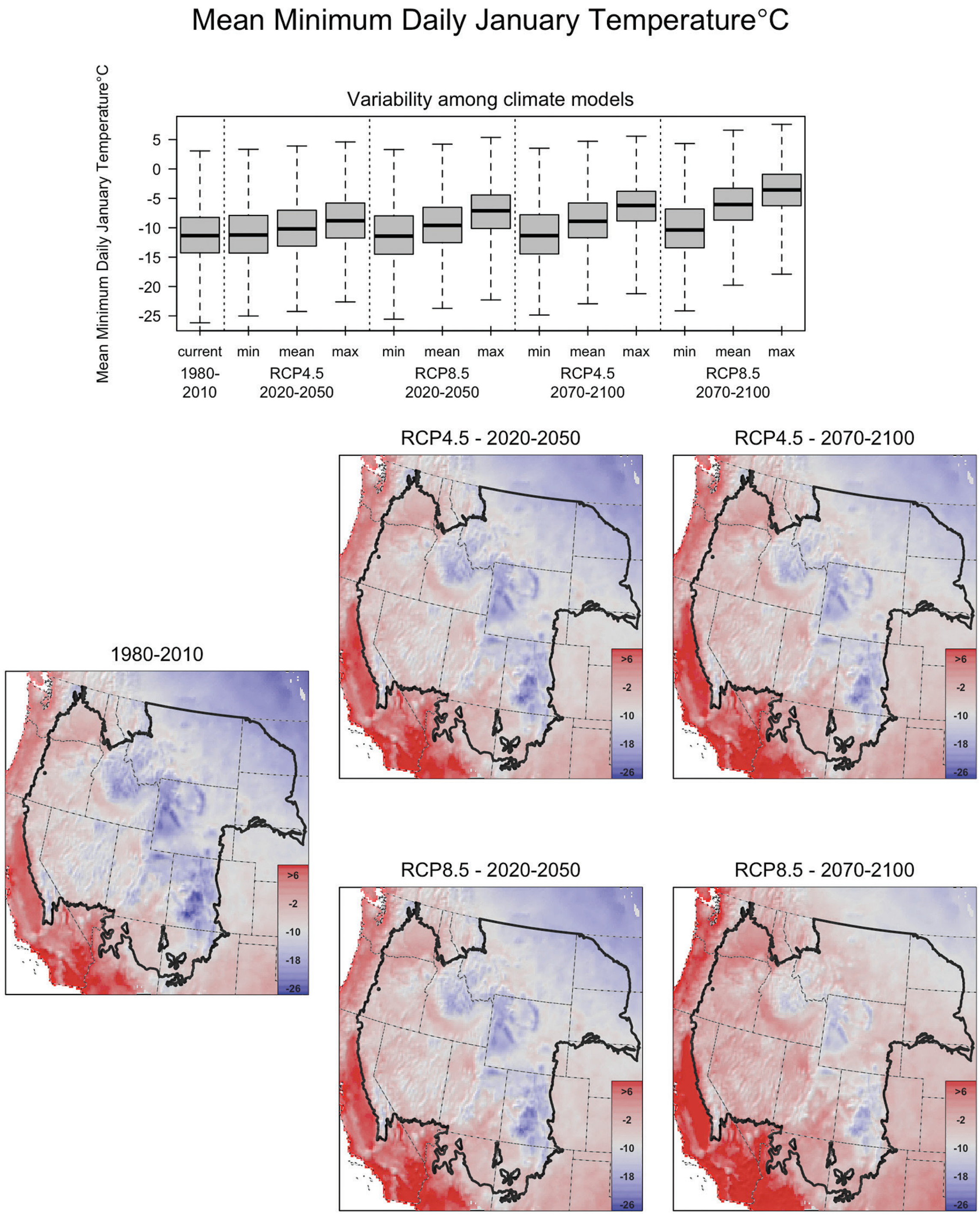

Mean Minimum Daily January Temperature°C
Variability among climate models
Mean Minimum Daily January Temperature°C
5
0
-5
-10
-15
-20
-25
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
1980-2010
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>6
-2
-10
-18
-26

Figure A3.5a.

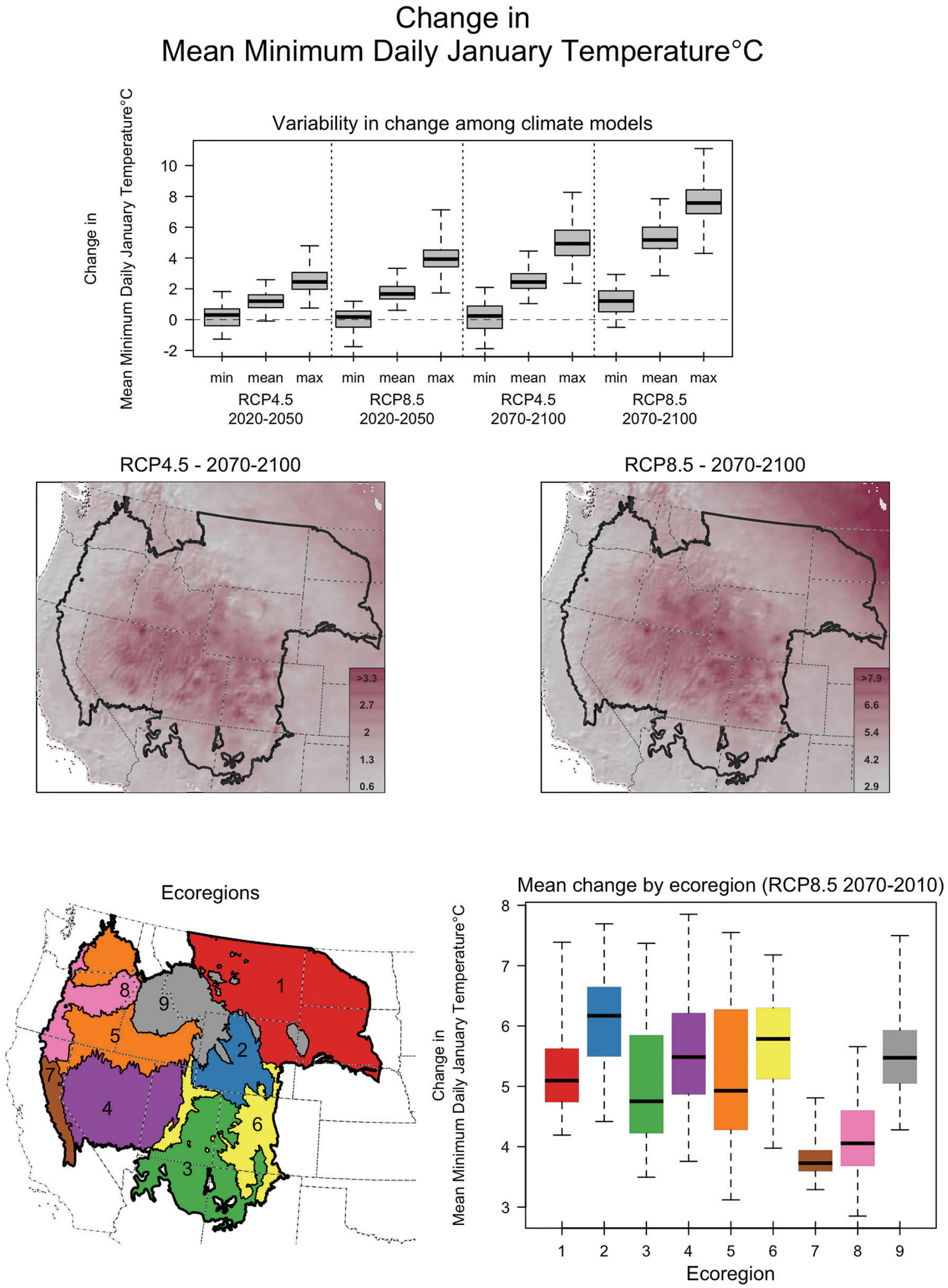

Change in
Mean Minimum Daily January Temperature°C
Variability in change among climate models
Change in
Mean Minimum Daily January Temperature°C
10
8
6
4
2
0
-2
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>3.3
2.7
2
1.3
0.6
RCP8.5 - 2070-2100
>7.9
6.6
5.4
4.2
2.9
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Change in
Mean Minimum Daily January Temperature°C
8
7
6
5
4
3
Ecoregion

Figure A3.5b.

Mean Maximum Daily July Temperature°C

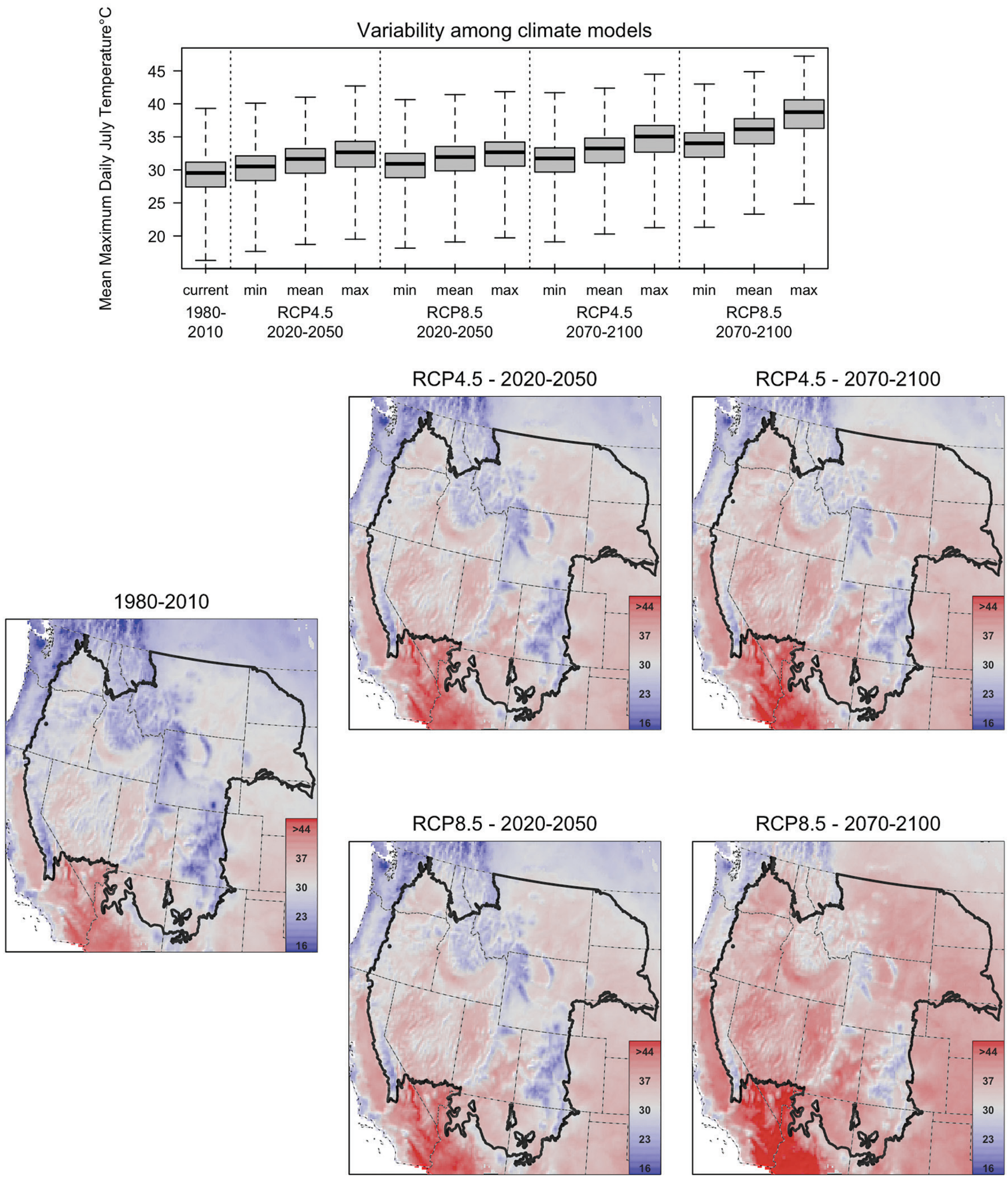


Figure A3.6a.

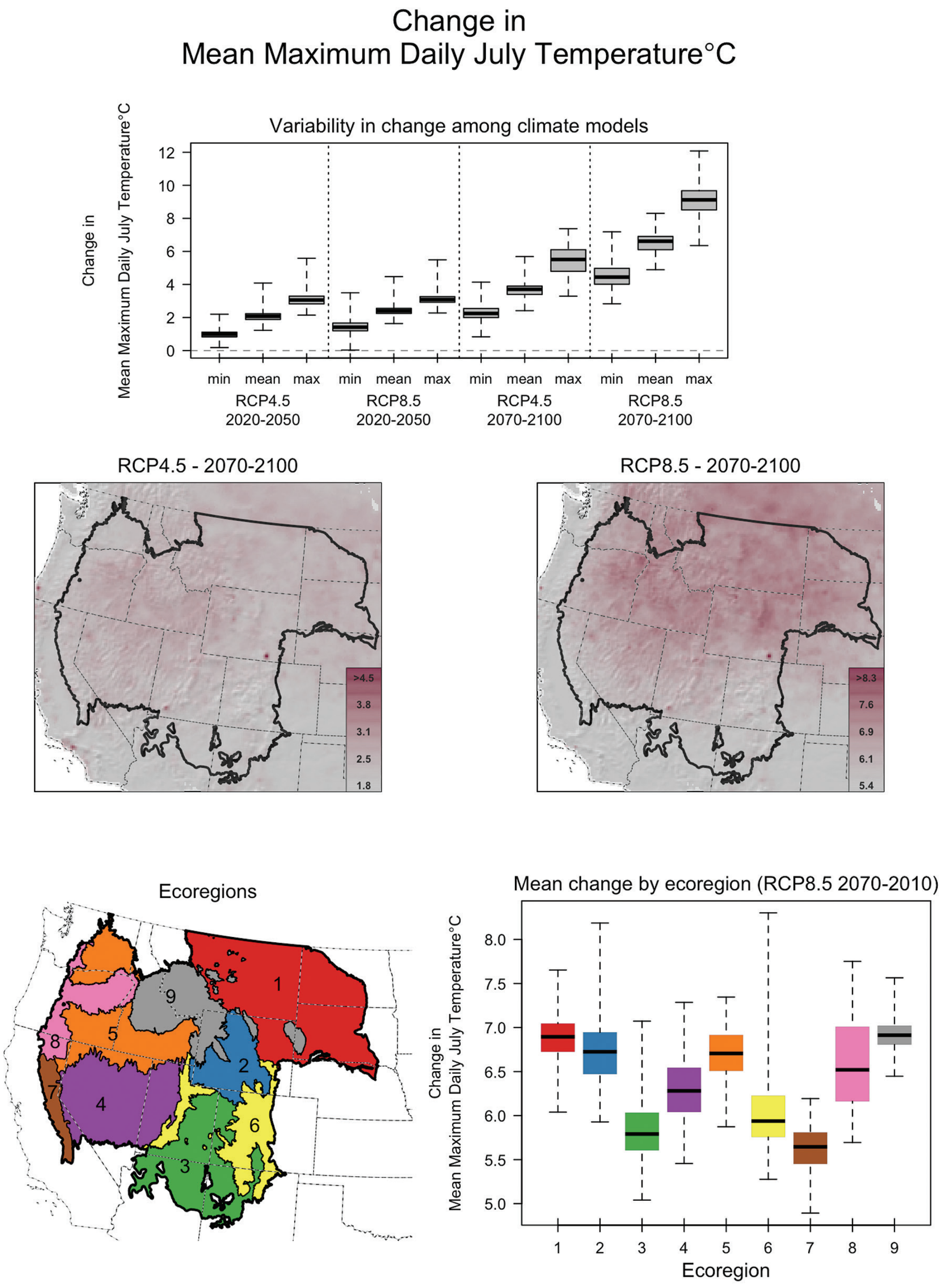

Change in
Mean Maximum Daily July Temperature°C
Variability in change among climate models
Change in
Mean Maximum Daily July Temperature°C
12
10
8
6
4
2
0
min
mean
max
min
mean
max
min
mean
max
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>4.5
3.8
3.1
2.5
1.8
RCP8.5 - 2070-2100
>8.3
7.6
6.9
6.1
5.4
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Change in
Mean Maximum Daily July Temperature°C
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1
2
3
4
5
6
7
8
9
Ecoregion

Figure A3.6b.

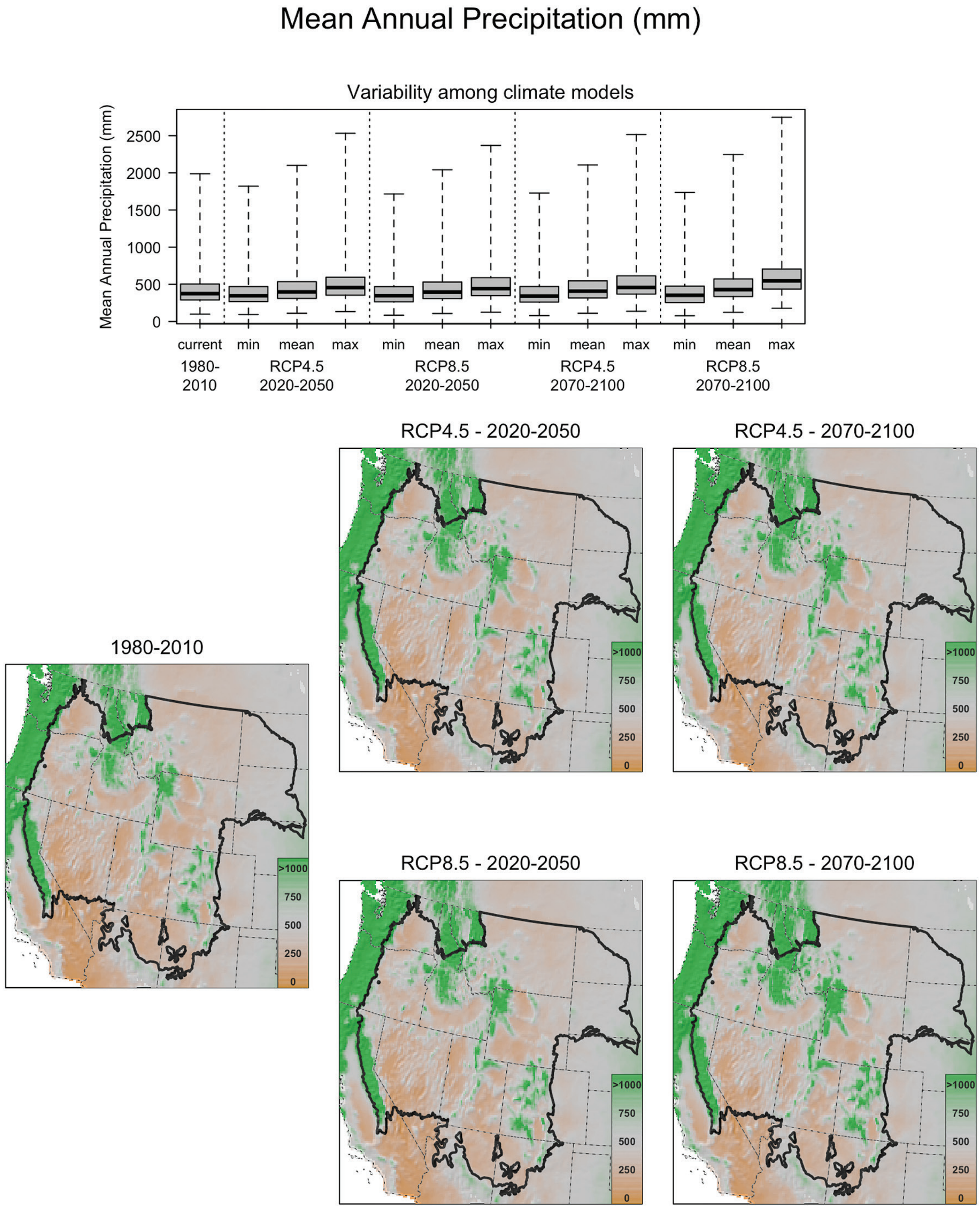

Mean Annual Precipitation (mm)
Variability among climate models
Mean Annual Precipitation (mm)
0
500
1000
1500
2000
2500
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
1980-2010
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>1000
750
500
250
0

Figure A3.7a.

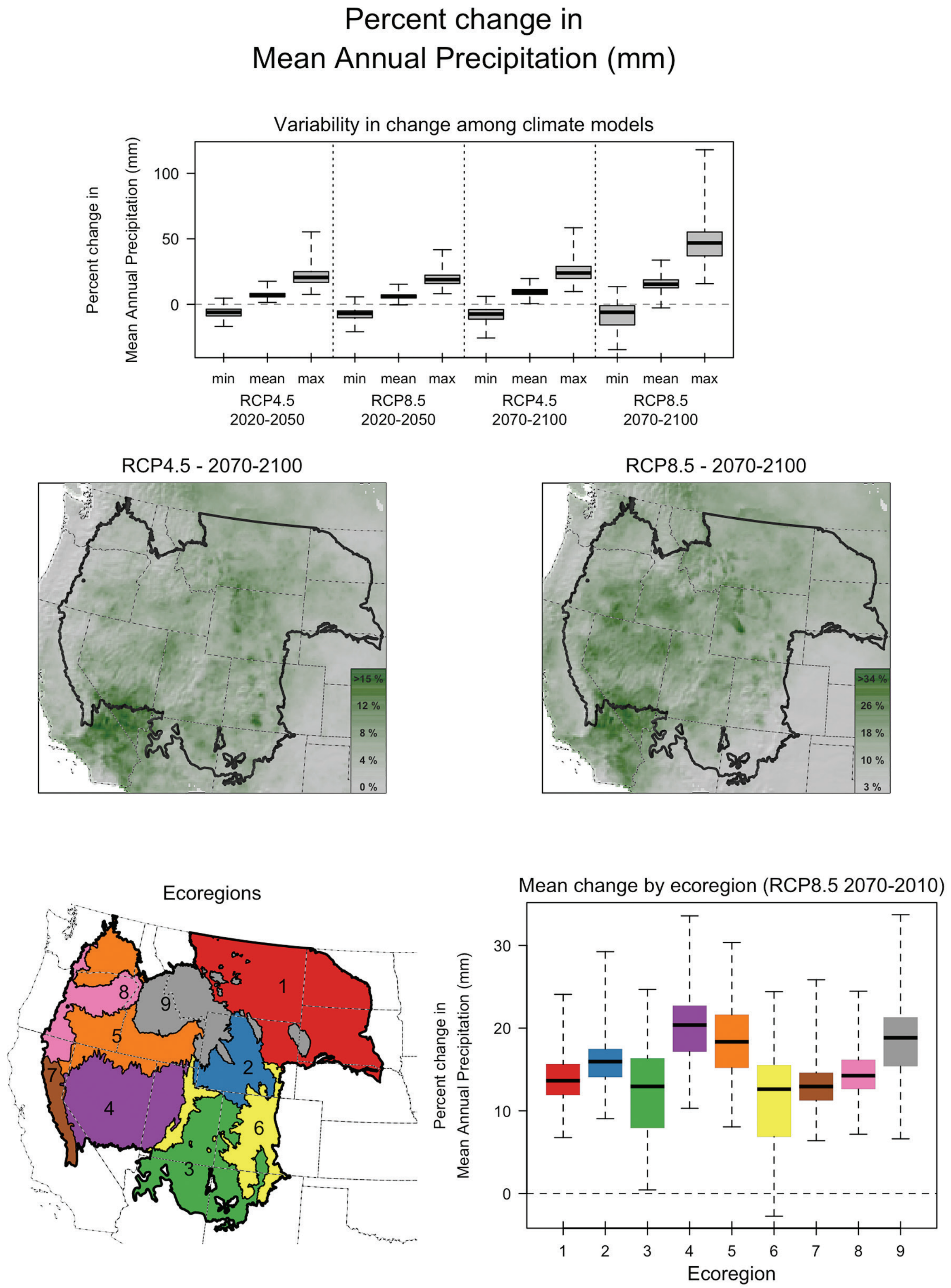

Percent change in
Mean Annual Precipitation (mm)
Variability in change among climate models
Percent change in
Mean Annual Precipitation (mm)
100
50
0
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>15 %
12 %
8 %
4 %
0 %
RCP8.5 - 2070-2100
>34 %
26 %
18 %
10 %
3 %
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Percent change in
Mean Annual Precipitation (mm)
30
20
10
0
1
2
3
4
5
6
7
8
9
Ecoregion

Figure A3.7b.

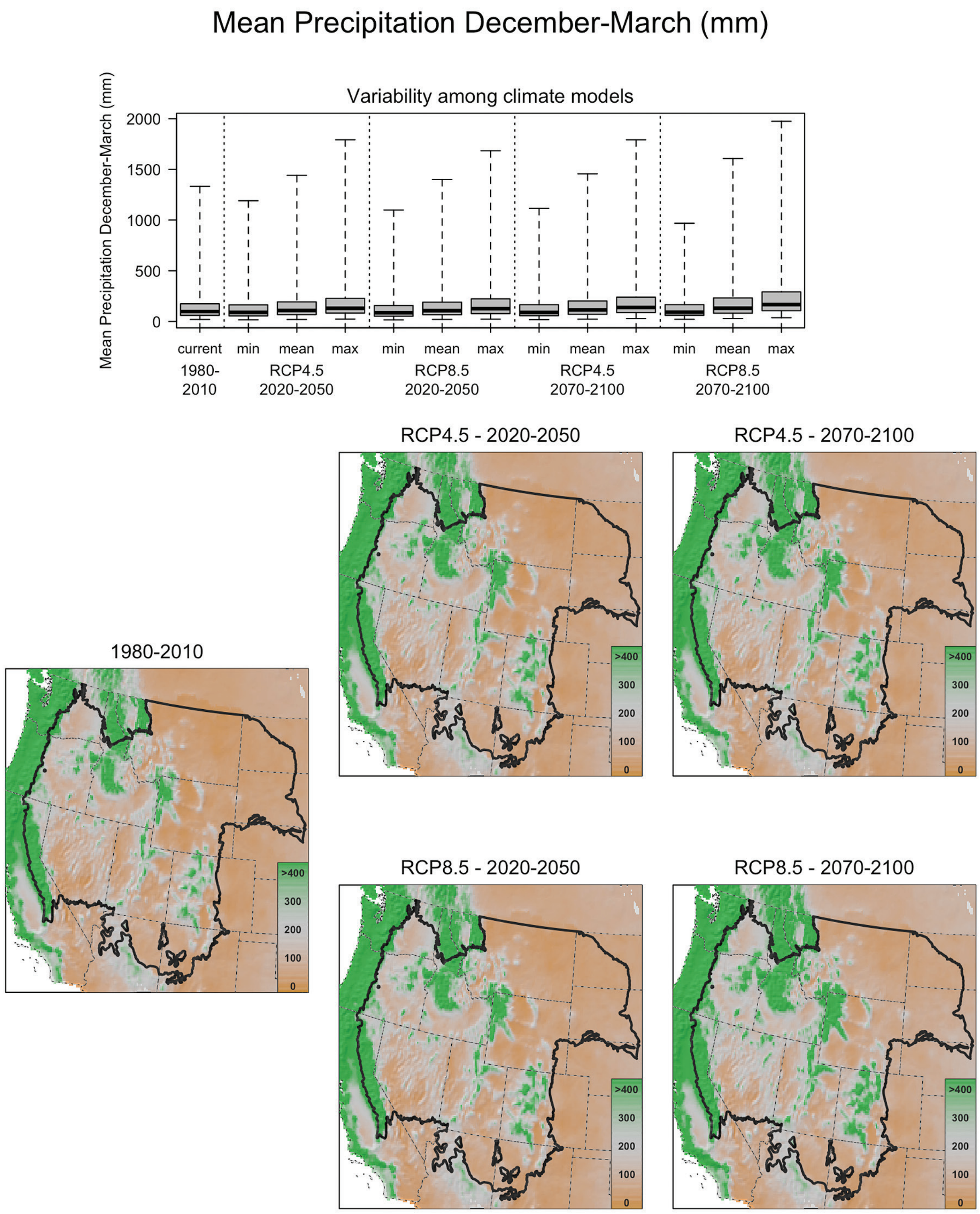

Mean Precipitation December-March (mm)
Variability among climate models
Mean Precipitation December-March (mm)
2000
1500
1000
500
0
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
1980-2010
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>400
300
200
100
0

Figure A3.8a.

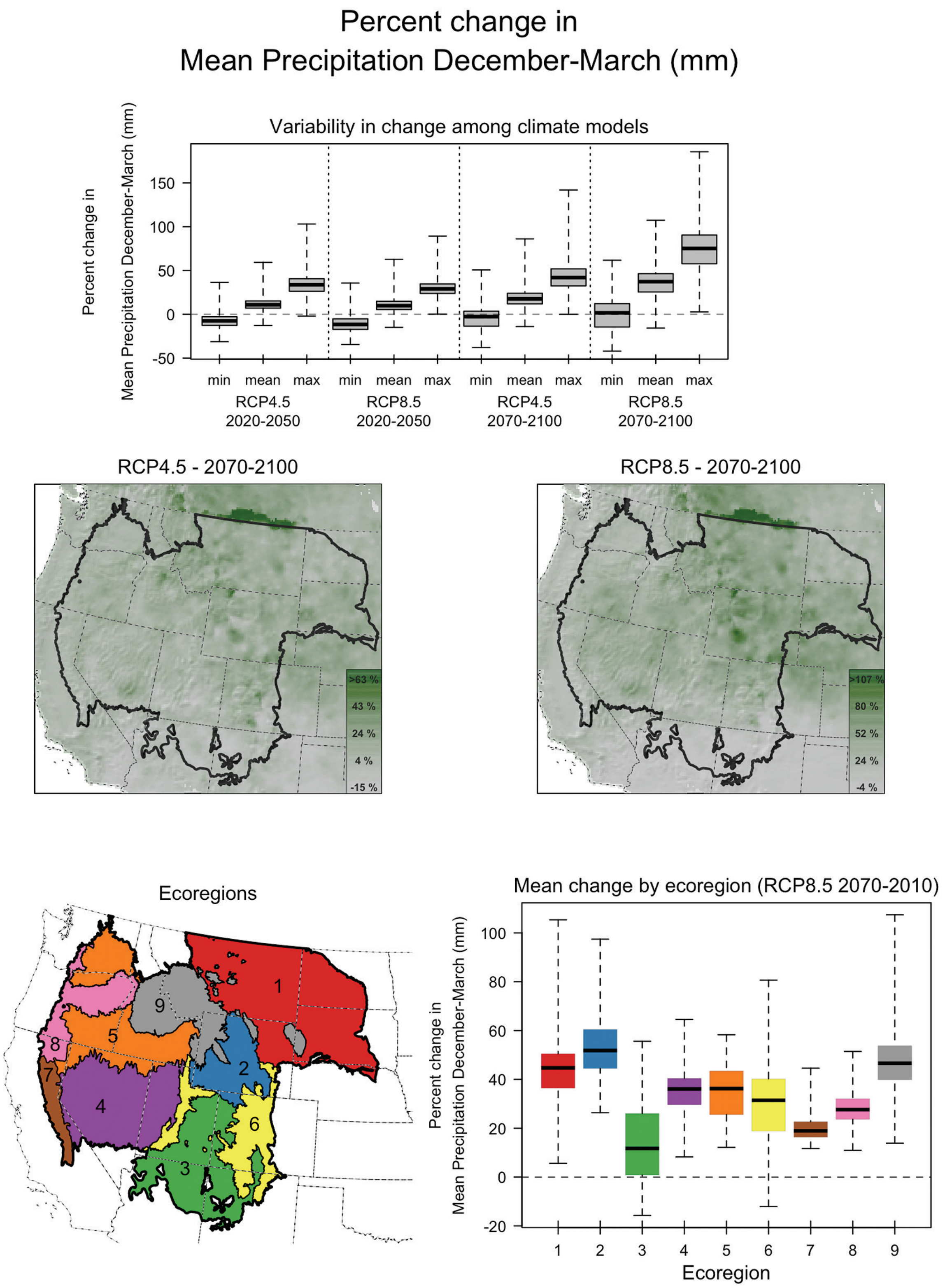

Percent change in
Mean Precipitation December-March (mm)
Variability in change among climate models
Percent change in
Mean Precipitation December-March (mm)
150
100
50
0
-50
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>63 %
43 %
24 %
4 %
-15 %
RCP8.5 - 2070-2100
>107 %
80 %
52 %
24 %
-4 %
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Percent change in
Mean Precipitation December-March (mm)
100
80
60
40
20
0
-20
Ecoregion

Figure A3.8b.

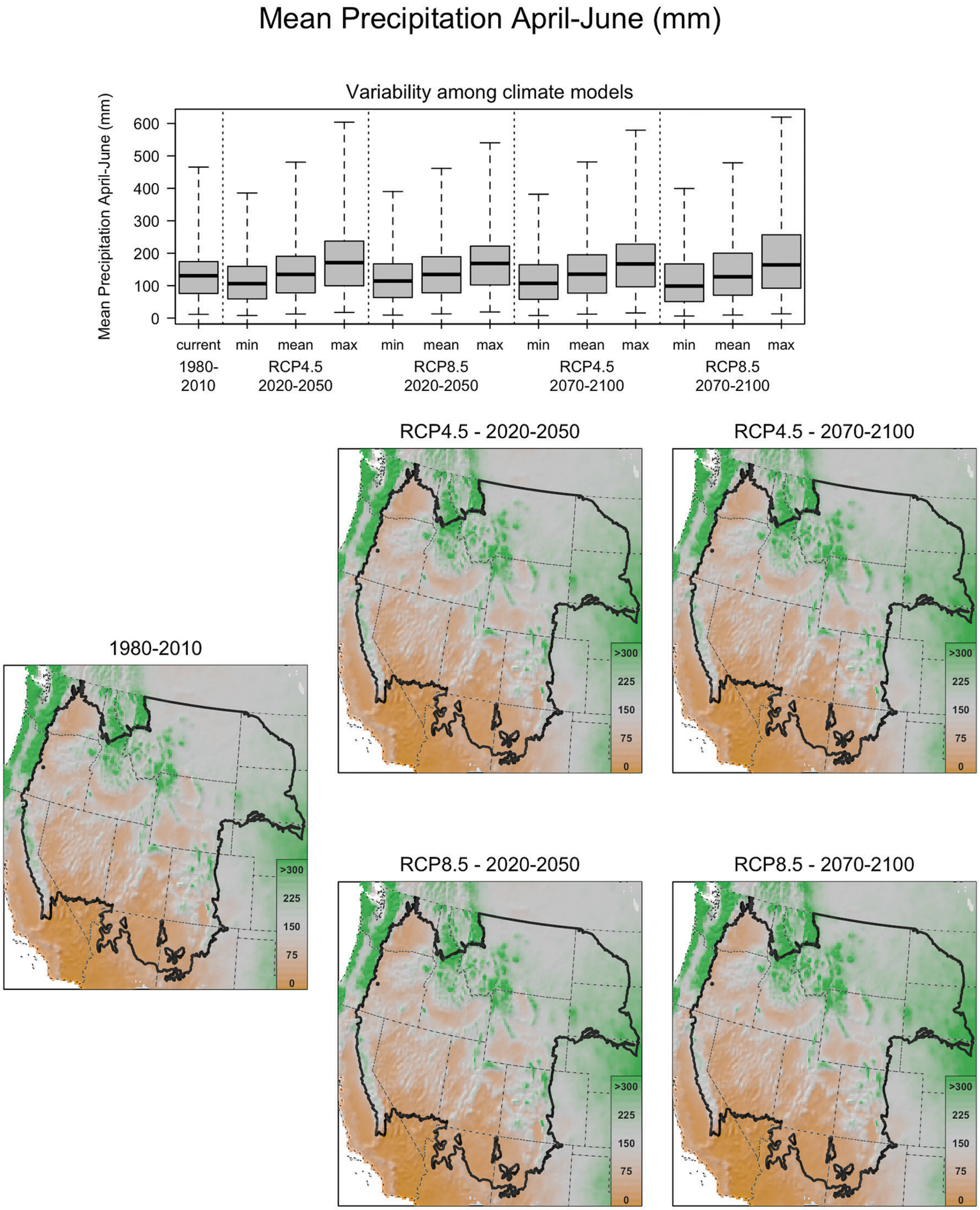

Mean Precipitation April-June (mm)
Variability among climate models
Mean Precipitation April-June (mm)
0
100
200
300
400
500
600
current
min
mean
max
min
mean
max
min
mean
max
min
mean
max
1980-
2010
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
1980-2010
RCP4.5 - 2020-2050
RCP4.5 - 2070-2100
RCP8.5 - 2020-2050
RCP8.5 - 2070-2100
>300
225
150
75
0

Figure A3.9a.

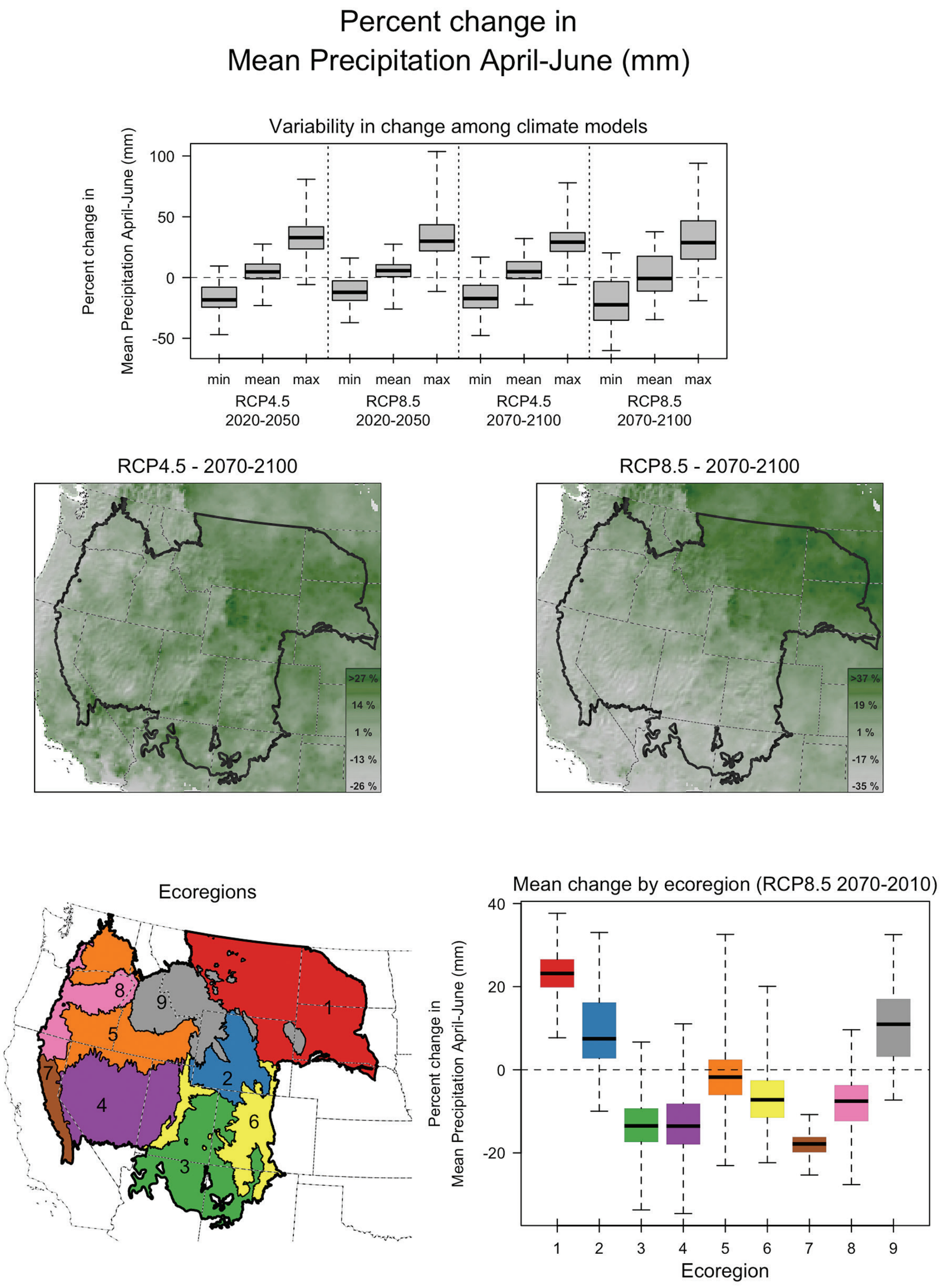
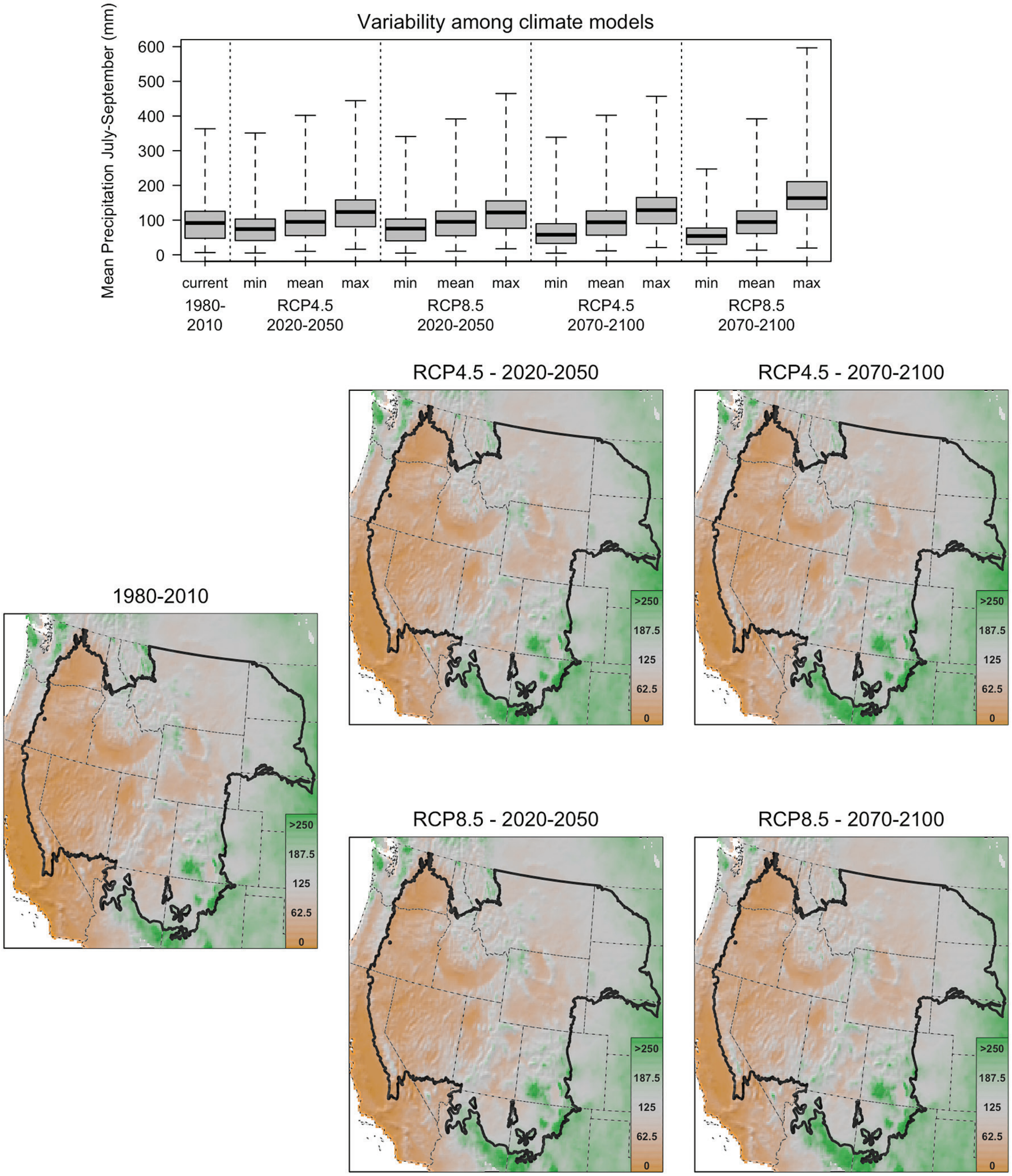

Percent change in
Mean Precipitation April-June (mm)
Variability in change among climate models
Percent change in
Mean Precipitation April-June (mm)
100
50
0
-50
min
mean
max
RCP4.5
2020-2050
RCP8.5
2020-2050
RCP4.5
2070-2100
RCP8.5
2070-2100
RCP4.5 - 2070-2100
>27 %
14 %
1 %
-13 %
-26 %
RCP8.5 - 2070-2100
>37 %
19 %
1 %
-17 %
-35 %
Ecoregions
1
2
3
4
5
6
7
8
9
Mean change by ecoregion (RCP8.5 2070-2010)
Percent change in
Mean Precipitation April-June (mm)
40
20
0
-20
Ecoregion

Figure A3.9b.

Mean Precipitation July-September (mm)



1980-2010

RCP4.5 - 2020-2050

RCP4.5 - 2070-2100

RCP8.5 - 2020-2050

RCP8.5 - 2070-2100

Figure A3.10a.

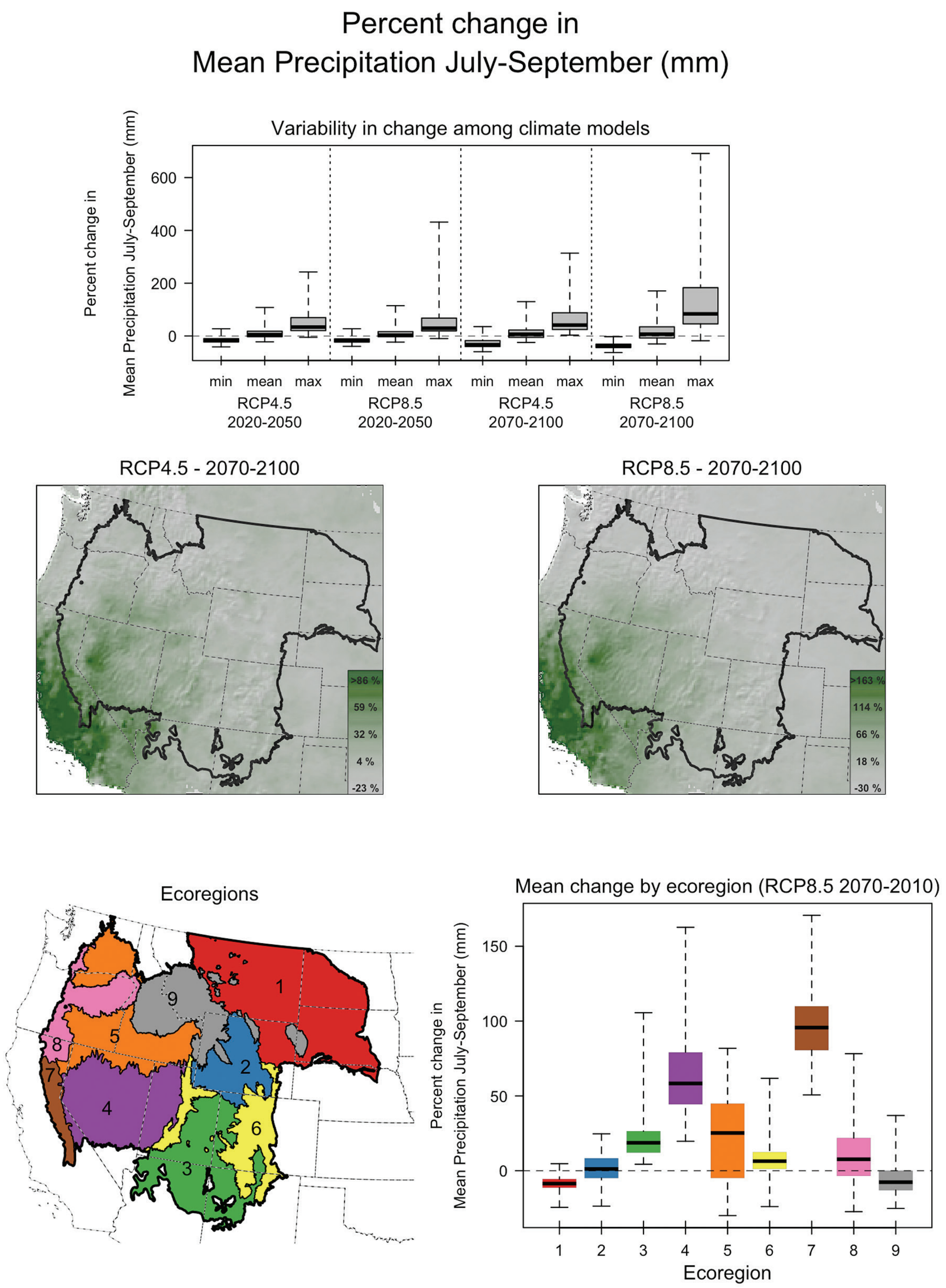


Figure A3.10b.

Proportion of Precipitation May-October

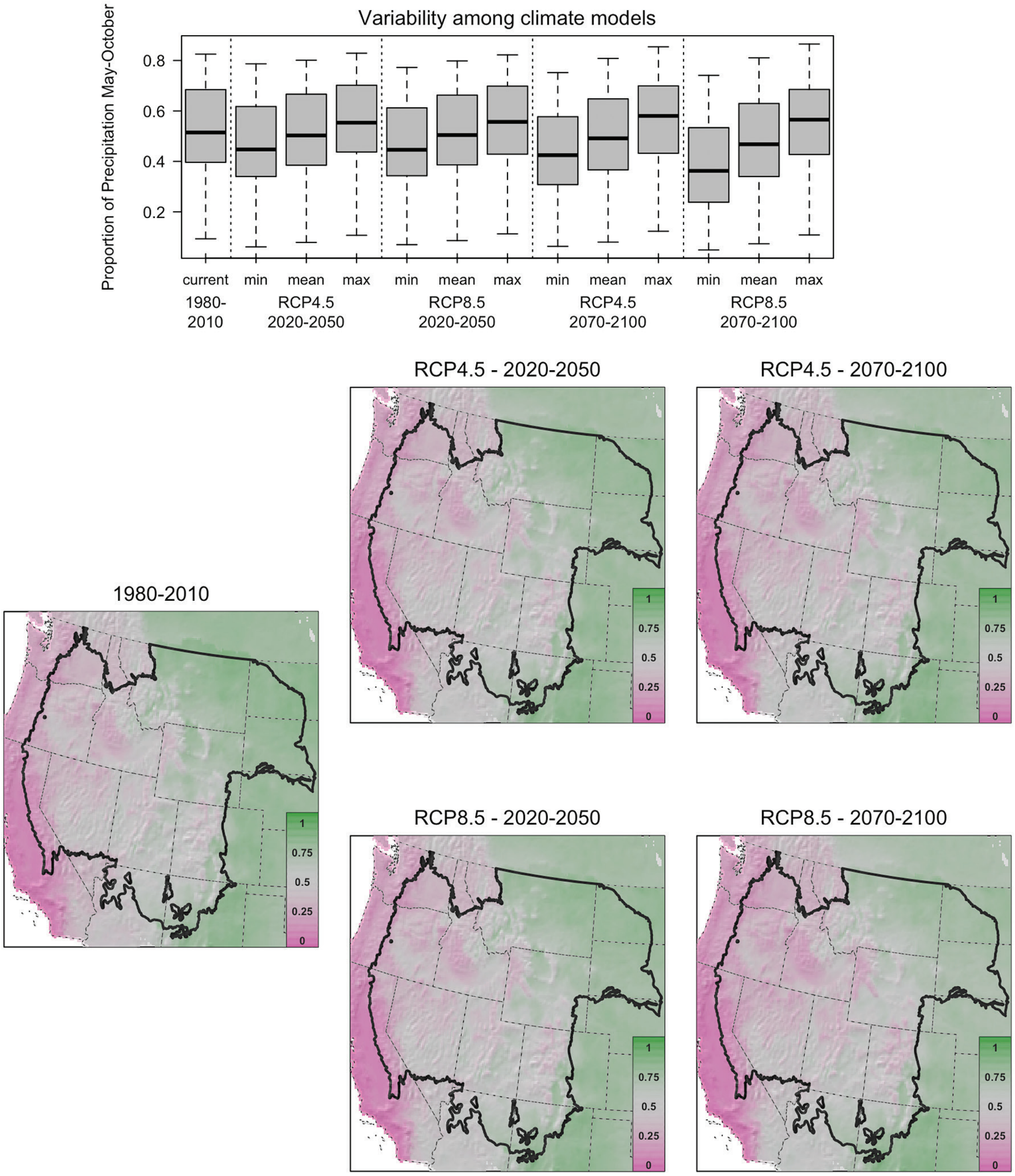


Figure A3.11a.

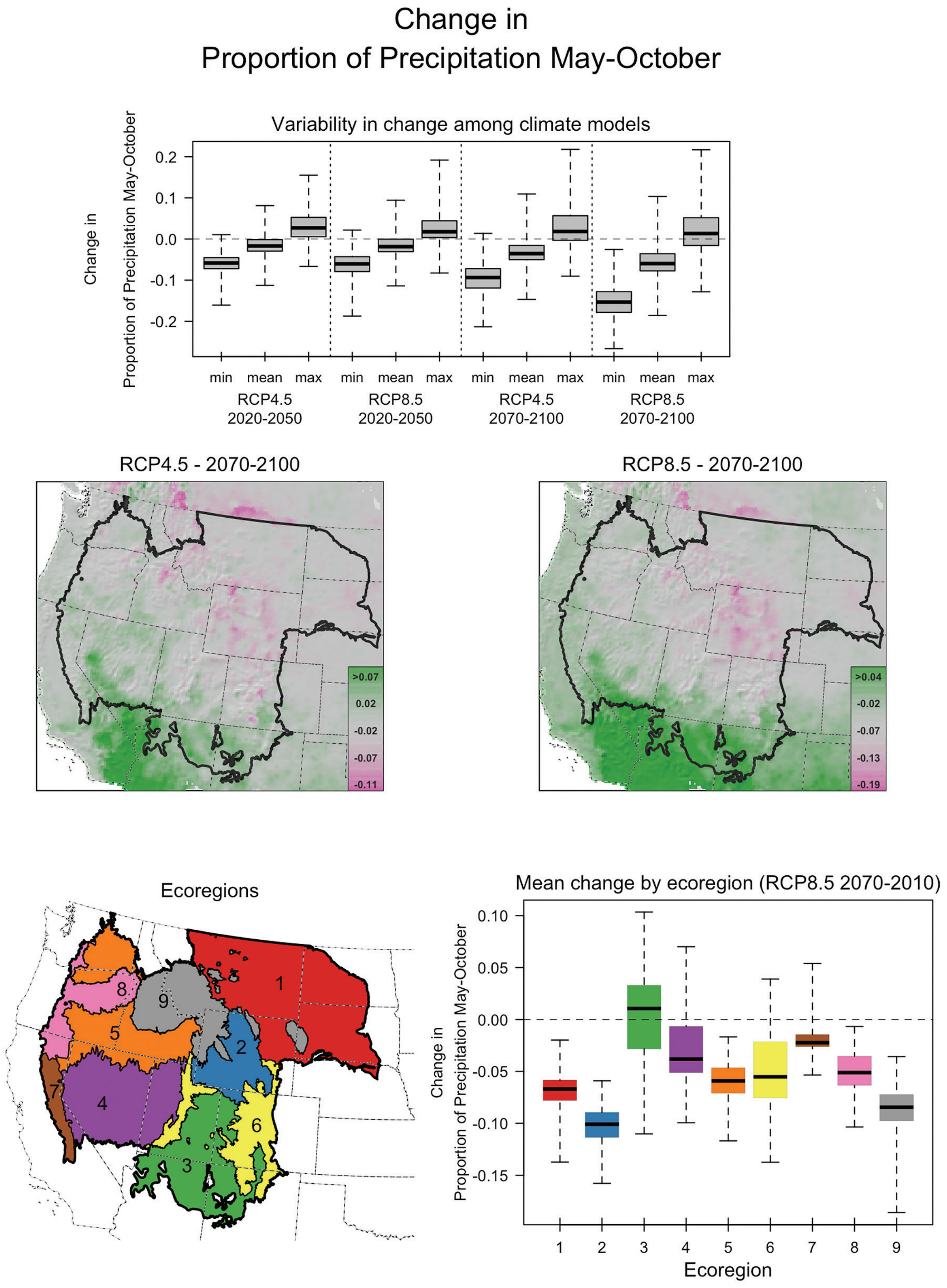


Figure A3.11b.

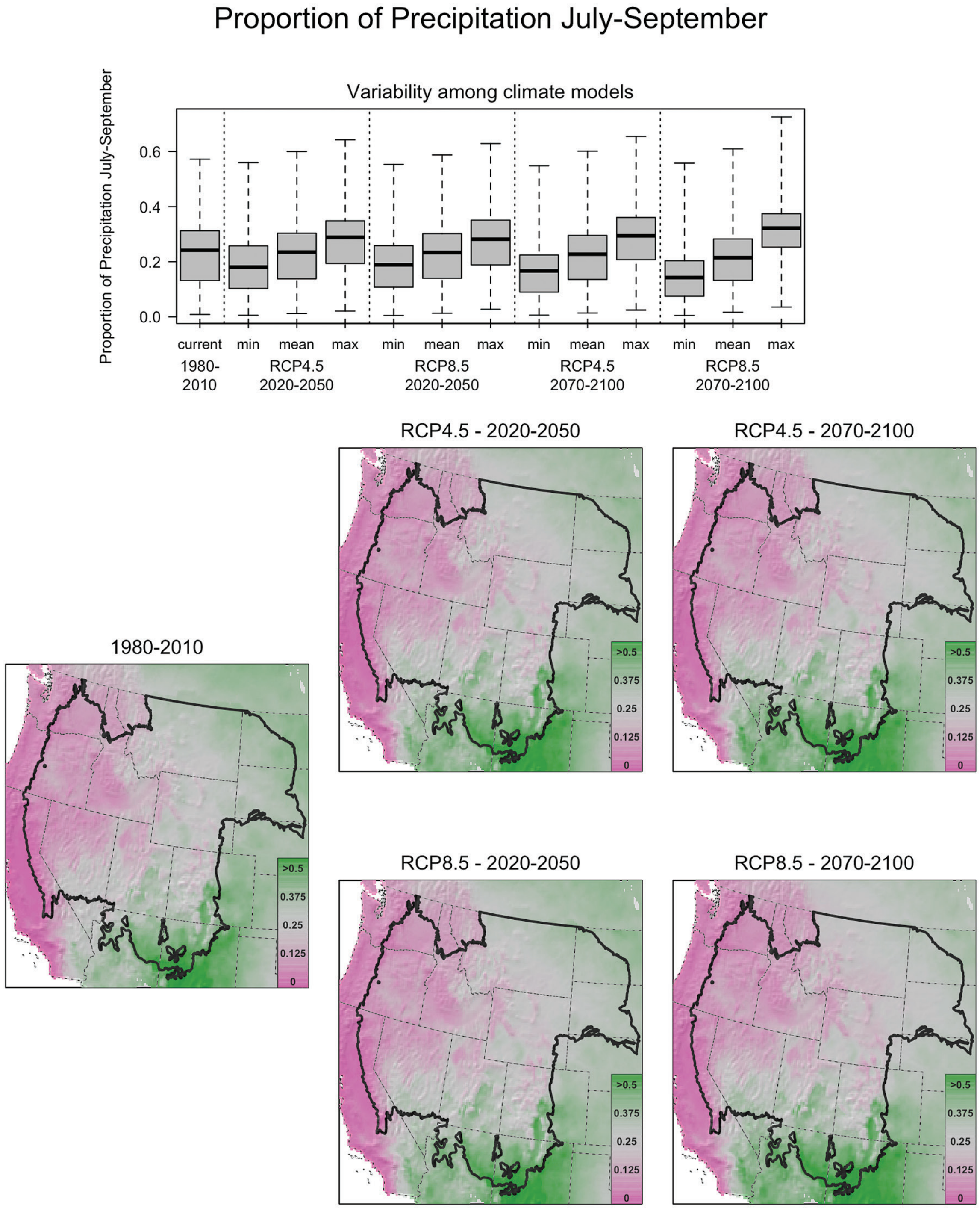


Figure A3.12a.

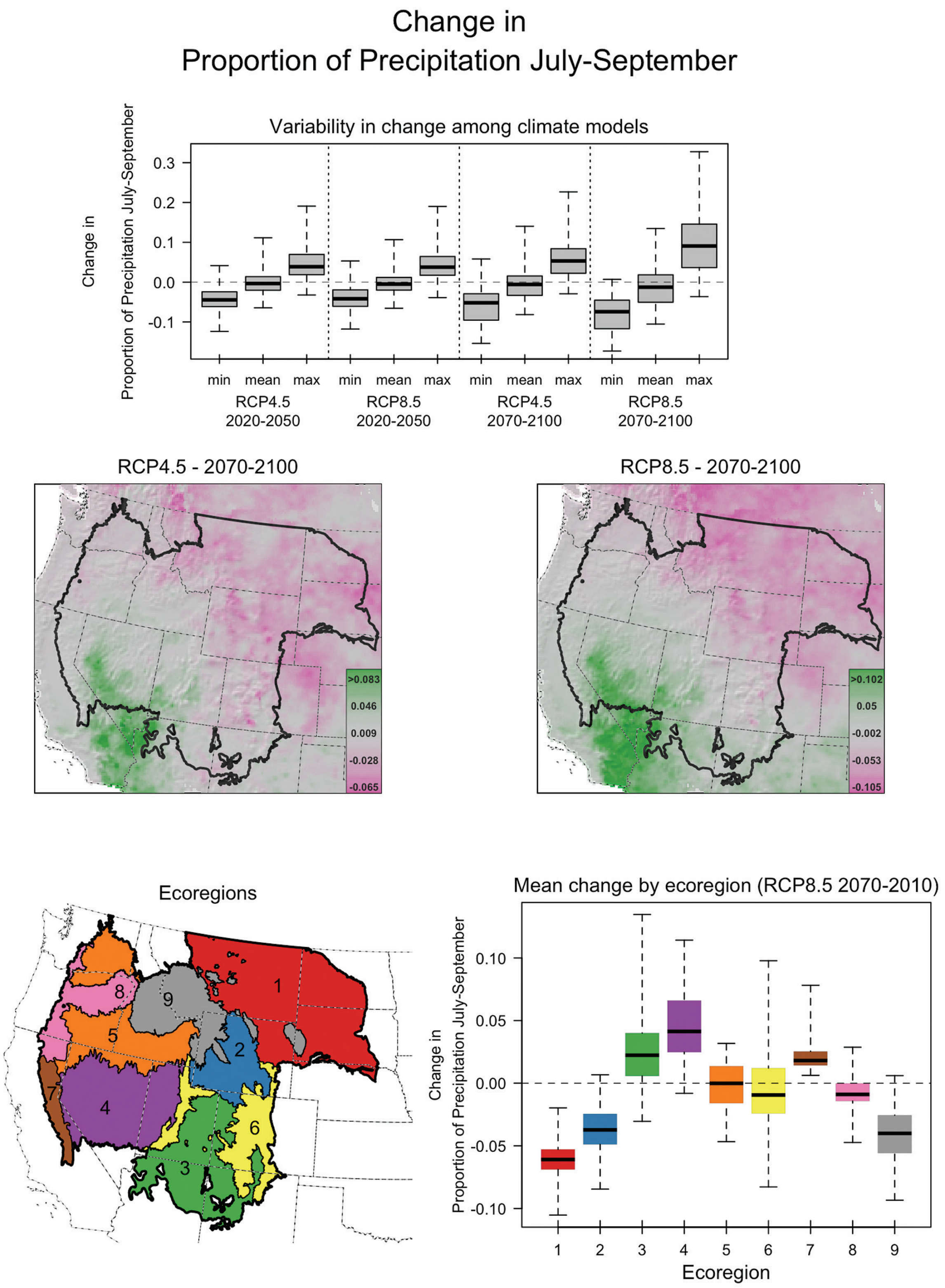


Figure A3.12b.

Appendix 4—Methods for Determining the Predominant Ecological Types

The ecological types in the Science Framework were developed for two earlier General Technical Reports (Chambers et al. 2014b, 2016a). For the purposes of the Science Framework, ecological type is used in a broad sense and refers to ecological type or ecological site groups. The ecological types are intended largely to inform mid-scale (ecoregion and Management Zone) analyses. The ecological type descriptions provide information on the relationships among soil temperature and moisture regimes, typical vegetation, resilience to disturbance, and resistance to invasive annual grasses for the dominant ecological types within sage-grouse habitat (FWS 2013) (see table 6). State-and-transition models for those ecological types that comprise the greatest area within sage-grouse habitat are in Appendices 5 and 6. Together, the ecological type descriptions and state-and-transition models are intended to link prioritizations of sage-grouse breeding habitat and resilience and resistance (fig. 38) to specific sagebrush ecological types, their likely response to disturbance and management treatments, and appropriate management strategies.

The ecological types for the western range of Greater sage-grouse (GRSG) were based on Chambers et al. (2014b,c). An overview of the methods used to develop the ecological types for the eastern range of GRSG follows. (See Chambers et al. 2016a for additional details.)

1. National Soil Information System (NASIS) data were exported for each EPA Level II Ecoregion, including Cold Deserts (10.1), Western Cordillera (6.2), and West Central Semiarid Prairies (9.3), within the eastern range of GRSG (Management Zones I, II, and VII) and the range of GUSG. The information exported included acreages of the dominant Ecological Site within the GRSG Priority Areas of Conservation and GUSG critical habitat as well as soil temperature regime, moisture regime, and moisture subclass assigned at the soil mapunit component level. The analyses were conducted by Steve Campbell, NRCS, Portland, OR.
    a. Ecological Site Descriptions were first sorted by Major Land Resource Area and State and then by soil temperature regime, moisture regime, and moisture subclass to evaluate the ecological sites most often correlated with the Priority Areas for Conservation. A map intersecting Level III Ecoregions with Major Land Resource Areas and Priority Areas for Conservation (fig. A4.1) was produced. Each Level II Ecoregion spreadsheet was filtered by central Major Land Resource Area concepts for the Ecoregion as described in Chambers et al. 2016a.
2. The Ecological Site Information System was used to query dominant ecological site descriptions supporting big sagebrush plant communities based on National Soil Information System data, Major Land Resource Area concepts, and consultation with NRCS State Rangeland Management Specialists or equivalent. In some cases, ecological site concepts exist with no state-and-transition models or there are variable state-and-transition model concepts depending on the age of the Ecological Site Descriptions. The most contemporary state-and-transition models were prioritized for consideration, but older products were used when they were the best available product to represent a regime concept.

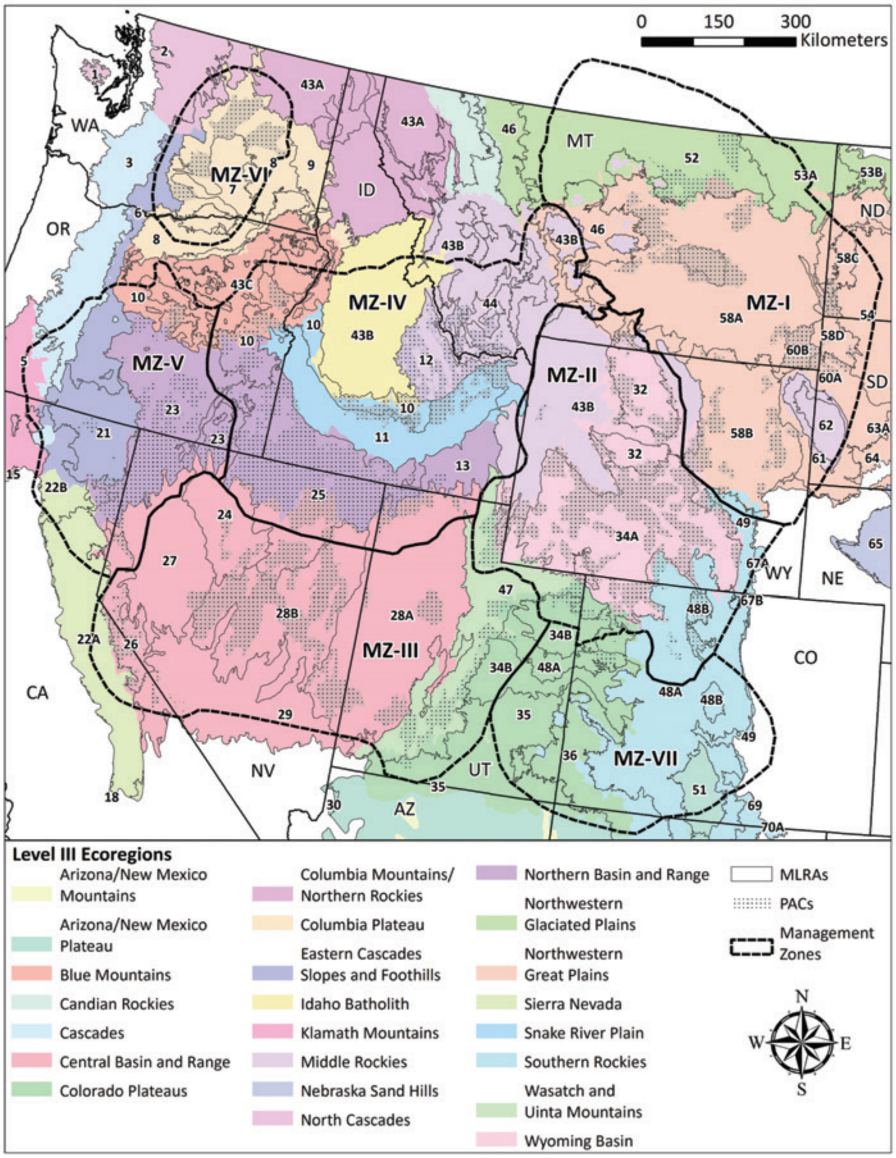


Figure A4.1—Overlay of the level III ecoregions (EPA 2016) and the Major Land Resource Areas (NRCS 2006) used to develop ecological types in the eastern portion of the range.

3. Potentially representative ecological sites were downloaded into folders and organized by soil temperature/moisture regime concepts. The various resources used were not always in agreement, and each area was reviewed to determine the best source of data. Resources used to determine the regime included:
    a. Ecological Site Description climate section;
    b. Land Resource Unit concept or State ecological zones, when available;
    c. Major Land Resource Area description climate section—edits to Major Land Resource Area descriptions are anticipated by local staff providing input on these descriptions, and have been incorporated as appropriate;

   d. National Soil Information System assigned temperature and moisture regime by mapunit component and accompanying map—some areas are populated with older mapping concepts or are not populated in the National Soil Information System;
   e. PRISM maps; and
   f. Local experts (see names in Chambers et al. 2016a).
4. Regime concepts with representative Major Land Resource Areas and Ecological Site Descriptions were derived and are in Chambers et al. 2016a. These were used to develop the ecological types. The ecological types were characterized by soil temperature and moisture regimes (to moisture subclass), vegetation, resilience to disturbance, and resistance to invasive annual grasses. In order to more accurately describe the temperature regime of the ecological types, a soil temperature subclass was derived for temperature regimes bordering on two different regimes. The terminology for soil temperature subclass is similar to the one used for soil moisture subclasses in the Soil Survey.

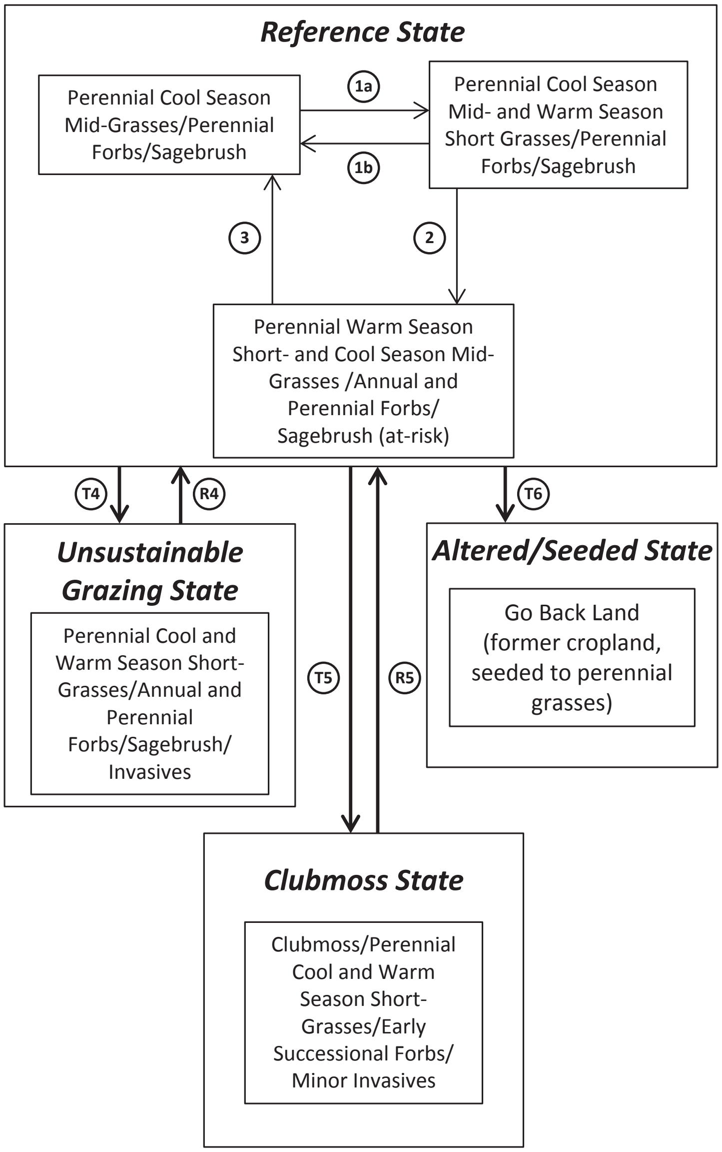
This appendix was prepared by Karen J. Clause. Steve Campbell, Jeanne Chambers, Jeremy Maestas, Dave Pyke, and Mary Manning contributed to the development of the methods used to derive the ecological types.

Appendix 5—Generalized State-and-Transition Models for Predominant Sagebrush Ecological Types in the West-Central Semiarid Prairies (MZ I), and Western Cordillera and Cold Desert (MZ II, VII) in the Eastern Portion of the Range

These generalized state-and-transition models are for a subset of the ecological types in table 6 and are based on comparisons of multiple individual Ecological Site Descriptions. See Appendix 4 for a description of the methods used to develop the ecological types. State-and-transition model development was prioritized for ecological types with the highest relative acreage in Priority Areas for Conservation (FWS 2013). These state-and-transition models can inform planning efforts at mid- to local scales, but for project scale planning efforts, state-and-transition models for specific ecological sites are most appropriate if available. Large boxes illustrate states that are comprised 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.

This appendix was prepared by Karen J. Clause and Mary Manning. Jeanne Chambers, Brian Mealor, and numerous resource professionals contributed to the development of these state-and-transition models.

A.5.1 West Central Semiarid Prairies
Frigid bordering on Cryic/Ustic bordering on Aridic
Grass Dominated w/ Silver Sagebrush (10-14 in PZ)
High Resilience and Resistance



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.

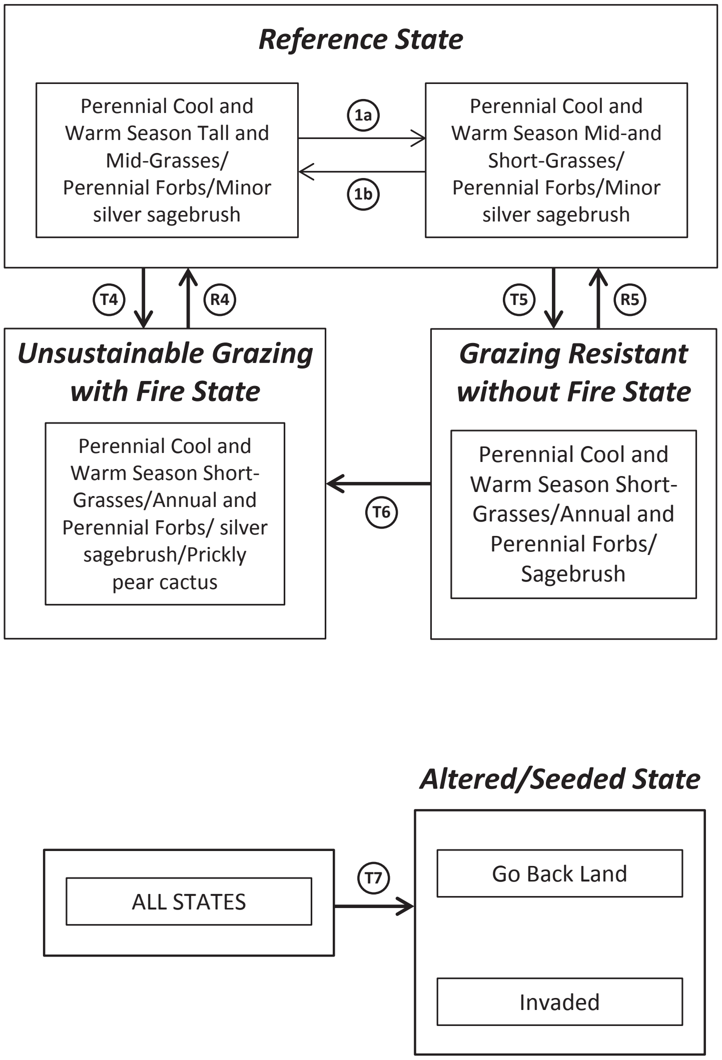
R4 Normal precipitation patterns, fire or fire surrogates (herbicides and/or mechanical treatments), and a grazing regime with proper timing and intensity that varies season of use can return the site to the reference state.

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.

A.5.2 West Central Semiarid Prairies
Frigid/Ustic
Grass Dominated (13-18 in PZ)
Moderate to High Resilience and Resistance



(1a) Proportion of cool and warm season tall and mid-grass Functional/Structural Groups decreases due to disturbances such as drought and spring grazing with a lack of disturbances such as fire.

(1b) Fire and normal precipitation patterns favor herbaceous understory. Reduced grazing intensity and/or duration allows for herbaceous recovery.

(T4) Extended drought, high intensity and long duration grazing, and a normal fire regime or fire surrogate (herbicides and/or mechanical treatments) will result in a transition to a grazing resistant state dominated by warm and cool season short-grass Functional/Structural Groups and silver sagebrush and prickly pear cactus. Forbs are early seral.

(R4) Normal precipitation patterns and proper timing and intensity of grazing that varies season of use can return the site to the reference state. Mechanical treatments are often used to renovate and return the site to one resembling the reference state.

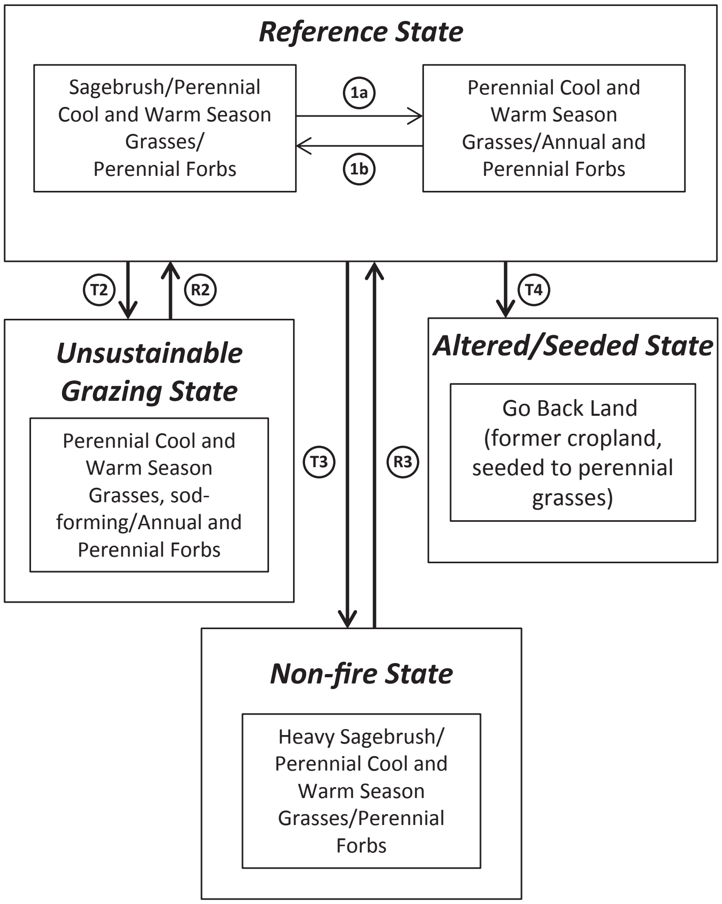
(T5) Extended drought, high intensity and long duration grazing, and lack of fire will result in a transition to a grazing resistant state dominated by short-statured warm and cool season grasses. Forbs are early seral.

(R5) Extended periods of normal precipitation, possibly seeding (if an adequate seedbank does not exist), mechanical renovation, and reduced grazing pressure that varies season of use can return the site to one resembling the reference state.

(T6) Introduction of fire results in loss of Wyoming big sagebrush and an increase in silver sagebrush. Continued high intensity and long duration grazing results in the increase of undesirable species like prickly pear cactus.

(T7) 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 seedings used both introduced and native species, mainly under the Conservation Reserve Program. An invaded plant community is possible if seed source is introduced or adjacent to area. Dominant species include field brome, smooth brome, Kentucky bluegrass, thistles, bindweed, knapweed, leafy spurge, hoary cress, and other introduced weedy species. Sagebrush is largely absent from this state.

A.5.3 West Central Semiarid Prairies
Frigid/Ustic bordering on Aridic
Wyoming Big Sagebrush (10-14 in PZ)
Moderate to High Resilience and Resistance



(1a) Sagebrush decreases due to fire and normal precipitation patterns that favor the herbaceous understory. Grazing intensity and/or duration is reduced to allow for herbaceous recovery.

(1b) Sagebrush increases and proportion of cool season grasses decrease due to disturbances such as drought and grazing, along with a lack of disturbances such as fire.

(T2) Prolonged drought, improper grazing, and frequent sagebrush control using fire or fire surrogates (herbicides and/or mechanical treatments) will result in transition to a grazing resistant state dominated by warm and cool season short-and sod-forming grass Functional/Structural Groups and undesirable species such as prickly pear cactus. Invasive species (e.g., cheatgrass, field brome) can occur in disturbed areas. Field brome invasion can occur in undisturbed rangelands at the upper end of the precipitation range.

(R2) Normal precipitation patterns, reducing the frequency and severity of disturbances that kill sagebrush, and proper timing and intensity grazing regime that varies season of use can return the site to the reference state.

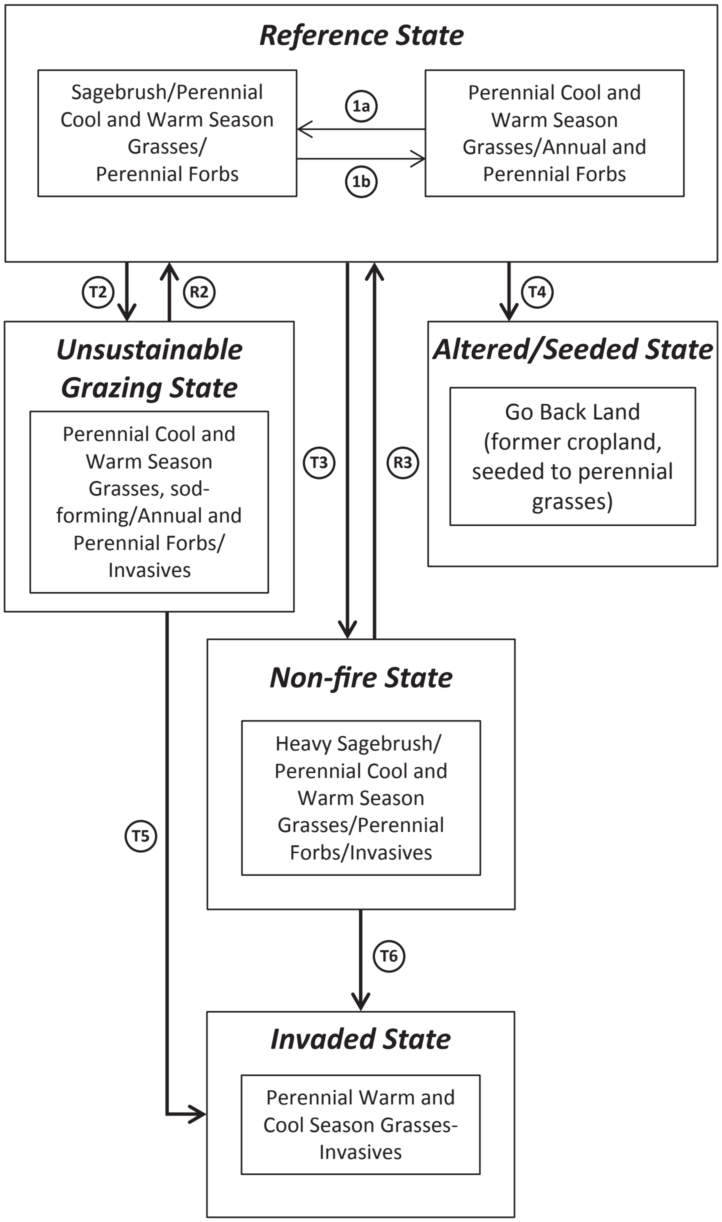
(T3) Extended drought, frequent and severe grazing, and removal of fire and fire surrogates (herbicides and/or mechanical treatments) will result in transition to a state dominated by sagebrush with minor warm and cool season short-grass and forb Functional/Structural Groups. Invasion can occur as bare ground increases in sagebrush canopy interspacesin disturbed areas.

(R3) Extended periods of normal precipitation, treatment with fire surrogates, seeding (if adequate seedbank does not exist), and reduced grazing pressure that varies season of use can return the site to the reference state.

(T4) Former cropland that has been 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 grasses were used, mainly under the Conservation Reserve Program. Sagebrush is largely absent.

A.5.4 WEST CENTRAL SEMIARID PRAIRIES MESIC/USTIC BORDERING ON ARIDIC WYOMING BIG SAGEBRUSH (10-14 IN PZ)

Low to Moderate Resilience and Resistance



(1a) Sagebrush increases and proportion of cool season grasses decrease due to disturbances such as drought and grazing with a lack of disturbances such as fire.

(1b) Sagebrush decreases due to fire and normal precipitation patterns that favor an herbaceous understory. Reduced grazing intensity and/or duration allows for herbaceous recovery.

(T2) Extended drought, frequent and severe grazing, and frequent sagebrush control using fire or fire surrogates result in a transition to a grazing resistant state dominated by warm and cool season short- and sod-forming grass Functional/Structural Groups and undesirable species such as prickly pear cactus. Invasion of cheatgrass and/or field brome can occur.

(R2) Normal precipitation that reduces the frequency and severity of sagebrush killing disturbances, and proper timing and intensity grazing that varies season of use can return the site to the reference state.

(T3) Extended drought, frequent and severe grazing, and removal of fire and fire surrogates will result in transition to a state dominated by sagebrush with minor warm and cool season short-grass and forb Functional/Structural Groups. Invasion often occurs as bare ground increases in sagebrush canopy interspaces.

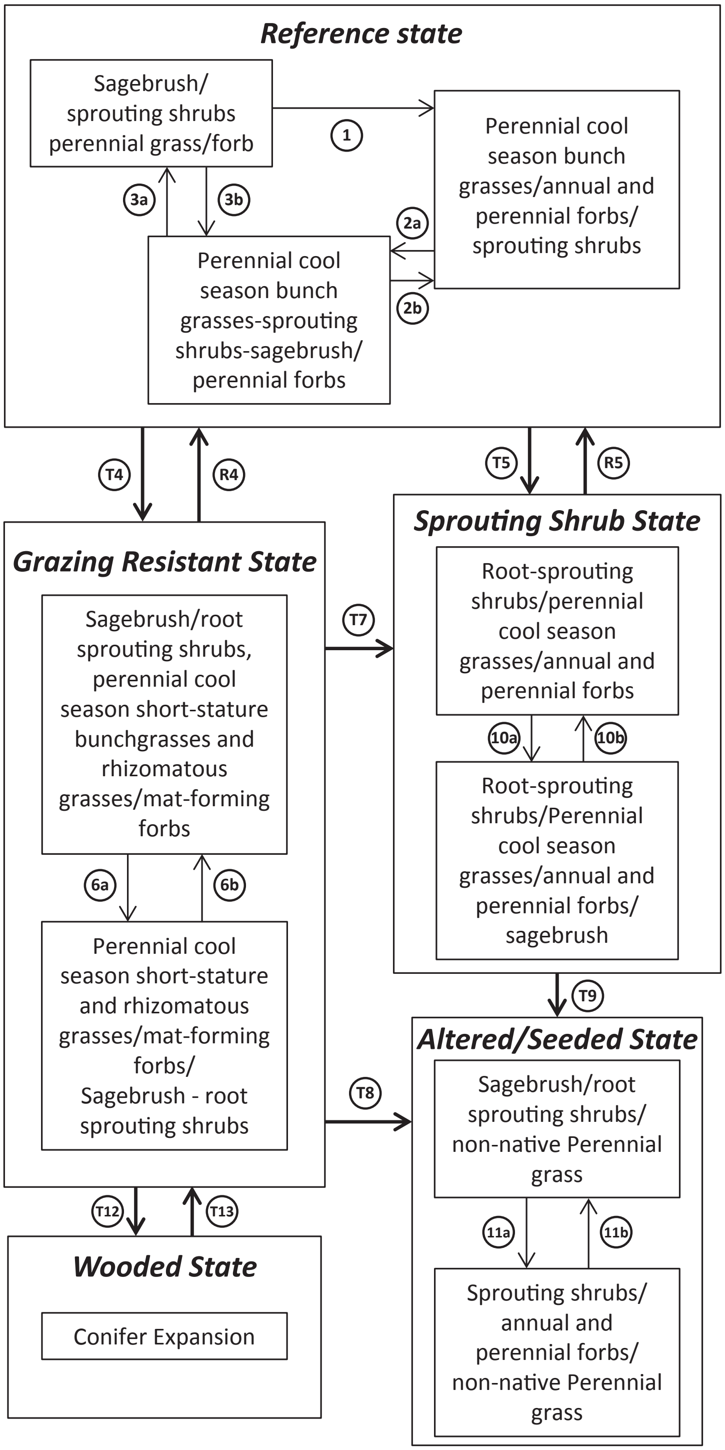
(R3) Extended periods of normal precipitation, treatment with fire surrogates, seeding (if adequate seedbank does not exist), and reduced grazing pressure that varies season of use can return the site to the reference state.

(T4) Former cropland that has been 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 seedings used both introduced and native grasses, mainly under the Conservation Reserve Program. Sagebrush is largely absent.

(T5) (T6) Fire and fire surrogates, followed by warm and wet springs and year-long grazing can result in an invaded state co-dominated by annual grasses (cheatgrass) and short-stature warm and cool season perennial grasses. Shrubs are largely absent.

A.5.5 Western Cordillera – Cryic/Typic Ustic Mountain Big Sagebrush/ Mixed Mountain Shrubs (15 -19 in + PZ)

High Resilience and Resistance



① Perennial grass, forbs and sprouting shrubs increase and dominate due to disturbances that decrease sagebrush, primarily wildfire.

(2a) Sagebrush and other shrubs increase with time until co-dominant with herbaceous species.

(2b) Perennial grass, forbs, and sprouting shrubs increase due to disturbances that decrease sagebrush, e.g., wildfire, insects, and disease.

(3a) Sagebrush and other shrubs increase with time.

(3b) Perennial grass, forbs, and sprouting shrubs increase due to minor disturbances that decrease sagebrush like cool fire, insects, and disease.

(T4) Continuous grazing with cattle during the critical growth period of cool season grasses results in dominance of sagebrush and an increase in grazing tolerant native forbs (e.g., lupine, pussy-toes). As bare ground increases, surface erosion (e.g., rills, sheet erosion) may occur, resulting in loss of the surface soil horizon, and pedestalled plants.

(R4) Sagebrush treatment via chemical, mechanical, or prescribed fire combined with a grazing system that allows periodic deferment during the critical growth period can result in return to the reference.

(T5) Increased disturbance frequency and/or intensity (e.g., fire, fire surrogates, and/or mechanical types of disturbance, and/or high density/frequency grazing) will result in dominance of root-sprouting shrubs.

(R5) Removal of disturbances and a grazing regime that allows for adequate rest and recovery of native perennial grasses and forbs can eventually result in a return to the reference state.

(6a) Perennial cool season short-stature bunchgrasses and rhizomatous grasses, mat-forming forbs, and sprouting shrubs increase in dominance due to disturbances that decreased sagebrush (e.g., wildfire, insects, disease).

(6b) Sagebrush, non-browsed shrubs, and mat-forming orbs increase with time.

(T7) An increase in disturbance frequency, fire, fire surrogates, mechanical types of disturbance and/or high density/frequency grazing will result in dominance of root-sprouting shrubs.

(T8) Introduction of grazing tolerant non-native species, such as Kentucky bluegrass during homesteading days or smooth brome during reclamation results in transition to this state.

(T9) Grazing tolerant non-native species are seeded, and disturbances are removed reducing sagebrush.

(10a) Sagebrush and other shrubs increase.

(10b) Perennial grass, forbs, and sprouting shrubs increase due to disturbances that decrease sagebrush (e.g., wildfire, insects, disease).

(11a) Sprouting shrubs, forbs, and non-native perennial grasses increase due to disturbances that decrease sagebrush (e.g., wildfire, insects, disease) or treatments that remove or reduce sagebrush.

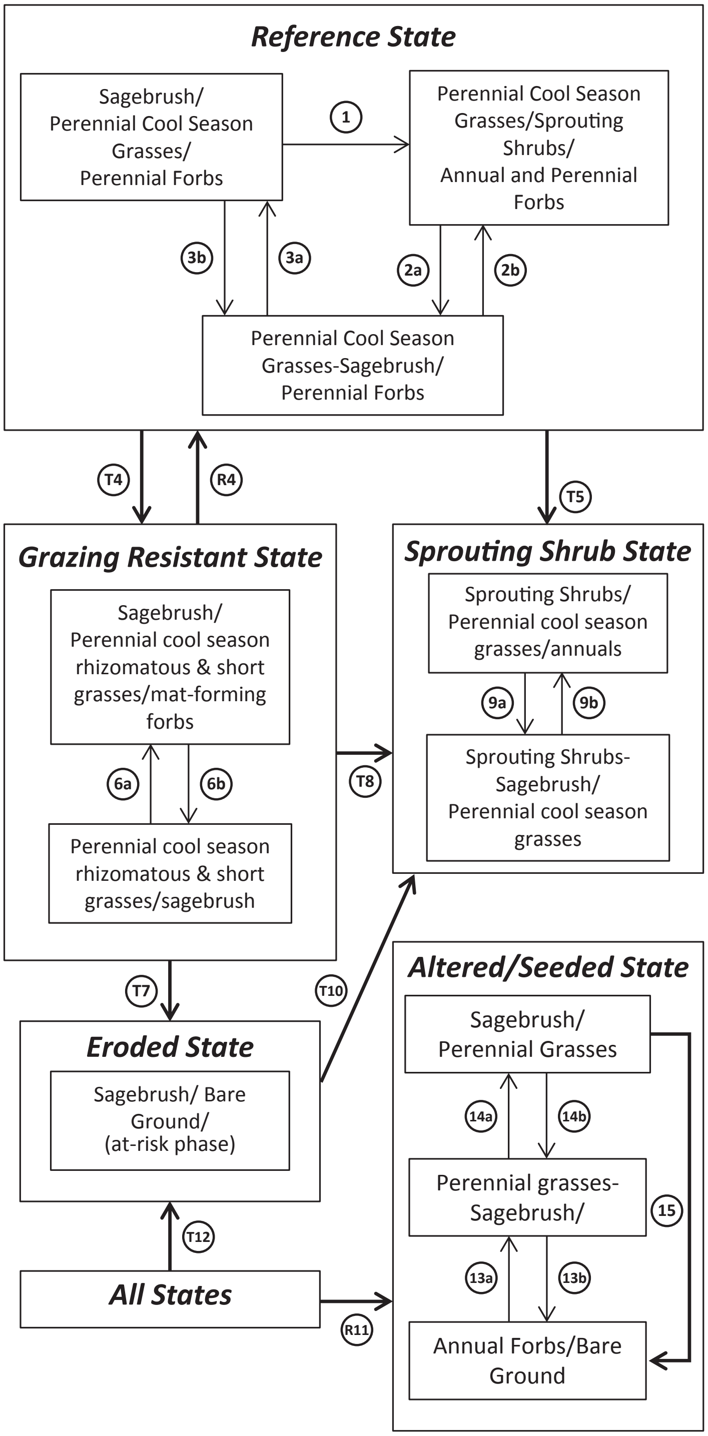
(11b) Sagebrush and other shrubs increase.

(T12) High levels of fuel reduction through grazing and fire suppression can lead to conifer expansion outside the normal range of variability for a site.

(T12) Above average precipitation and/or reduced grazing pressure allow fine fuel accumulation, and the use of fire or fire surrogates can result in return to the Grazing Resistant State, but return to the Reference State is only achievable through (R4) with the appropriate grazing prescription.

A.5.6 Cold Deserts – Frigid/Ustic bordering on Aridic Wyoming Big Sagebrush (9-14 in PZ)

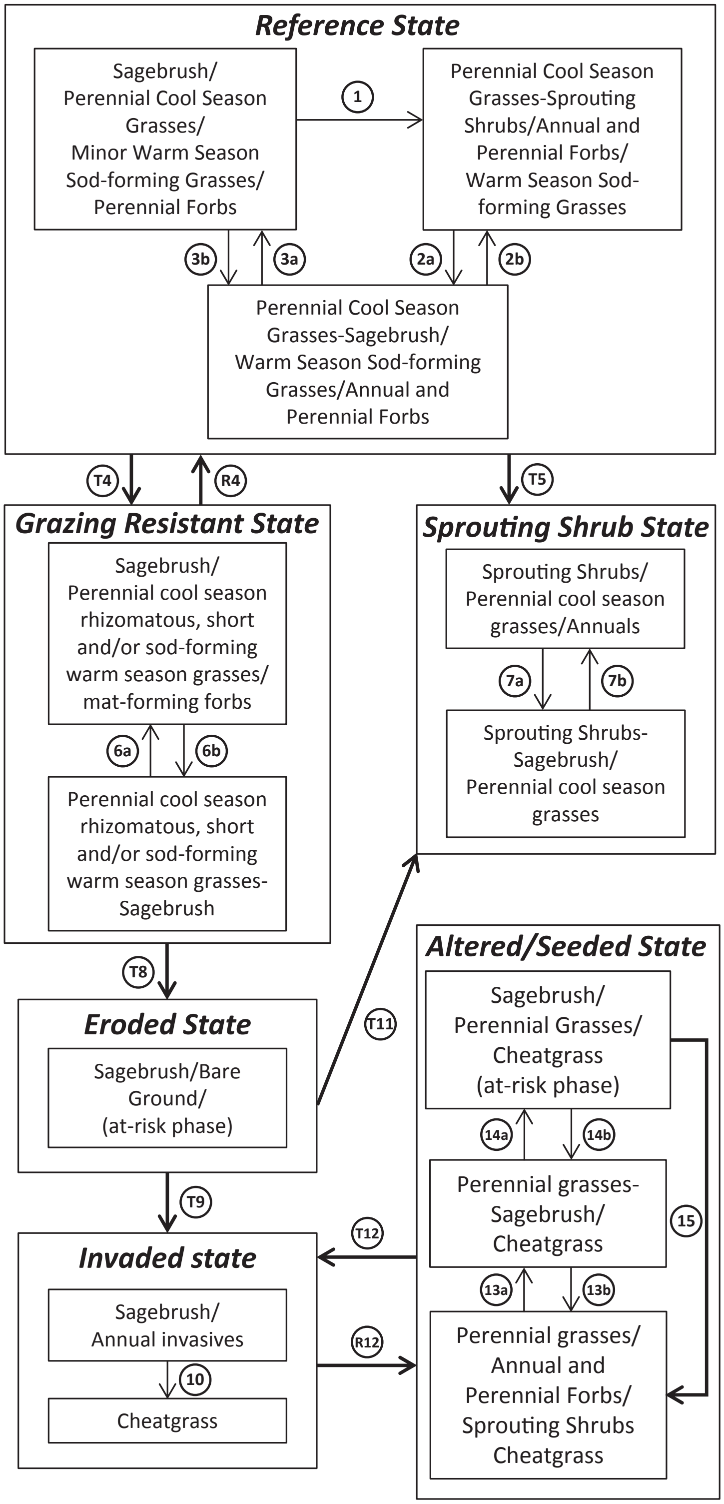
Moderate to Low Resilience and Moderately High Resistance



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. Fire is rare.
(2a)	Sagebrush increases with time until it is co-dominant with the herbaceous understory.
(2b)	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.
(3a)	Sagebrush increases with time until dominant.
(3b)	Perennial grass and forbs increase due to minor disturbances that decrease sagebrush.
(T4)	Continuous spring grazing during the critical growth period of cool season grasses results in dominance of grazing tolerant species, like short-statured bunchgrasses (e.g. Sandberg bluegrass) and rhizomatous species. As bareground increases, surface erosion (e.g., rills, sheet erosion)and pedestalled plants (especially bunchgrasses) result.
(R4)	Light to moderate grazing with periodic rest during critical growth periods along with fire, herbicides, and/or mechanical treatments result in return to reference state.
(T5)	An increase in fire, fire surrogates, mechanical disturbance, and/or high density/frequency grazing results in disturbance-adapted sprouting shrubs like rabbitbrush.
(6a)	Sagebrush increases with time until dominant.
(6b)	Grazing tolerant perennial cool season grasses increase due to disturbances that decrease sagebrush.
(T7)	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 of invasion by annuals after a catastrophic sagebrush killing event.
(T8)	Chemical or mechanical treatments to reduce sagebrush in the 1940s through 70s followed by improper stocking rates and seasons of use resulted in a shift toward sprouting shrubs, such as rabbitbrush.
(9a)	Sagebrush increases with removal of disturbances over time until co-dominant with sprouting shrubs.
(9b)	Perennial cool season grasses and sprouting shrubs increase due to disturbances that decrease sagebrush.
(T10)	Chemical or mechanical treatments to reduce sagebrush in the 1940s through 70s followed by improper stocking rates and seasons of use resulted in a shift toward sprouting shrubs, such as rabbitbrush.
(R11)	All states are subject to disturbance from oil and gas exploration or other mechanical disturbances that remove surface soils. Restoration success on good soil management, proper seeding techniques, and weather. Due to native seed availability, grass and shrubs can be restored, but forb diversity and applicability to site conditions can be a limiting factor for biotic integrity. Something resembling the reference state may be achieved with key differences in soil and hydrologic function.
(T12)	Many abandoned oil and gas wells without proper reclamation practices (no top soil management/replacement or seeding) from the 1980s are now in the Eroded State.
(13a)	Sagebrush increases with time and no disturbances until co-dominant with the herbaceous understory.
(13b)	Perennial grass and forbs become dominant due to disturbances that decrease sagebrush.
(14a)	Sagebrush increases with no disturbances over time.
(14b)	Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush.
⑮	Annual forbs become dominant due to disturbances that remove existing perennial vegetation.

A.5.7 Cold Deserts – Frigid/Ustic bordering on Aridic Wyoming Big Sagebrush (10-14 in PZ)

Moderate Resilience and Resistance

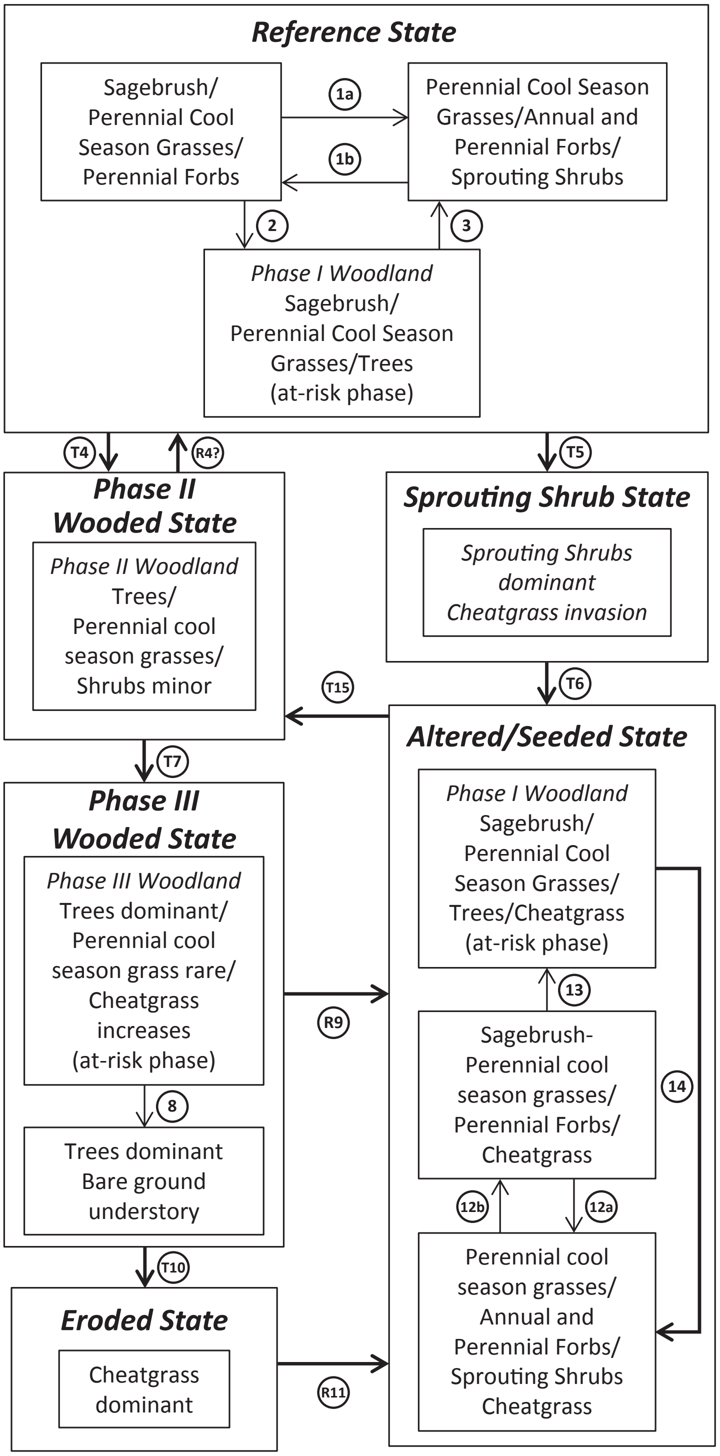


①	Perennial grass, sprouting shrubs, and forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens.
2a	Sagebrush increases with time until co-dominant with the herbaceous understory.
2b	Perennial grass, 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.

A.5.8 COLD DESERTS – FRIGID BORDERING ON MESIC/USTIC WYOMING BIG SAGEBRUSH (14-18 IN PZ)

Piñon pine and/or juniper potential

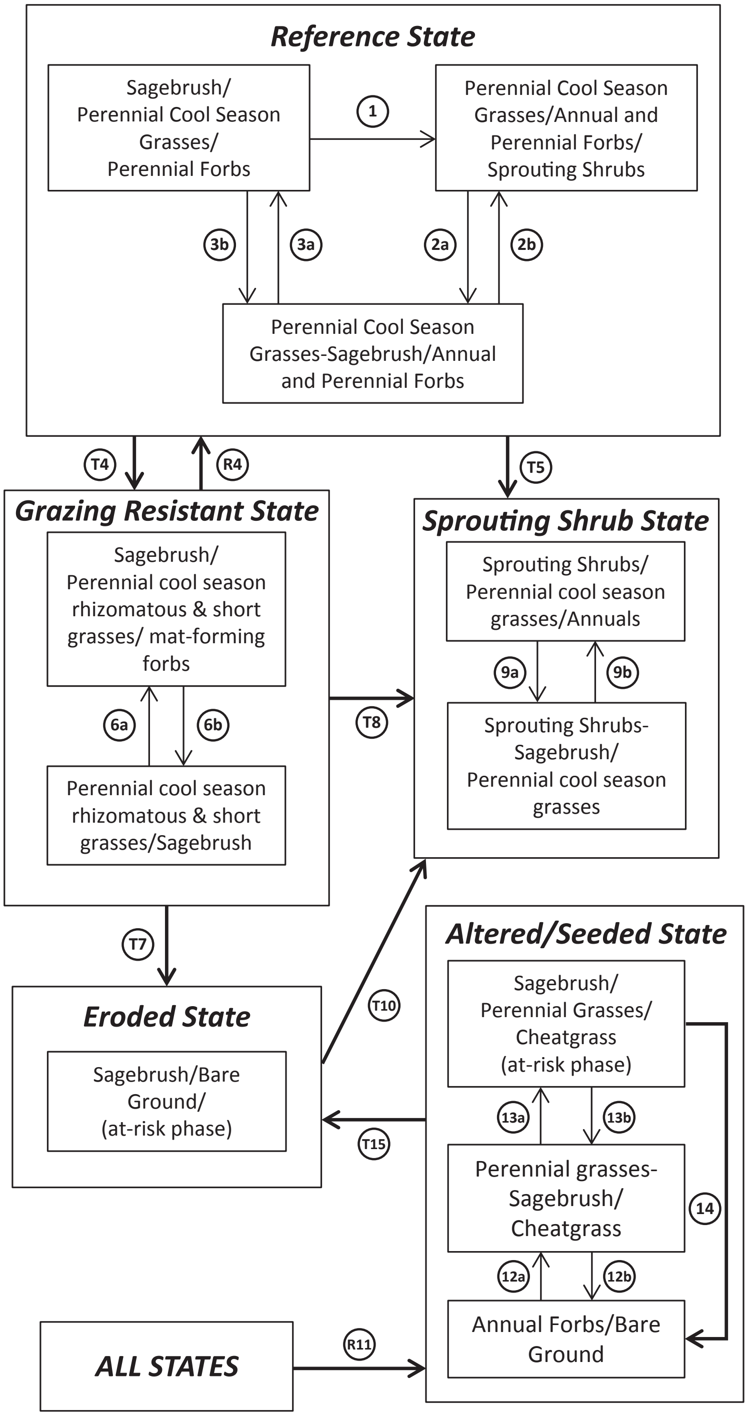
Moderate to High Resilience and Moderate Resistance



1a	Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial cool season grasses, forbs, and sprouting shrubs like rabbitbrush.
1b	Sagebrush increases with time until dominant.
2	Time without fire or fire surrogates combined with seed sources for piñon and/or juniper trigger a Phase I Woodlandinvasion and an at-risk phase.
3	Fire and/or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial cool season grasses and forbs, but these activities often also reduce sagebrush temporarily.
T4	Increasing tree abundance results in a Phase II woodland with decreasing sagebrush cover due to competition for sunlight, water and nutrients, and a transition to a tree-dominated state. Cheatgrass invasion is common during this transition.
R4	Fire and fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial cool season grasses, annual/perennial forbs, and eventually sagebrush dominance if treated during Phase II invasion.
T5	An increase in fire, fire surrogates, mechanical types of disturbance and/or high density/frequency grazing will favor sprouting shrubs like rabbitbrush. Cheatgrass often invades.
T6	Removal of disturbances can result in a restored state over time. Seeding may be necessary depending on the type and amount of disturbance.
T7	Infilling of trees and/or improper grazing can result in further increase in tree canopy cover, resulting in near complete loss of sagebrush component, decreased perennial cool season grasses, and increased risk of high severity crown fires. Cheatgrass will likely increase with favorable climate conditions.
8	As crown canopy increases, all other vegetation, including perennial understory and cheatgrass decreaseuntil trees are almost the only remaining vegetation.
R9	Seeding after fire or fire surrogates may be necessary on sites with depleted perennial cool season grasses, forbs, and shrubs. If soils are not highly altered and native species seeded, it is possible to transition to a state that is similar to the Reference State, but with altered biotic function.
T10	Catastrophic fire without proper rehabilitation can result in an abiotic hydrologic and biotic threshold crossing to an eroded state depending on soils, slope, and understory species. Key soil properties can change, altering site potential. Cheatgrass dominates the system and it burns before perennial vegetation becomes established.
R11	Seeding after catastrophic fire or fire surrogates will be necessary due to lack of a perennial cool season grass, forb, and shrub seedbank. Seeding with nonnatives may decrease annual invasives, but will also reduce native species. Biotic and hydrologic function may be irreversibly altered. Restoration could be cost prohibitive.
12a	Disturbances result in less sagebrush and more perennial cool season grasses, forbs, and sprouting shrubs like rabbitbrush. Increases in soil water and nutrient availability result in increased cheatgrass.
12b	Sagebrush increases until co-dominant with the herbaceous species. Cheatgrass decreases, but is present.
13	Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland and an at-risk phase.
14	Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial cool season grasses and annual/perennial forbs, but these activities often reduce sagebrush and increase cheatgrass temporarily.
T15	Increasing tree abundance results in a Phase II woodland with decreasing sagebrush due to competition, resulting in a transition to a Phase I Wooded State.

A.5.9 COLD DESERTS – FRIGID/ARIDIC BORDERING ON USTIC WYOMING BIG SAGEBRUSH (7-10 IN PZ)

Moderate to Low Resilience and Moderate Resistance



(1) Perennial grass and forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens. Fire is rare in this system.

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

(2b) Perennial grass/annual and perennial forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens. Fire is rare.

(3a) Sagebrush increases with time until dominant.

(3b) Perennial grass and forbs increase due to minor 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 which 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] result.

(R4) Light to moderate grazing that includes periodic rest during critical growth periods along with herbicide and/or mechanical treatments can result in return to the Reference State.

(T5) An increase in mechanical treatments, high density/frequency grazing, or fire/fire surrogates will favor sprouting shrubs such as rabbitbrush and/or greasewood. Fire is rare. Cheatgrass can occur.

(6a) Sagebrush increases with time. Cheatgrass is often present with other weedy species.

(6b) Perennial cool season grasses increase due to disturbances that decrease sagebrush. Cheatgrass is often present with other weedy species.

(T7) Perennial grasses and forbs are eliminated and sagebrush increases with high density/frequency grazing, resulting in altered biotic, hydrologic, and soil function. This state is at-risk to invasion by annual grasses.

(T8) Multiple chemical or mechanical treatments, or biological disturbances to reduce sagebrush can result in a shift toward sprouting shrub dominance with potential for cheatgrass to invade.

(9a) Sagebrush increases with time and removal of disturbances until co-dominant with sprouting shrubs.

(9b) Perennial cool season grasses, sprouting shrubs, and annuals increase due to disturbances that decrease sagebrush.

(T10) Multiple treatments of chemical, mechanical, or biological disturbances to reduce sagebrush will result in a shift toward sprouting shrub dominance with potential for cheatgrass to occur.

(R11) A restoration treatment, including chemical treatment for cheatgrass and seeding can restore a perennial grass community and eventually support an altered sagebrush community with some invaders.

(12a) Sagebrush increases with time and no disturbances until co-dominant with the herbaceous understory, but cheatgrass may be present.

(12b) Perennial grass/annual and perennial forbs become dominant due to disturbances that decrease sagebrush like drought, freezing, flooding, insects, disease, and pathogens. There may be a temporary flush of annuals.

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

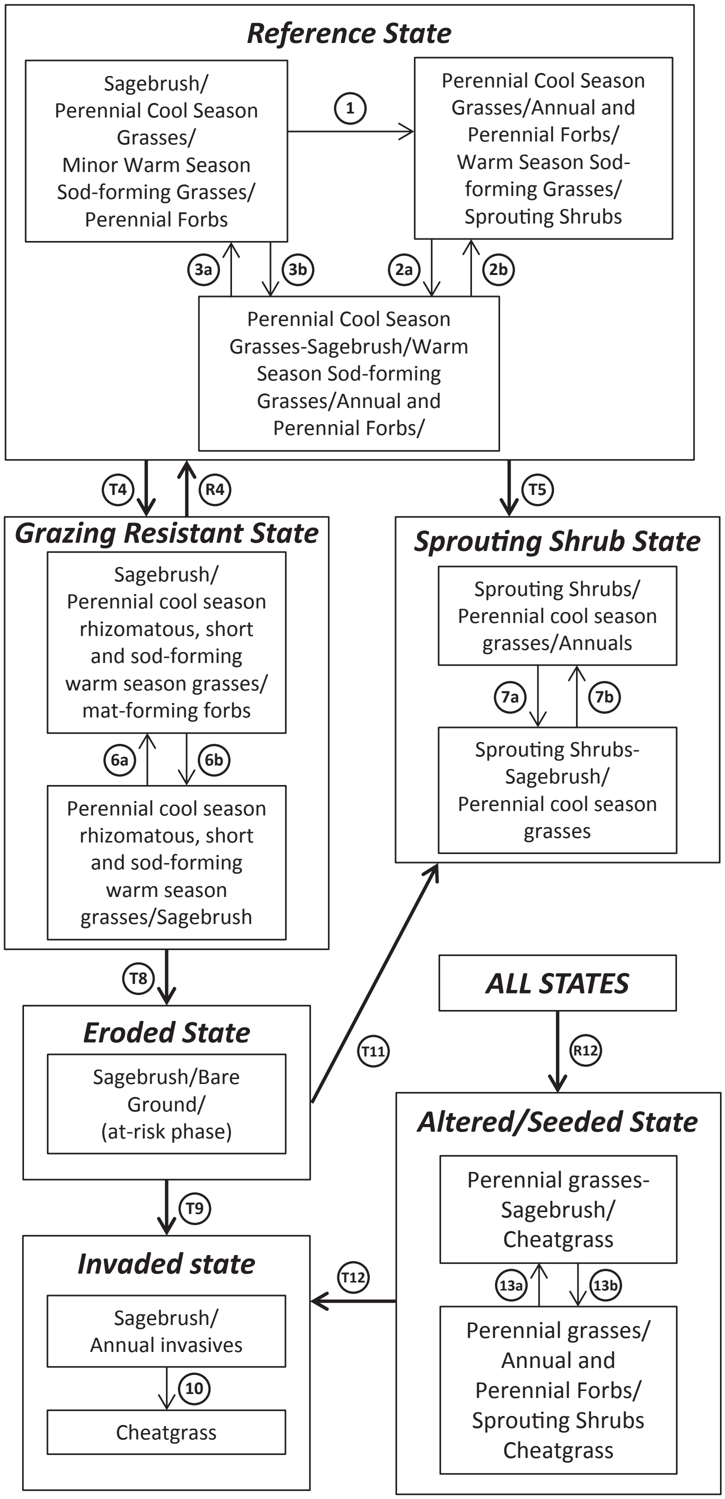
(13b) Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush. There may be a temporary flush of annuals.

(14) Perennial grass/annual and perennial forbs become dominant due to disturbances that decrease sagebrush. There may be a temporary flush of annuals.

(T15) Perennial grasses and forbs are eliminated and sagebrush increases with high density/frequency grazing, resulting in altered biotic, hydrologic, and soil function. Cheatgrass is often present in the understory, and could be considered an "invaded" state, except that it does not alter fire regimes and ecological dynamics of the site.

A.5.10 COLD DESERTS – MESIC/ARIDIC BORDERING ON USTIC WYOMING BIG SAGEBRUSH (8-12 IN PZ)

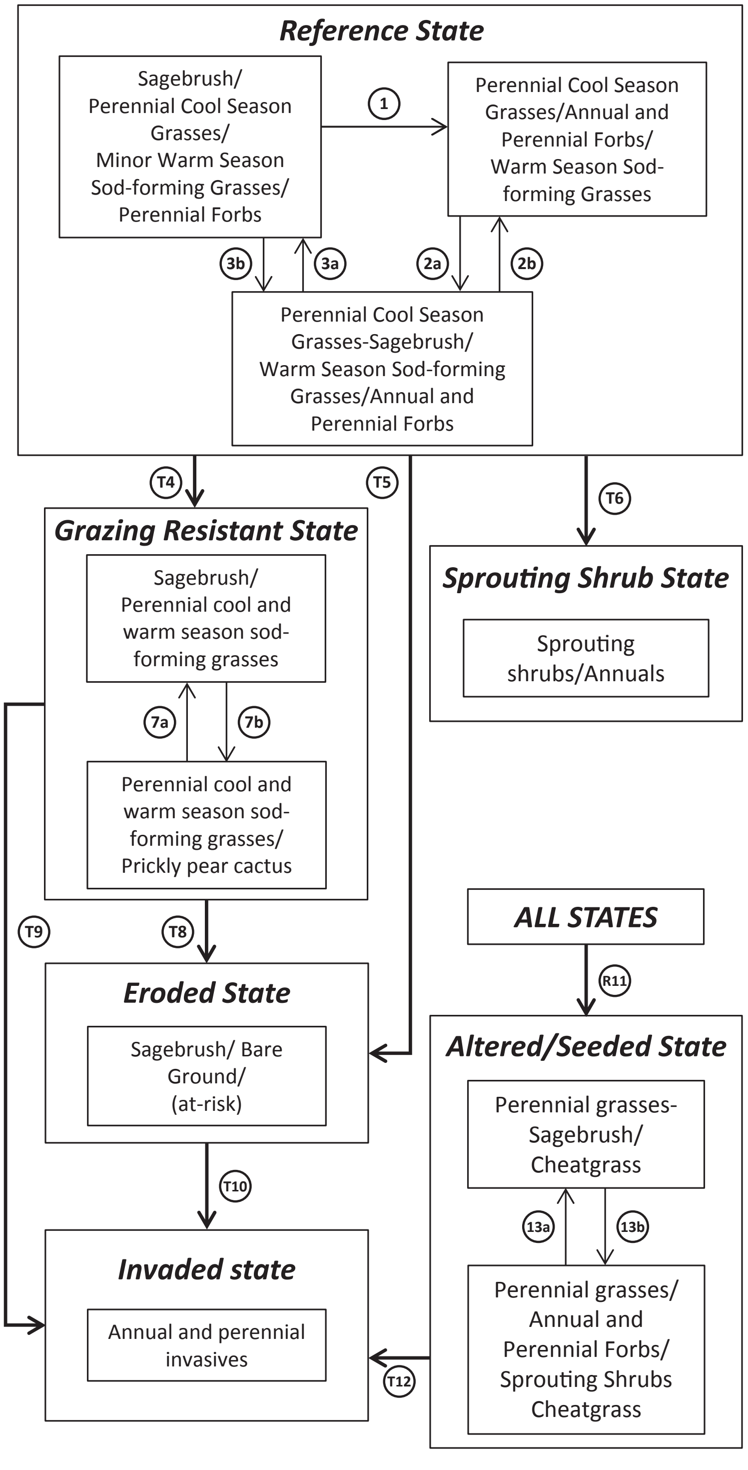
Moderate to Low Resilience and Low Resistance



1	Perennial grass/annual and perennial 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 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 minor 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 and increases in warm season species. As bare ground increases, surface erosion (e.g., rills, sheet erosion) and pedestalled plants (especially bunchgrasses) result.
R4	Light to moderate grazing that includes periodic rest during critical growth periods along with fire, herbicides, and/or mechanical treatments can restore perennial cool season perennial grasses and eventually sagebrush.
T5	An increase in fire, fire surrogates, mechanical types of disturbance, and or high density/frequency grazing favors sprouting shrubs like rabbitbrush. Cheatgrass can invade.
6a	Sagebrush increases with time until dominant. Cheatgrass and other weedy species are often present.
6b	Perennial cool season grasses increase due to disturbances that decrease sagebrush.
7a	Sagebrush increases with time and removal of disturbances until co-dominant with sprouting shrubs.
7b	Perennial cool season grasses and sprouting shrubs increase in dominance due to disturbances that decrease sagebrush.
T8	Perennial grasses and forbs are eliminated and sagebrush increases with high density/frequency grazing, resulting in altered biotic, hydrologic, and soil function. This state is at-risk to invasion by annuals such as cheatgrass, especially with loss of sagebrush.
T9	If a cheatgrass seed source is introduced, and climatic conditions are conducive to establishment (warm wet spring), cheatgrass will invade.
10	A sagebrush killing event, such as fire and fire surrogates results in conversion to cheatgrass. Some perennial species may be present, but the system dynamics will be driven by annual invasives.
T11	Multiple treatments of chemical, mechanical, or biological disturbances to reduce sagebrush will result in a shift toward sprouting shrub dominance with potential for cheatgrass to occur.
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 after severe ground disturbing activities, including mechanical treatment, seeding with non-native perennials can restore a perennial grass community and eventually support an altered sagebrush community with some invaders present. Sagebrush will be slow to reestablish.
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. There will likely be a temporary flush in annual invasives.
T16	A restoration treatment after ground disturbing activities, including mechanical treatment, seeding with native perennials adapted to site conditions can result in a perennial grass community and eventually support an altered sagebrush community with some invaders present. Sagebrush will be slow to reestablish.

A.5.11 COLD DESERTS – MESIC/ARIDIC-TYPIC WYOMING BIG SAGEBRUSH (5-9 IN PZ)

Low Resilience and Resistance



① Perennial grass/annual and perennial forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens. Fire is rare in this system.

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

(2b) Perennial grass and forbs become dominant due to disturbances that decrease sagebrush. Fire is rare.

(3a) Sagebrush increases with time until dominant.

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

(T4) Frequent and severe grazing coupled with frequent brush management and/or drought results in dominance of grazing tolerant and sod-forming warm and cool season species. As bare ground increases, surface erosion (e.g., rills, sheet erosion) and pedestalled plants (especially bunchgrasses) result.

(T5) Improper grazing, consisting of frequent and severe grazing without other disturbances such as fire or drought, results in dominance of sagebrush with excessive bare ground, resulting in altered hydrologic function and compromised soil stability.

(T6) Annual invasives are introduced to the site through ground disturbing activity. Site is dominated by sprouting shrubs such as rabbitbrush and/or greasewood.

(7a) Sagebrush increases with time and removal of disturbances until dominant.

(7b) Perennial cool season sod-forming grasses and cactus increase due to disturbances that decrease sagebrush such as sagebrush treatment, drought, freezing, flooding, insects, disease, and pathogens.

(T8) Perennial grasses and forbs are eliminated and sagebrush increases with high density/frequency grazing by cattle and absences of sagebrush killing disturbances, resulting in altered biotic, hydrologic, and soil function. This state is at-risk of cheatgrass invasion.

(T9) If a cheatgrass seed source is introduced, and catastrophic event occurs to kill perennial vegetation, such as drought followed by wet spring, cheatgrass can invade and dominate.

(T10) A sagebrush killing event, such as fire and fire surrogates will dramatically increase cheatgrass while removing sagebrush from the system.

(R11) A restoration treatment, including chemical treatment for cheatgrass and seeding (native or introduced mix), favorable climatic conditions (wet spring), rest from grazing during establishment, and a grazing system that allows for adequate rest and recovery of perennial forage species can restore a perennial grass community and eventually support an altered sagebrush community with invaders present. Sagebrush will not likely dominate in the foreseeable future. The Altered/Seeded State is possible from any state after a severe ground disturbing activity such as mineral extraction.

(T12) A catastrophic event such as fire or drought, followed by a wet spring can result in a system dominated by annual invasive species.

(13a) Sagebrush increases with time and no disturbances until co-dominant with the herbaceous understory, but cheatgrass will be present. Introduced species are likely present if seeded during a restoration activity.

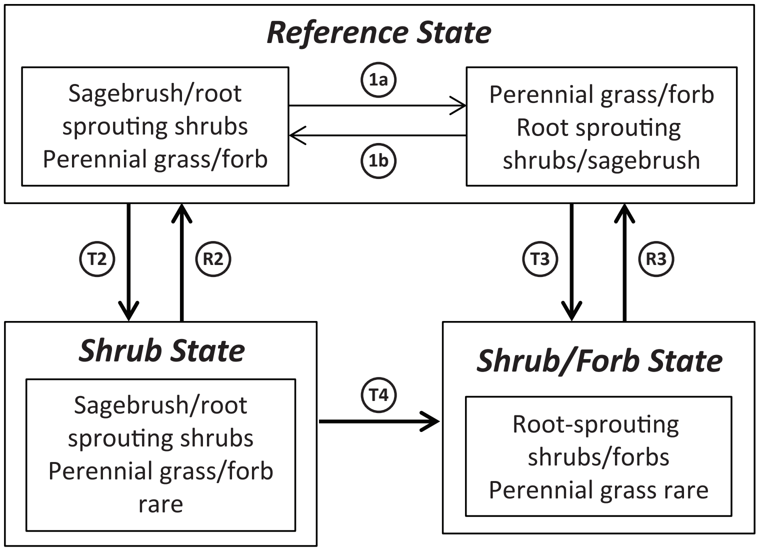
(13b) Perennial grass/annual and perennial forbs become dominant due to disturbances that decrease sagebrush. There will commonly be a temporary flush of annual invasives.

Appendix 6—Generalized State-and-Transition Models for Predominant Sagebrush Ecological Types in the Cold Deserts (MZ III, IV, V) in the Western Portion of the Range

These generalized state-and-transition models are for a subset of the ecological types in table 6 and are derived from Chambers et al. 2014b, c. These state-and-transition models can inform planning efforts at mid- to local-scales. However, for project scale planning efforts, state-and-transition models for specific ecological sites are most appropriate if available. Large boxes illustrate states that are comprised 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.

A.6.1 Cold Deserts – Cryic/xeric-Typic mountain big sagebrush/Mountain brush (14 in + PZ)

Moderately High Resilience and High Resistance



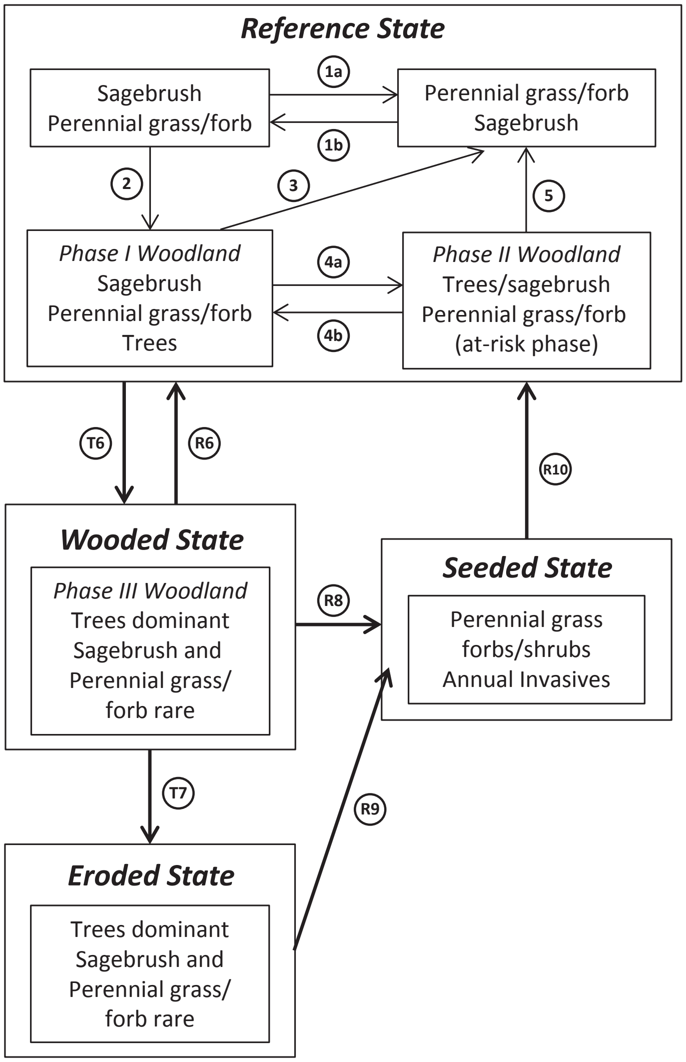
1a	Perennial grass/forb increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.
1b	Sagebrush and other shrubs increase with time.
T2	Improper grazing triggers a shrub dominated state.
R2	Proper grazing results in return to the reference state.
T3 T4	Fire or other disturbances that remove sagebrush result in dominance by root-sprouting shrubs and an increase in native forbs like lupines.
R3	Proper grazing and time result in return to the reference state.

Note: Resilience is lower on cold cryic sites due to short growing seasons.

A.6.2 Cold Deserts – Frigid/Xeric-Typic Mountain big sagebrush (12-22 in PZ)

Piñon pine and/or juniper potential

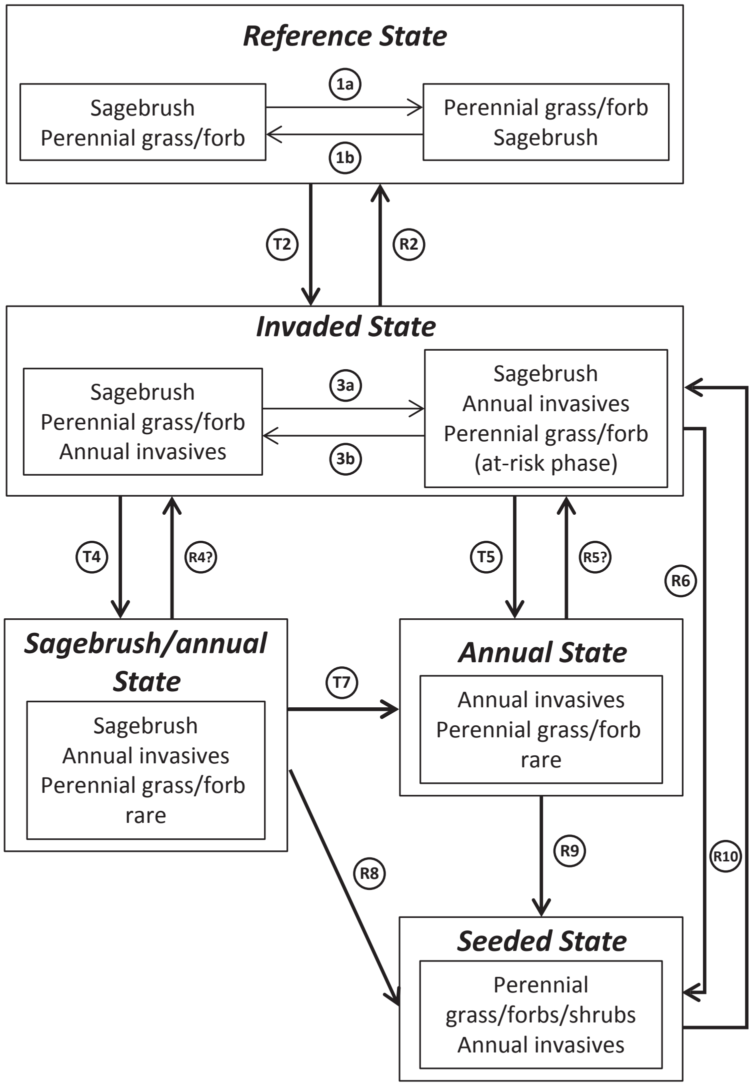
Moderately High Resilience and Moderate Resistance



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.

A.6.3 Cold Deserts – Frigid bordering on Mesic/Xeric-Typic Mountain big sagebrush (12-16 in PZ)

Moderate Resilience and Resistance

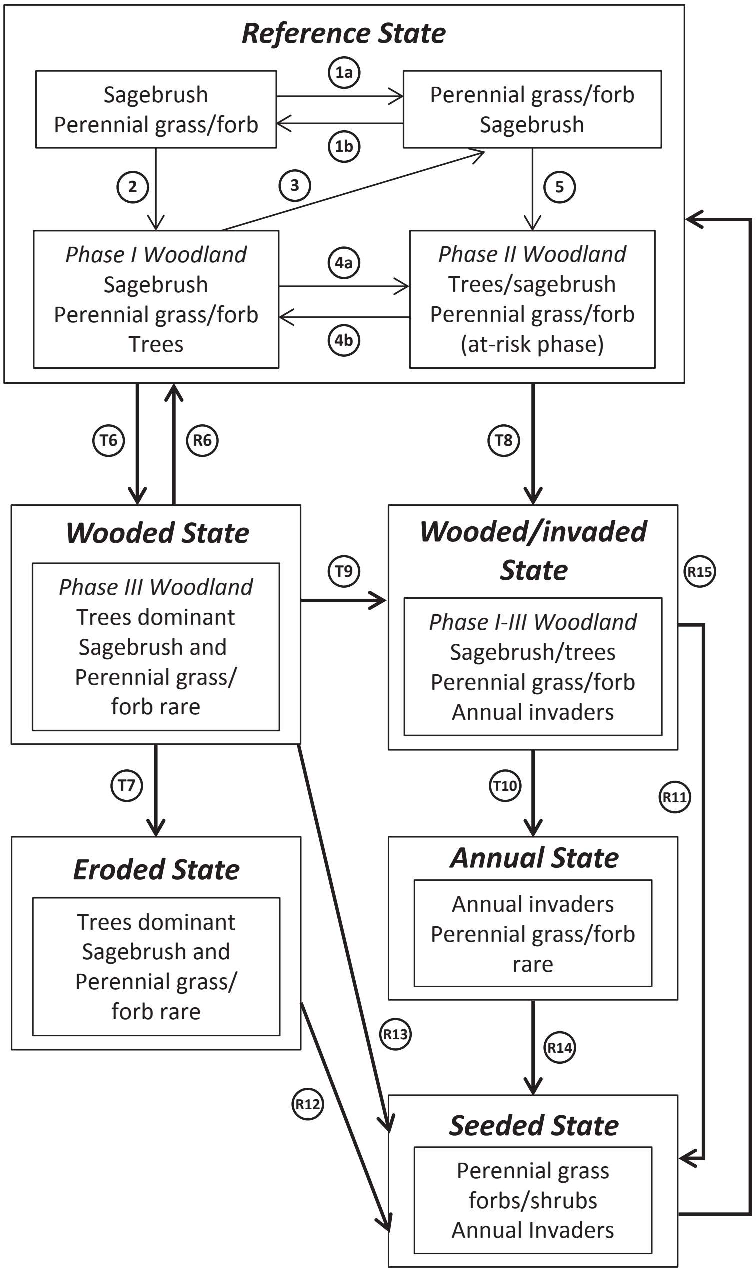


⓵a	Perennial grass/forb increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.
1b	Sagebrush increases with time.
T2	An invasive seed source and/or improper grazing trigger an invaded state.
R2	Proper grazing, fire, herbicides, and/or mechanical treatments may restore perennial grass/forb and sagebrush dominance with few invasives.
3a	Perennial grass/forb decreases and sagebrush and invasives increase with improper grazing by livestock resulting in an at-risk phase. Decreases in sagebrush due to insects, disease, or pathogens can further increase invasives.
3b	Proper grazing, herbicides, or mechanical treatments that reduce sagebrush may increase perennial grass/forb and decrease invasives.
T4	Improper grazing results in a sagebrush/annual state.
R4	Proper grazing may facilitate return to the invaded state on cooler/wetter sites if sufficient grass/forb remains.
T5 T7	Fire or other disturbances that remove sagebrush result in an annual state. Perennial grass/forb are rare and recovery potential is reduced. Repeated fire can result in a biotic threshold crossing to annual dominance on warmer/drier sites, and root-sprouting shrubs may increase.
R5	Cooler and wetter sites may return to the invaded or reference state with lack of fire, proper grazing, and favorable weather.
R6 R8 R9	Seeding following fire and/or invasive species control results in a seeded state. Sagebrush may recolonize depending on patch size, but annual invaders are still present.
R10	Cooler and wetter sites may return to the invaded or possibly reference state depending on seeding mix, grazing and weather.

A.6.4 Cold Deserts – Mesic bordering on Frigid/Xeric-Typic Basin Big sagebrush (12-16 in PZ)

Piñon pine and/or juniper potential

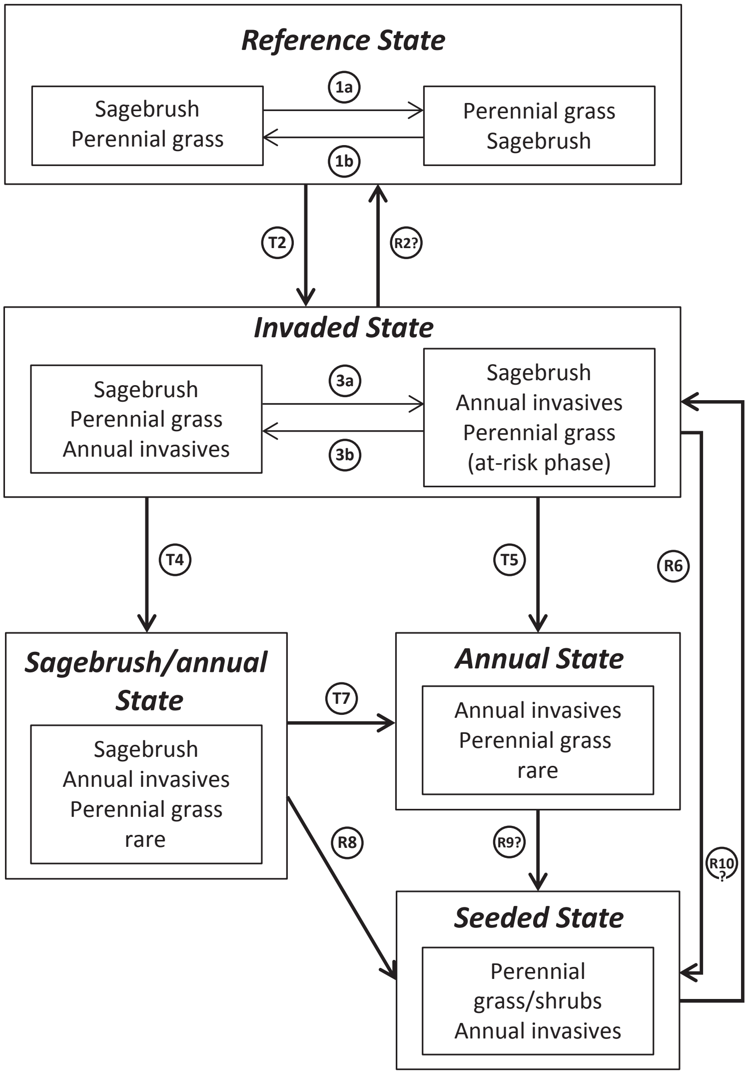
Moderate Resilience and Moderately Low Resistance



(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 piñonand/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 on cooler/wetter sites. On warmer/drier sites with low perennial grass/forb abundance resistance to invasion is moderately low.
(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 sagebrush and perennial grass/forb dominance.
(T6)	Infilling of trees and 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 on cooler/wetter sites. Seeding may be required.
(T7)	An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.
(T8) (T8)	An invasive seed source and/or improper grazing can trigger a wooded/invaded state.
(T10)	Fire or other disturbances that remove trees and sagebrush can result in a biotic threshold crossing to annual dominance on warmer/drier sites with lower resistance.
(R11) (R12) (R13) (R14)	Seeding after fire and/or invasive species control increases perennial grass/forb. Sagebrush may recolonize depending on seed sources, but annual invaders are still present. Seeded eroded states may have lower productivity.
(R15)	Depending on seed mix, grazing, and level of erosion, return to the reference state may occur on cooler and wetter sites if an irreversible threshold has not been crossed.

A.6.5 Cold Deserts – Frigid bordering on Mesic/Aridic-Typic Wyoming big sagebrush (6-12 in PZ)

Low Resilience and Moderately Low Resistance



(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 may result in return to the reference state on wetter 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 (6-10”) and/or sites with low abundance of perennial grass.

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

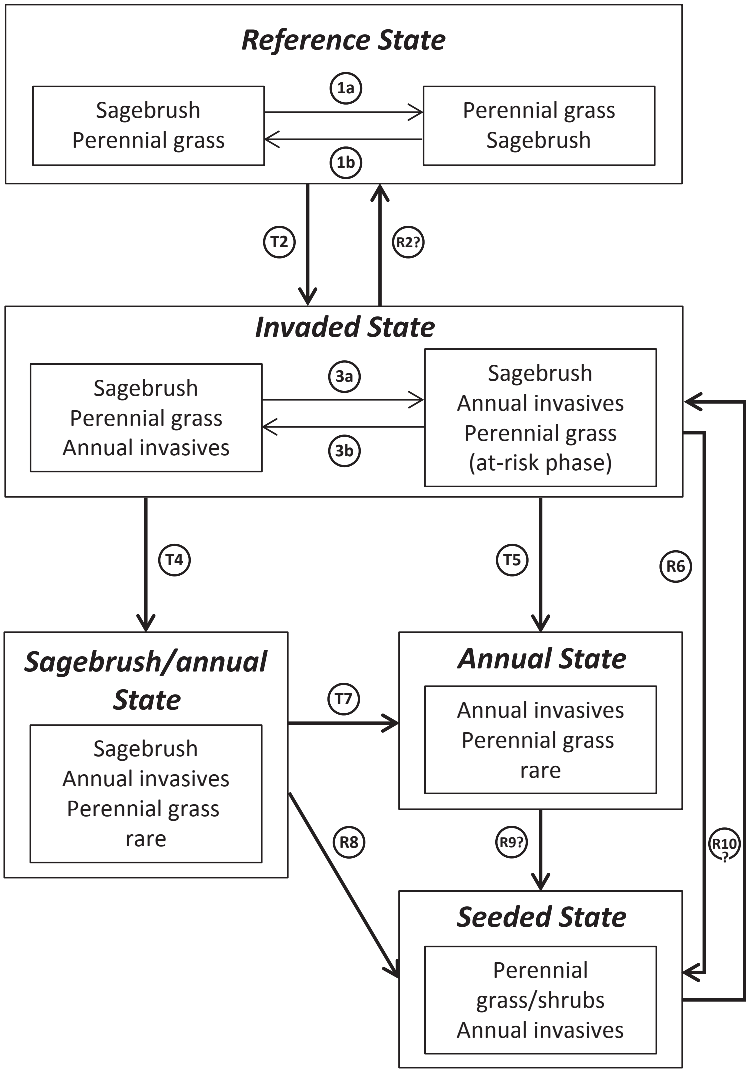
(T5) (T7) Fire or other disturbances that remove sagebrush result in an annual state.Perennial grass is rare and recovery potential is low on sites with low precipitation. Repeated fire can cause further degradation.

(R6) (R8) (R9) Seeding following fire and/or invasive species control results in a seeded state. 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.

A.6.6 COLD DESERTS – MESIC/ARIDIC BORDERING ON XERIC WYOMING BIG SAGEBRUSH (8-12 IN PZ)

Low to Moderate Resilience and Low Resistance



(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) Sagebrush may recolonize depending
(R9) 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.

Appendix 7—Explanation of the Use of Landscape Measures to Describe Sagebrush Habitat

Understanding landscape concepts of plant cover relative to typical management concepts of plant cover is important for prioritizing lands for management of sage-grouse. Ground-based measurements of sagebrush canopy cover (for example, using line-intercept measurements) should not be confused with landscape cover due to vast differences in measurement scale (e.g., square meters for management units and square kilometers for landscapes).

A landscape is defined rather arbitrarily as a large area in total spatial extent, somewhere in size between sites (acres or square miles) and regions (100,000s of square miles). The basic unit of a landscape is a patch, which is defined as a bounded area characterized by a similar set of conditions. A habitat patch, for example, may be the polygonal area on a map representing a single land cover type. Landscapes are composed of a mosaic of patches. The arrangement of these patches (the landscape configuration or pattern) has a large influence on the way a landscape functions and for landscape species, such as sage-grouse, sagebrush habitat patches are extremely important for predicting if this bird will be present within the area (Connelly et al. 2011).

Remotely sensed data of land cover is typically used to represent landscapes. These data may combine several sources of data and may include ancillary data, such as elevation, to improve the interpretation of data. These data are organized into pixels that contain a size or grain of land area. For example, Landsat Thematic Mapper spectral data used in determining vegetation cover generally have pixels that represent ground areas of 900 m^2 (30 x 30 m). Each pixel's spectral signature can be interpreted to determine what type of vegetation dominates that pixel. Groups of adjacent pixels with the same dominant vegetation are clustered together into polygons that form patches.

Landscape cover of sagebrush is determined initially by using this vegetation cover map, but a rolling window of a predetermined size (e.g., 5 km^2 or 5,556 pixels that are 30 by 30 m in size) is then moved across the region one pixel at a time to smooth the data. In this process, the central pixel of the window is reassigned a value equal to the proportion of pixels in the window for which sagebrush is the dominant vegetation. The process is repeated until the value for each pixel within the analysis region has been reassigned to represent the landscape cover of sagebrush within a 5-km^2 window.

This appendix was prepared by David A. Pyke.

Appendix 8—Data Sources and Websites for the Maps in This Report

Annually tilled agriculture (cropland)

Source: USDA National Agricultural Statistics Service Cropland Data Layer. 2014. Published crop-specific data layer. UDSA-NASS, Washington, DC. http://nassgeodata.gmu.edu/CropScape/ [Accessed Sept 16, 2015].

Available: http://nassgeodata.gmu.edu/CropScape/

Figures: 14, 42

Climate change: Climate variables

Source: Appendix 3

Available: https://www.sciencebase.gov/catalog/item/5850549ae4b0f24ebfd9368f

Figures: Appendix 3

Climate change: Wyoming big sagebrush climate niche models

Source: Still, S.M.; Richardson, B.A. 2015. Projections of contemporary and future climate niche for Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*): A guide for restoration. Natural Areas Journal. 35: 30–43.

Available: https://www.sciencebase.gov/catalog/item/58516105e4b0f99207c4f063

Figure: 35

Cultivation risk

Source: Smith, J.T.; Evans, J.S.; Baruch-Mordo, S.; [et al.]. 2016. Reducing cropland conversion risk to sage-grouse through strategic conservation of working rangelands. Biological Conservation. 201: 10–19. http://dx.doi.org/10.1016/j.biocon.2016.06.006

Available: http://map.sagegrouseinitiative.com/

Figure: 42

Ecoregions: Levels II and III

Source: U.S Environmental Protection Agency [EPA]. 2016 Level II and III Ecoregions of North America. https://www.epa.gov/eco-research/ecoregions-north-america [Accessed Sept 16, 2015].

Available: https://www.epa.gov/eco-research/ecoregions-north-america

Figures: 1, 3, 5, 6, 7, 10, Appendix 3

Precipitation and temperature data: 30 year normals

Source: PRISM Climate Group, Northwest Alliance for Computational Science and Engineering. 2016. 30-year Normals. http://prism.oregonstate.edu/normals [Accessed Sept 16, 2015].

Available: http://prism.oregonstate.edu/normals

Figures: 2, 3

Fire perimeters: Geomac

Source: Walters, S.P; Schneider, N.J.; Guthrie, J.D. 2011. Geospatial Multi-Agency Coordination (GeoMAC) wildland fire perimeters, 2008. Data Series 612. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. 6 p. http://www.geomac.gov/ [Accessed Feb 1, 2016].

Available: http://www.geomac.gov/

Figures: 7, 51

Fire perimeters: MTBS

Source: Eidenshink, J.; Schwind, B.; Brewer, K.; [et al.]. 2007. A project for monitoring trends in burn severity: Fire Ecology. 3: 3–21. http://www.mtbs.gov/nationalregional/burnedarea.html [Accessed Sept 15, 2015].

Available: http://www.mtbs.gov/nationalregional/burnedarea.html

Figures: 7, 51

Fire risk

Source: Crist, M.R.; Chambers, J.C.; Haas, J.R.; [et al.]. 2016. Fire Risk Assessment for the Greater Sage-Grouse Raster. Washington, DC: U.S. Department of the Interior, Bureau of Land Management.

Available: https://www.sciencebase.gov/catalog/item/5846d366e4b04fc80e52376b

Figures: A.10.1

Greater sage-grouse breeding habitat model

Source: Doherty, K.E.; Evans, J.S.; Coates, P.S.; [et al.]. 2016. Importance of regional variation in conservation planning: A rangewide example of the Greater sage-grouse. Ecosphere. 7(10): Article e01462. http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1462/full

[Accessed Nov 9, 2016].

Available: https://www.sciencebase.gov/catalog/item/57a26bbae4b006cb45553f57

Figures: 25, 38

Greater sage-grouse connectivity for Priority Areas for Conservation

Source: Crist, M.R.; Knick, S.T.; Hanser, S.E. 2017. Range-wide connectivity of priority areas for Greater sage-grouse: Implications for long-term conservation from graph theory. Condor. 117: 44–57.

Available: https://www.sciencebase.gov/catalog/item/58504cebe4b0f24ebfd93670

Figure: A.9.1

Greater sage-grouse population index model

Source: Doherty, K.E.; Evans, J.S.; Coates, P.S.; [et al.]. 2016. Importance of regional variation in conservation planning: A rangewide example of the Greater Sage-Grouse. Ecosphere. 7(10): Article e01462. http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1462/full

[Accessed Nov 9, 2016].

Available: https://www.sciencebase.gov/catalog/item/57a379ffe4b006cb455690aa

Figures: 26, 39, 43, 47, 52, A.10.1

Greater sage-grouse lek data

Source: Western Association of Fish and Wildlife Agencies (WAFWA)

Contact: Tom Remington, WAFWA, 2700 W. Airport Way, Boise, ID 83705; remingtontom@msn.com.

Table: 7

Human disturbance

Source: NLCD 2011 Percent Developed Imperviousness 2014. 2011 Edition, amended 2014. Metadata. Sioux Falls, SD: U.S. Department of the Interior, U.S. Geological Survey. http://www.mrlc.gov/nlcd11_data.php [Accessed May 11, 2016]

Available: http://www.mrlc.gov/nlcd11_data.php

Figure: 18

Land cover: Cheatgrass occurrence (historic range of sage-grouse)

Source: Downs, J.L.; Larson, K.B.; Cullinan, V.I. 2016. Mapping cheatgrass across the range of the Greater sage-grouse: Linking biophysical, climate and remote sensing data to predict cheatgrass occurrence. PNNL 22517. Richland, WA: Pacific Northwest National Laboratory. 16 p.

Available: https://www.sciencebase.gov/catalog/item/585169aae4b0f99207c4f093

Figure: 33

Land cover: Cheatgrass (Northeast Nevada)

Source: Boyte, S.P.; Wylie, B.K. 2016. Near-real-time cheatgrass percent cover in the Northern Great Basin, USA, 2015. Rangelands. 38: 278–284. http://www.bioone.org/doi/full/10.1016/j.rala.2016.08.002 [Accessed Nov 9, 2016].

Available: https://www.sciencebase.gov/catalog/item/55ad3a16e4b066a2492409d5

Figure: 51

Land cover: Conifer

Source: U.S. Geological Survey (USGS). 2012. LANDFIRE 1.3.0 Existing Vegetation Type layer. Updated December 17, 2014. Washington, DC: U.S. Department of the Interior, Geological Survey. http://landfire.cr.usgs.gov/viewer/ [Accessed Aug 26, 2015].

Available: http://landfire.cr.usgs.gov/viewer/

Figure: 10

Land cover: Conifer (Northeast Nevada)

Source: Falkowski, M.J.; Evans, J.S.; Naugle, D.E.; [et al.]. 2017. Mapping tree canopy cover in support of proactive prairie grouse conservation in western North America. Rangeland Ecology and Management. 70: 15–24. http://dx.doi.org/10.1016/j.rama.2016.08.002.

Available: http://map.sagegrouseinitiative.com/

Figure: 51

Land cover: Sagebrush

Source: U.S. Geological Survey [USGS]. 2012. LANDFIRE 1.3.0 Existing Vegetation Type layer. Updated December 17, 2014. Washington, DC, U.S. Department of the Interior, Geological Survey. http://landfire.cr.usgs.gov/viewer/ [Accessed Aug 26, 2015].

Available: http://landfire.cr.usgs.gov/viewer/

Figures: 5, 28, 29

Large fire probability

Source: Short, K.C.; Finney, M.A.; Scott, J.H.; [et al.]. 2016. Spatial dataset of probabilistic wildfire risk components for the conterminous United States. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0034.

Available: https://www.sciencebase.gov/catalog/item/58516a0be4b0f99207c4f096

Figure: 34, A.10.1

Major Land Resource Area

Source: USDA Natural Resource Conservation Service [NRCS]. 2006. 2006 MLRA Geographic Database, version 4.2. Washington, DC: U.S. Department of Agriculture, Natural Resource Conservation Service. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053624. [Accessed Dec 1, 2016]

Available: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053624

Figure: A.3.1

Oil and gas wells

Source: Point density analysis conducted by the Bureau of Land Management and derived from AFMSS Currently Active Oil and Gas Well Points 2015; IHS Currently Active Oil and Gas Well Points 2015. https://www.ihs.com/products/us-well-data.html [Accessed May 11, 2016].

Available: https://www.ihs.com/products/us-well-data.html

Figures: 16, 46

Roads

Source: Line density analysis conducted by the Bureau of Land Management and derived from ESRI Street Maps Premium. Copyright © 1995–2014 ESRI. All rights reserved. Published in the United States of America. http://www.esri.com/data/streetmap [Accessed May 11, 2016].

Available: http://www.esri.com/data/streetmap

Figure: 20

Sage-grouse Management Zones

Source: Stiver, S.J.; Apa, A.D.; Bohne, J.R.; [et al.]. 2006. Greater sage-grouse comprehensive conservation strategy. Cheyenne, WY: Western Association of Fish and Wildlife Agencies. 442 p. http://wdfw.wa.gov/publications/01317/wdfw01317.pdf [Accessed Aug 2, 2016].

Available: https://www.sciencebase.gov/catalog/item/56f96b30e4b0a6037df06216

Figures: 1, 2, 3, 5, 6, 7, 10, 14, 16, 18, 20, 25, 26, 28, 29, 32, 33, 34, 35, 38, 39, 49, 50, 51, 52, A.3.1, A.9.1, A.10.1

Sage-grouse Priority Areas for Conservation

Source: U.S. Fish and Wildlife Service [FWS]. 2013. Greater sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. Denver, CO: U.S. Fish and Wildlife Service. 91 p. https://www.fws.gov/greatersagegrouse/documents/COT-Report-with-Dear-Interested-Reader-Letter.pdf [Accessed Aug 8, 2016].

Available: https://www.sciencebase.gov/catalog/item/56f96d88e4b0a6037df066a3

Figures: 25, 26, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 49, 50, 51, 52, A.3.1, A.9.1

Seed zones: Provisional

Source: Bower, A.D.; St. Clair, J.B.; Erickson, V. 2014. Generalized provisional seed zones for native plants. Ecological Applications. 24: 913–919.

Available: http://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneData.php

Figure: A.11.1

Seed zones: Adaptive seed zones for bluebunch wheatgrass (*Pseudoroegneria spicata*)

Source: St. Clair, J.B.; Kilkenny, F.F.; Johnson, R.C.; [et al.]. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evolutionary Applications. 6: 933–938.

Available: http://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneData.php

Figure: A.11.2

Soil data (SSURGO)

Source: Soil Survey Staff. 2014a. Soil Survey Geographic (SSURGO) Database. Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service. http://sdmdataaccess.nrcs.usda.gov/ [Accessed Oct 3, 2015].

Available: http://sdmdataaccess.nrcs.usda.gov/

Figures: 6, 32, 38, 39, 40, 43, 44, 47, 49, 52

Soil data (STATSGO)

Source: Soil Survey Staff. 2014b. Soil Survey Geographic (STATSGO2) Database. United States Department of Agriculture, Natural Resources Conservation Service. http://sdmdataaccess.nrcs.usda.gov/ [Accessed Oct 3, 2015].

Available: http://sdmdataaccess.nrcs.usda.gov/

Figures: 6, 32, 38, 39, 40, 43, 44, 47, 49, 52, A.10.1

Soil temperature and moisture regimes

Source: Campbell, S.B. 2016. Soil temperature and moisture regimes across sage-grouse range. Data product. Portland, OR: U.S. Department of Agriculture, Natural Resources Conservation Service. https://www.sciencebase.gov/catalog/item/538e5aa9e4b09202b547e56c [Accessed May 10, 2016].

Available: https://www.sciencebase.gov/catalog/item/538e5aa9e4b09202b547e56c

Figures: 6, 32, 38, 39, 40, 43, 44, 47, 49, 52, A.10.1

Surface land management

Source: Surface Management Agency. Complied and maintained by the Department of the Interior, Bureau of Land Management. 2015. http://www.geocommunicator.gov/GeoComm/ [Accessed May 7, 2016].

Available: http://www.geocommunicator.gov/GeoComm/

Figures: 41, 45, 50

This appendix was prepared by Jacob D. Hennig, Steven E. Hanser, and Jeanne C. Chambers with input from Victoria Smith-Campbell and Megan Waltz.

Appendix 9—Connectivity Between Priority Areas for Conservation of Greater Sage-Grouse

Focusing conservation actions for sage-grouse within Priority Areas for Conservation (PACs; FWS 2013) or higher level habitat designations can have the greatest habitat benefits with limited resources. However, management actions in regions surrounding PACs could potentially lead to a spatially disjunct set of areas that no longer retain the characteristics necessary to sustain Greater sage-grouse (GRSG) populations and sagebrush-dependent species that utilize similar habitat conditions. In addition, priorities and land use plans often differ among state and federal management agencies both within and outside of the PAC structure (Copeland et al. 2014; Knick and Connelly 2011). These different conservation and management priorities among administrative units could disrupt the current sage-grouse population spatial structure leading to greater isolation and potentially initiate or accelerate population declines.

A recent evaluation of habitat connectivity among the PACs found that a majority of PACs had limited connectivity (Crist et al. 2017). https://www.sciencebase.gov/catalog/item/58504cebe4b0f24ebfd93670). The PACs with few habitat connections averaged greater environmental resistance to movement along connecting pathways. Without maintaining corridors to larger PACs or a clustered group, isolation of small PACs could lead to regional loss of GRSG.

Crist et al. (2017) used circuit theory to model potential movement pathways (McRae et al. 2008) and graph theory (Urban and Keitt 2001) to measure the strength of connectivity among PACs as a network. A rangewide map of habitat suitability for GRSG was created at 1-km^2 resolution from a model of ecological minimum requirements following similar protocols developed previously for the western portion of the range (Knick et al. 2013). However, Crist et al. (2017) used a random sample of habitat conditions within PACs rather than those within 5 km of lek locations, which were used in Knick et al. 2013. The sage-grouse habitat suitability map was transformed to environmental resistance to movement under the assumption that the likelihood of sage-grouse movement through a 1-km^2 grid cell follows an inverse relationship to habitat suitability.

Circuitscape (Circuitscape version 4.0, http://www.circuitscape.org; McRae and Shah 2008) was used to model potential movement pathways between PACs. The capacity for movement is based on an effective resistance (ER) that combines distance and the mapped environmental resistance (described above) in electric current density algorithms (McRae 2006; McRae et al. 2008). Effective resistance is a measurement on a scale between complete absence of environmental resistance (in which all PACs are interconnected because there is no cost of movement) to total barrier (all PACs are isolated from each other). A low ER between pairs of PACs represented a relatively high potential pathway for GRSG movement. A final map of maximum current density represents the spatial structure of connectivity (movement pathways) for the network of PACs (fig. A9.1). Locations of high current densities may function as bottlenecks (pinch points) to Greater sage-grouse connectivity where movement is constricted or alternative pathways are not available (Dickson et al. 2013; McRae et al. 2008).

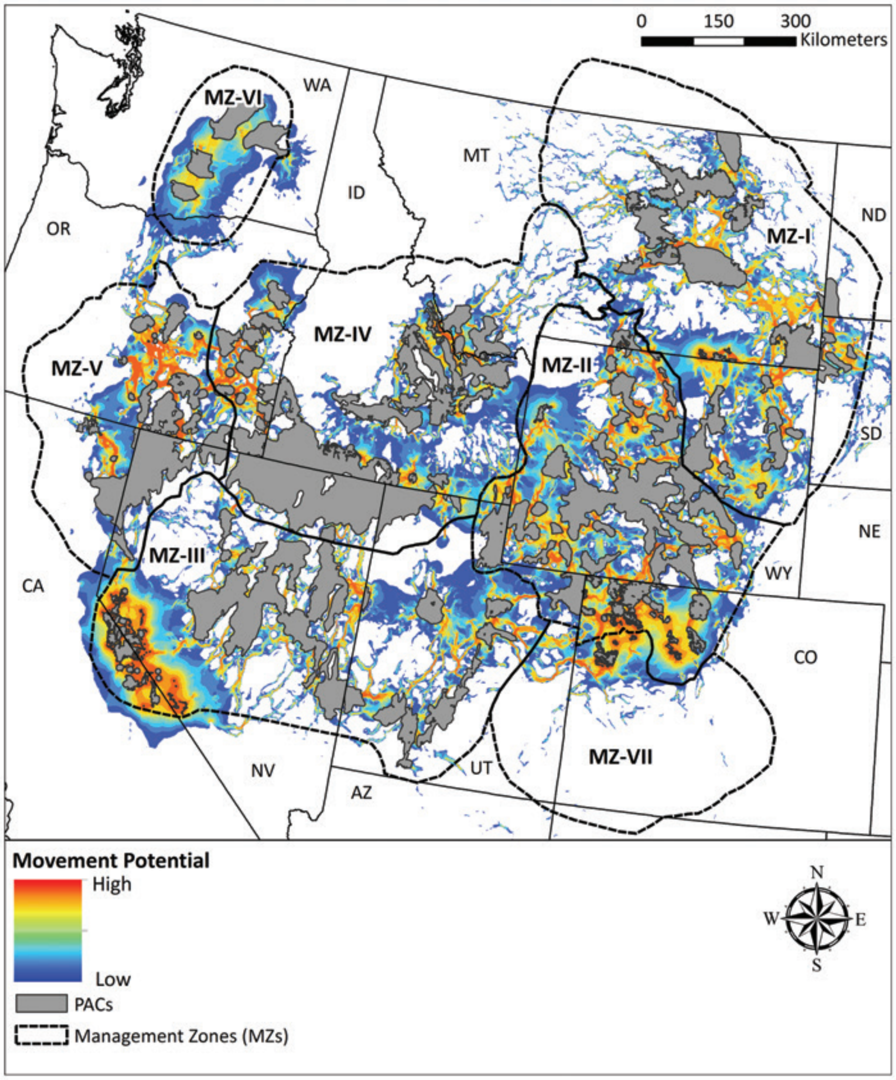


Figure A9.1— Estimated potential for sage-grouse movement between Priority Areas for Conservation (Crist et al. 2017). Areas of high to medium movement potential represent pinch points.

Landscape connectivity is often assessed to identify critical habitat connections where, if severed, could potentially isolate populations (Bunn et al. 2000; LaPoint et al. 2013; Urban and Keitt 2001). Characteristics of these habitat connections between PACs can help land managers target conservation actions to help ensure sage-grouse seasonal and dispersal movements (Crist et al. 2017). Areas of high movement potential (fig. A9.1) can be used to identify the critical locations where movement is constrained. If resources are limited, sagebrush restoration efforts that improve or expand habitat areas at pinch points between PACs might enhance potential corridors and preserve the likelihood of population persistence by facilitating movements that sustain or augment populations and for dispersal and gene flow.

The current network structure of PACs has many important characteristics for maintaining GRSG populations (Crist et al. 2017). For example, the range of large and small sizes of PACs may provide different functions, particularly as sources and connecting habitat along movement corridors. Conservation actions that maintain connectivity between clusters of PACs will be important to retain movement potential among PACs that might be too small individually to sustain viable populations. Also, decision support tools can be developed using modeled surfaces of genetic divergence, isolation, and landscape resistance. Such spatially explicit tools would be used to identify and prioritize areas for habitat restoration (e.g., conifer removal) that reduce barriers to movement and increase gene flow among populations and PACs.

This appendix was prepared by Michele R. Crist, Steve E. Hanser, and Peter S. Coates.

Appendix 10—Fire Risk Assessment for Greater Sage-Grouse Breeding Habitat

An assessment of wildfire risk for Greater sage-grouse (GRSG) habitat can offer a consistent means for understanding and comparing the threat of fire to GRSG, as well as predicting and prioritizing investments in management activities that mitigate fire risk. In the context of the Science Framework, wildfire processes may have varying negative and positive effects on sagebrush ecosystems depending on the relative resilience of a site to disturbance and resistance to invasive annual grasses. Geospatial analyses can be used to assess the relative resilience and resistance, and thus recovery potential, of areas that support species or resources at-risk. They can also be used to assess the probability of wildfire occurring within these same areas and the interactions of wildfire with resilience and resistance and sagebrush habitat. For species at risk, like sage-grouse, the process involves overlaying key data layers to both visualize and quantify: (1) species locations and abundances, (2) the probability that an area has suitable habitat for the species of interest, (3) the likely response of the area to either wildfire or management treatments, and (4) the dominant threats, such as wildfire, for the assessment area. Calculating the areas within different resilience and resistance and habitat categories along with the different burn probabilities can be another step in the process.

This fire risk assessment was conducted to understand how resilience and resistance and sage-grouse breeding bird habitat may inform wildland fire management decisions including preparedness, suppression, fuels management and postfire recovery across the sagebrush biome (Crist et al. 2016; https://www.sciencebase.gov/catalog/item/5846d366e4b04fc80e52376b). The assessment is based on the premise that risk is equal to the probability of a threat and the consequences of that threat (negative or positive). Fire risk was determined by the probability of a large wildfire (>300 acres in shrub/grass systems) and the consequences of fire on GRSG breeding habitat. These consequences were modified by resilience to disturbance, or recovery potential, and resistant to invasive annual grasses of sage-grouse habitat. The focus area for the assessment was the dominant sagebrush ecological types and grassland with sagebrush components ecological types in LANDFIRE that occur across portions of eleven western States: Washington, Oregon, California, Idaho, Nevada, Utah, Montana, Wyoming, Colorado, North Dakota and South Dakota.

Three GIS datasets described in Section 8 were modified and used in the assessment: large fire burn probability extracted for the sagebrush biome (fig. 34; Short et al. 2016), GRSG breeding habitat probabilities (fig. 25; Doherty et al. 2016), and resilience and resistance as indicated by soil temperature and moisture regimes (fig. 32; Maestas et al. 2016a). The large fire probability spatial dataset was derived by simulating fire ignition and growth using the Fire Simulation (FSim) system (Finney et al. 2011; Short et al. 2016). Contemporary weather scenarios were generated for each simulation unit using: (1) a fire danger rating index known as the Energy Release Component (ERC), which is a proxy for fuel moisture; (2) a time-series analysis of ERC to represent daily and seasonal trends and variability; and (3) distributions of wind speed and direction from surface weather records. Fire growth was based on the characteristics of relatively large and generally fast moving fires because they account for the majority (80−97 percent) of total area burned, and thus contribute the most to the probability of a wildland fire burning a given parcel of land therein. Fire occurrence in FSim is stochastically modeled based on historical relationships between large fires (largest 3−5 percent for each simulation unit) and ERC. Because its objective is to simulate the behavior of large, spreading fires, FSim restricts fire growth to days on which ERC reaches or exceeds the 80th percentile condition. Final burn probabilities indicate, for each 270 m pixel, the number of times that cell was burned by an FSim-modeled fire, divided by the total number of annual weather scenarios simulated. The burn probabilities are intended to support an actuarial approach to quantitative wildfire risk analysis.

The Greater sage-grouse breeding habitat probabilities dataset provides an estimate of the probability of occupied breeding habitat at a spatial resolution of 120 by 120 m based on habitat characteristics for each Greater sage-grouse Management Zone. Greater sage-grouse breeding habitat probabilities were combined into three categories: low, equal to a habitat probability ranging from 0.26–0.50; moderate, equal to a habitat probability ranging from 0.5–0.75; and high, equal to a habitat probability ranging from 0.76–1.00.

The following values were assigned to the three categories: Low Habitat Probability had a value of 10, Moderate Habitat Probability had a value of 20, and High Habitat Probability had a value of 30. The resilience and resistance dataset was resampled using a nearest neighbor assignment to a 120-m resolution and assigned a value of 1 to the high category of resilience and resistance; a value of 2 was assigned to the moderate category, and a value of 3 to the low category.

The three datasets were combined by summing the values in a raster grid format. The resulting fire exposure map depicts 27 different combinations of sage-grouse breeding habitat probability, resilience and resistance, and burn probability (fig. A10.1).

The final fire risk map identifies areas where sagebrush and sage-grouse habitats are at highest risk from fire across the sagebrush biome and historic sage-grouse range. It also identifies the relative resilience to disturbance and resistance to invasive annual grasses of areas that are at high risk from fire. The assessment shows the differences in fire among Management Zones and ecoregions. The fire risk assessment can be used to help: (1) evaluate the level of risk to vegetation types and species to wildfire, (2) target areas for wildfire management, and (3) determine the most appropriate types of fire management actions at the biome and ecoregion or Management Zone scales. Incorporating information on invasive annual grasses and land cover of juniper expansion further informs the type of management actions and the allocation of resources at broad to mid-scales and the specific types of treatments at local scales.

This appendix was prepared by Michele R. Crist, Jeanne C. Chambers, Jessica R. Haas, and Kevin E. Doherty. Dave Calkin, Karen Short, Susan Goodman, Matthew Brooks, Douglas Shinneman, Kurtis Nelson, Nathan Benson, Tonja Oppermen, Victoria Smith-Campbell, Craig Thomson, Matthew Reeves, Krista Gollnick-Wade, Kim Van Hemelryck, Douglas Havlina and Joesph Kafka contributed to the development and review of methodology for the fire risk assessment.

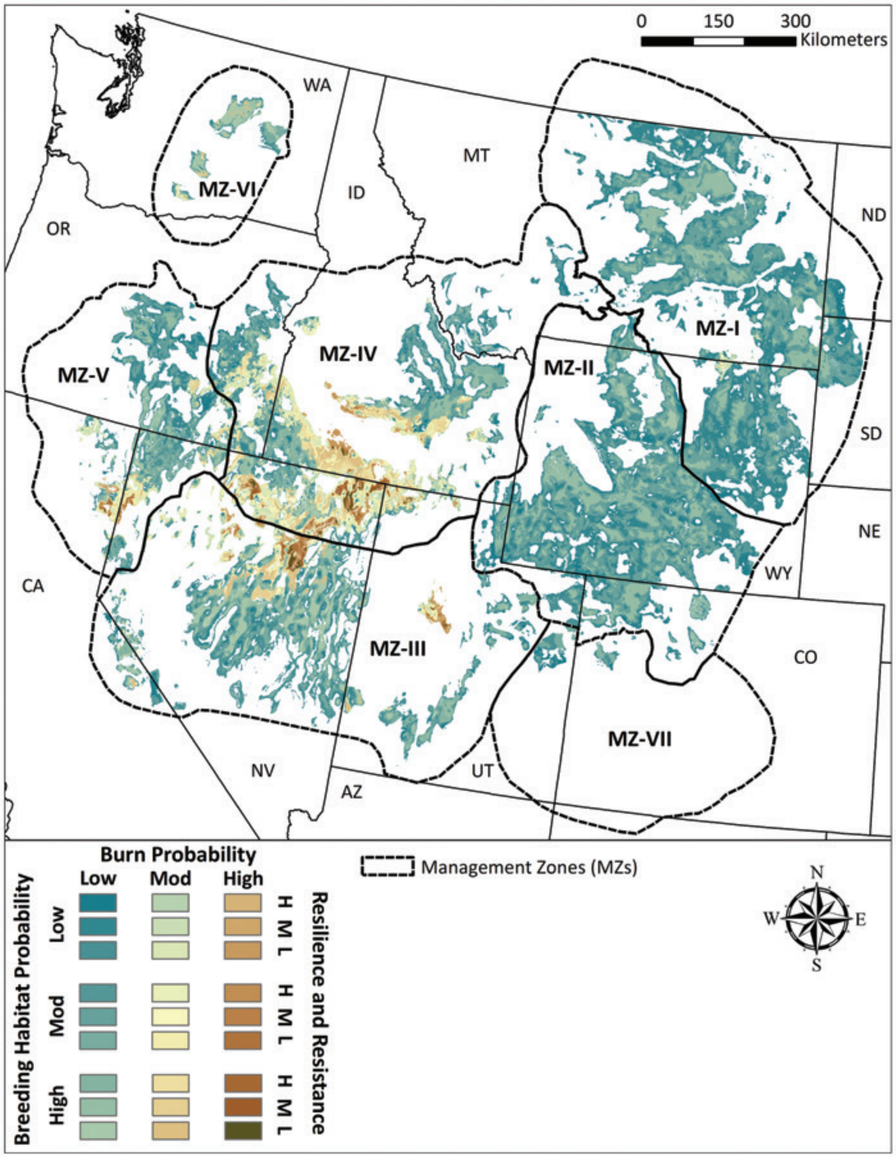


Figure A10.1— Fire risk map depicting 27 different combinations of sage-grouse breeding habitat probability (Doherty et al. 2016), resilience and resistance (Maestas et al. 2016a), and large fire probability (Short et al. 2016). The map identifies areas where sagebrush and sage-grouse habitats are at highest risk from fire across the sagebrush biome and historic sage-grouse range. It also identifies the relative resilience to disturbance and resistance to invasive annual grasses of areas that are at high risk from fire.

Appendix 11—Explanation of Seed Transfer Guidance

Ecosystem resilience to disturbance and resistance to invasive annual grasses can be increased by selecting appropriate seed mixtures for restoration. The capacity of a plant species to establish and persist following seeding depends on whether or not it is adapted to the environmental conditions on the site. Common garden and reciprocal transplant studies, where plants from two or more climatic regimes are seeded together into each of the different climatic regimes and their performance is monitored, have often shown that plant populations are 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 that locally adapted plants can generally outperform plants from other areas (e.g., Bischoff et al. 2006; Humphrey and Schupp 2002; Leimu and Fischer 2008; Rice and Knapp 2008; Rowe and Leger 2012). Poor seed source choices may have long-term consequences for plant communities including genetic degradation of the surrounding plant population, loss of fitness, and loss of evolutionary potential (Crémieux et al. 2010; McKay et al. 2005; Mijnsbruggea et al. 2010; Schröder and Prasse 2013). Ultimately, the seed sources used in restoration can affect future plant community resilience and resistance. The National Seed Strategy for Rehabilitation and Restoration (Seed Strategy; PCA 2015) provides a coordinated approach for developing and procuring native and genetically appropriate seed sources that are adapted to individual restoration and vegetation management project areas. The Seed Strategy also identifies research, technology, and monitoring actions needed to integrate and manage genetic diversity of plant communities across the sagebrush biome.

The use of locally adapted and genetically appropriate native seed and plant materials ensures the best genetic fit between a restoration site and the seed source used for the project. However, under many circumstances, using locally adapted seeds and plant materials may not be the most practical solution. Project-specific seed collections and grow-outs can add 2 to 5 years to project implementation schedules. Local seed may not be available because the species may be locally extinct, or local seed sources may no longer be the best genetic fit for the site because of climate change. Through seed zones and seed transfer guidelines, the National Seed Strategy provides a way for integrating agronomic approaches for seed production while managing for genetics and local adaptation.

Originally developed in forestry, seed zones and seed transfer guidelines are a science based tool used to describe local adaptation. Seed zones and seed transfer guidelines define acceptable distances from the original source that plant materials can be seeded or transplanted and still preserve ecological and evolutionary relationships (Kilkenny 2015). When coupled with climate models, the predicted shifts in seed transfer zones can be used to guide seed sourcing decisions and anticipate vegetation management and seed procurement needs under future climate conditions. In particular, vulnerable source populations can be identified and the direction of shifts in optimal plant traits can be identified.

Generalized seed zones (also called provisional seed zones) are based on climate variables that have been shown to be important to plant establishment and survival, or are based on other broad scale ecological considerations, such as plant communities or soil types. A recent generalized seed zone approach developed by Bower et al. (2014) uses minimum temperature and aridity variables to define generalized seed zones for the U.S. Omernik's (1987) ecoregional classification. Bower's approach for delineating ecosystem boundaries at various scales is based primarily on vegetation classes and has also been adapted for use as a generalized seed zone map. When generalized seed zones are combined with level III ecoregions (as defined by Omernik), the resulting map captures much of the variation existing in adaptive seed zones (fig. A11.1; Bower et al. 2014; Kramer et al. 2015). Therefore, the combined generalized seed zone and ecoregion mapping approach is a good starting place to incorporate adaptive genetic variation into seeding decisions (Miller et al. 2011b).

Recently, adaptive seed zones (also called empirical seed zones) have been constructed for a number of non-tree species in western North America, including grasses (e.g., St. Clair et al. 2013), forbs (e.g., Johnson et al. 2013), and shrubs (Horning et al. 2010). Adaptive seed zones are species specific and are developed through common garden studies of plant adaptive traits and correlation of these traits with climate. Information from these studies is then synthesized into seed zone maps that delineate regions where specific seed sources are likely to be well adapted (fig. A11.2; Kilkenny 2015; St. Clair et al. 2013). Common garden and reciprocal transplant studies can define the full adaptive range of the seed sources in the study, as well as test the efficacy of existing adaptive seed zones. Common garden studies are data rich, so that products other than seed zone maps can be produced. In particular, models of traits, such as growth or reproduction, and their interactions with climate can be constructed. These models are especially useful in predicting the effects of climate change on the performance of different seed sources in restoration seedings.

DNA marker sampling across the range of a species can also be used to describe the distribution of genetic variation of populations and develop genomic seed zone maps (De Kort et al. 2014; Narum et al. 2013). Genomic seed zones are useful for determining the level of relatedness and genetic diversity among seed sources. Genomic seed zones can also be used to conserve the genetic makeup of a population and to prevent poor genetic fit between seeded and local plant populations.

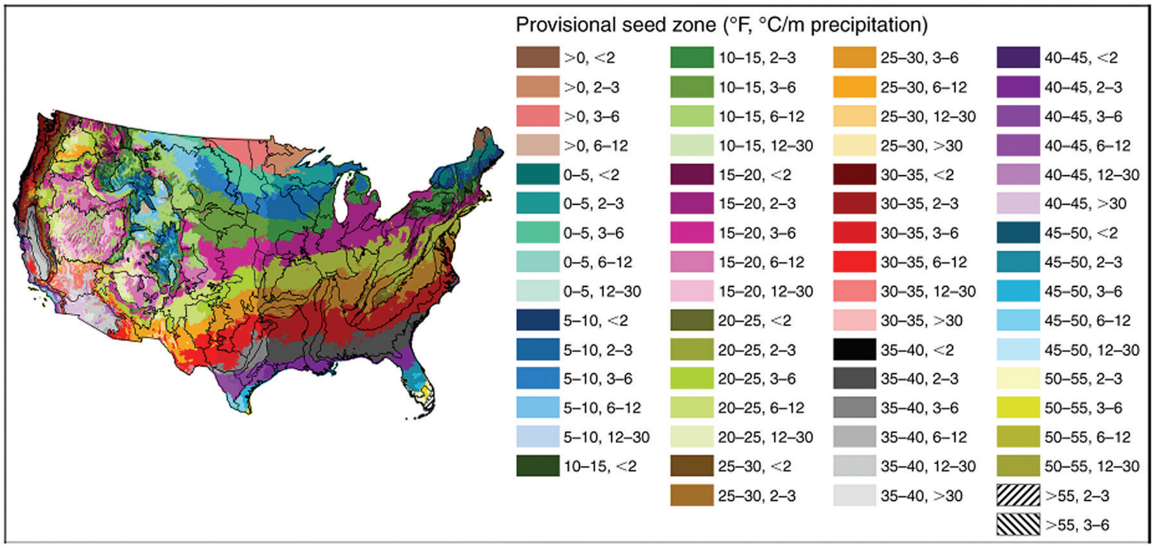


Figure A11.1—Provisional seed zones for native plants (color polygons) overlain with Omernik's (Omernick 1987) level III ecoregion boundaries (black lines). Provisional seed zones are the first step in defining seed transfer guidelines, and level III ecoregions can be used to refine seed movement within 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 AH:M index class bands (°C/m precipitation) (from Bower et al. 2014).

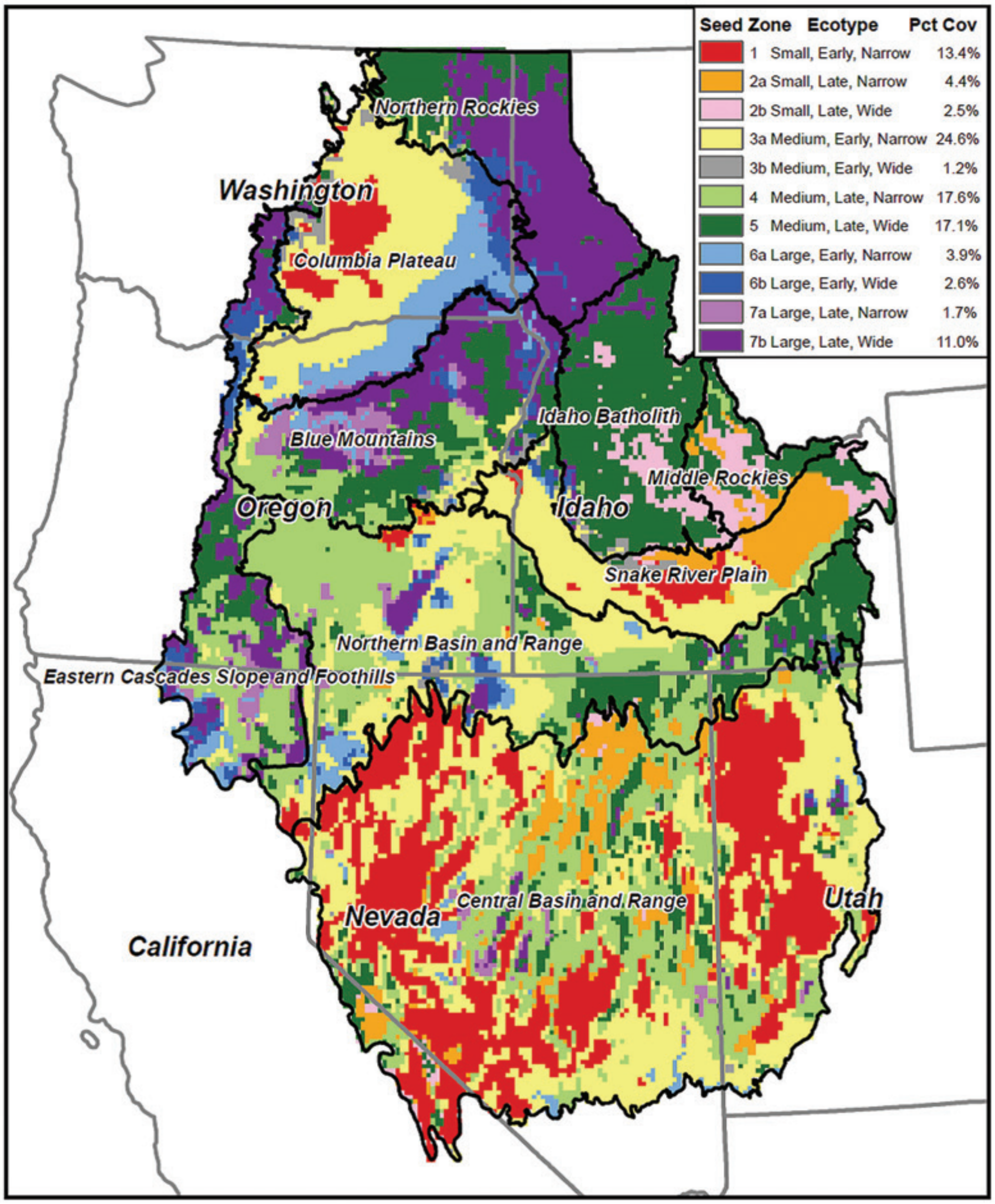


Figure A11.2—Adaptive seed zones (labeled 1–7b) for bluebunch wheatgrass (*Pseudoroegneria spicata*). Ecotypes correspond to small, medium, or large plant size; early or late phenology; and narrow or wide leaf width. Percentages of the total areas within study area for each seed zone are given in the legend (from St. Clair et al. 2013).

This can help prevent the degradation of local plant populations and future genetic resources from swamping by genetically inappropriate seed sources. Given the reduced cost of genetic testing, most studies that construct adaptive seed zones will also include genetic marker information in the future.

In addition to generalized and adaptive seed zones and transfer guidelines, another approach to understanding local adaptation is to use species distribution models to describe the climatic envelope of a species (describes the climate where a species currently lives, i.e., its "envelope," and maps the geographic shift of that envelope under climate change) (Elith and Leathwick 2009). Species distribution models are generally developed by statistically associating spatially explicit climate data with geo-referenced presence and/or absence data. Species distribution models, by themselves, have limited usefulness in plant restoration because they treat plant species as single entities without considering the existence of local or regional ecotypes. However, species distribution models can be combined with data from studies of adaptive and/or genomic characteristics to inform seed transfer guidelines (Still and Richardson 2015), and may be especially useful in studies of how climate may affect seed zones (Kilkenny 2015).

Once seed zones are defined, seeds can be collected and developed for use in restoration. For example, bluebunch wheatgrass is a grass species that occurs throughout most of the sagebrush biome and is a workhorse restoration species. Seeds of bluebunch wheatgrass were collected based on empirical seed zones, are currently being increased, and will be available for use by emergency stabilization and rehabilitation projects within the next few years (Shock et al. 2016; St. Clair et al. 2013). Additionally, seeds and plant materials that were developed prior to seed zone construction for a particular species, or initially collected without using an existing seed zone framework, can be incorporated into either generalized or empirical frameworks as long as the seeds or plant materials are source-identified. For example, several source-identified forb releases, that are important in the diets of sage-grouse, are being incorporated into the Bower et al. (2014) seed zone framework to be used in restoration (such as species identified in Johnson and Bushman 2016). Seeds and plant materials that are not specifically source-identified, or that have been selected over long time periods or from mixed stock, may be incorporated into the seed zone framework if their traits and characteristics are well known and can be placed in categories that fit seed zone models.

This appendix was prepared by Sarah M. Kulpa,
Fred Edwards, and Francis F. Kilkenney.

Appendix 12—Tables and Figures Summarizing the Relative Resilience and Resistance, Greater Sage-Grouse Breeding Habitat Probabilities, and Greater Sage-Grouse Breeding Populations for the Sagebrush Biome

This appendix was prepared by Jacob D. Hennig and Jeanne C. Chambers.

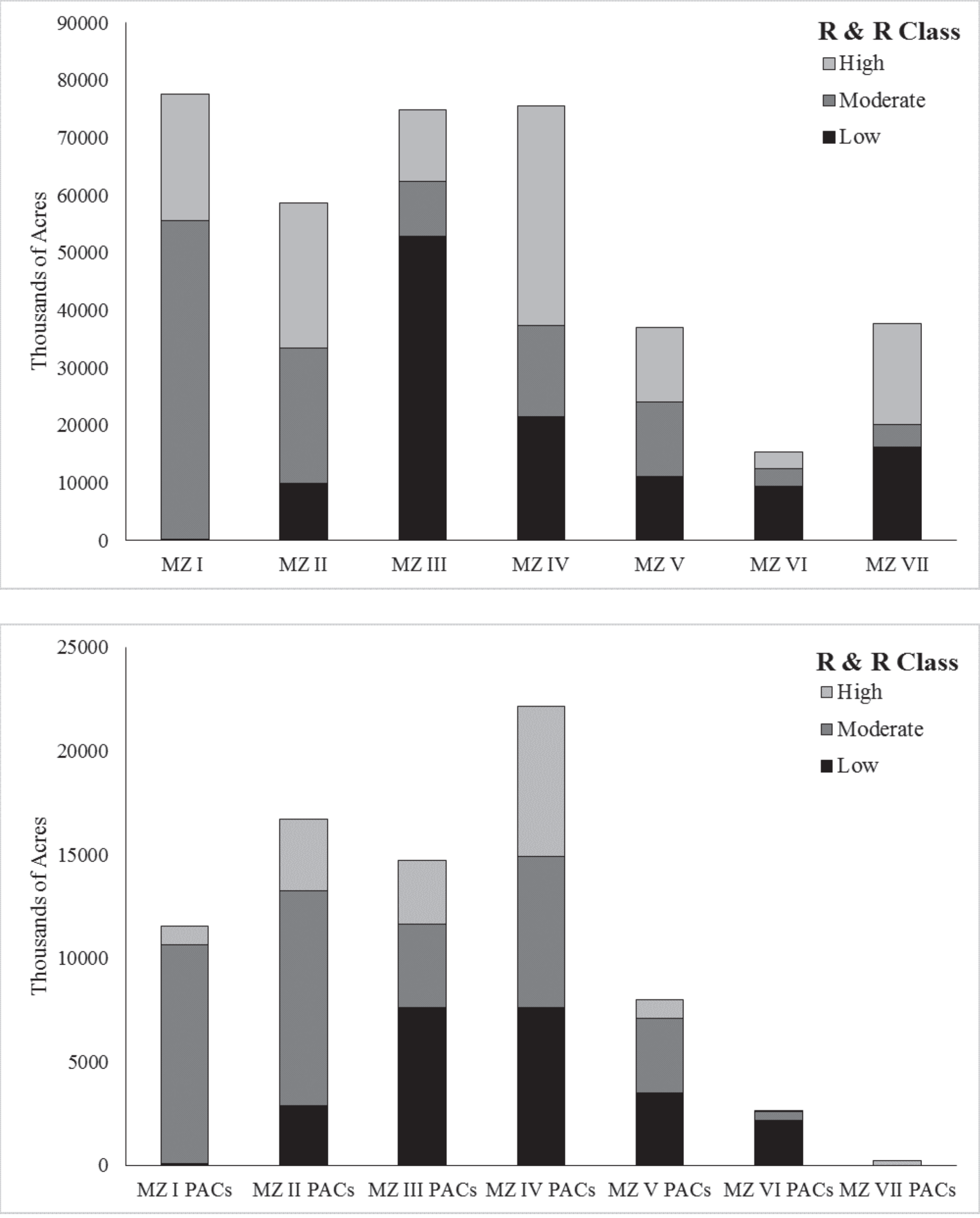


Figure A12.1—Relative resilience and resistance in thousands of acres for (A) the Management Zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone. The resilience and resistance categories are explained in Appendix 2.

Table A12.1—Area and percentage of resilience and resistance classes for (A) the Management Zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone.

A

Management	Resilience and resistance									
	High			Moderate			Low			Total
Zone	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres
MZ I	21,993,546	89,005	28	55,414,038	224,253	71	145,724	590	1	77,553,308
MZ II	25,270,281	102,265	43	23,466,452	94,966	40	9,913,884	40,120	17	58,650,618
MZ III	12,510,192	50,627	17	9,429,555	38,160	13	52,943,498	214,255	71	74,883,246
MZ IV	38,184,371	154,527	51	15,925,610	64,449	21	21,460,005	86,846	28	75,569,986
MZ V	12,945,989	52,391	35	12,970,545	52,490	35	11,090,422	44,881	30	37,006,957
MZ VI	2,879,898	11,655	19	3,041,919	12,310	20	9,393,392	38,014	61	15,315,210
MZ VII	17,614,769	71,285	47	3,830,409	15,501	10	16,297,510	65,954	43	37,742,688

B

Priority Areas for Conservation Management	Resilience and resistance									
	High			Moderate			Low			Total
Zone	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres
MZ I PACs	901,296	3,647	8	10,549,022	42,690	91	97,818	396	1	11,548,135
MZ II PACs	3,450,456	13,964	21	10,384,371	42,024	62	2,871,828	11,622	17	16,706,655
MZ III PACs	3,067,357	12,413	21	4,002,108	16,196	27	7,635,757	30,901	52	14,705,223
MZ IV PACs	7,244,058	29,316	33	7,264,048	29,397	33	7,643,628	30,933	35	22,151,734
MZ V PACs	899,886	3,642	11	3,564,318	14,424	45	3,512,093	14,213	44	7,976,298
MZ VI PACs	6,426	26	1	427,666	1,731	16	2,164,763	8,760	83	2,598,856
MZ VII PACs	210,705	853	90	20,400	83	9	2,121	9	1	233,226

Table A12.2—Area and percentage of Greater sage-grouse breeding habitat probability category for (A) the Management Zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone.

A

Management	Breeding Habitat Probability													
	High			Moderate			Low			Unsuitable			Total	
Zone	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres	km^2
MZ I	5,488,682	22,212	12	13,919,754	56,331	30	15,693,021	63,508	34	10,924,858	44,211	24	46,026,314	186,262
MZ II	6,586,037	26,653	18	13,311,428	53,870	36	11,330,253	45,852	31	5,647,767	22,856	15	36,875,485	149,230
MZ III	6,110,305	24,728	20	7,923,361	32,065	26	8,564,917	34,661	29	7,405,146	29,968	25	30,003,729	121,421
MZ IV	7,360,774	29,788	19	10,498,707	42,487	28	10,146,221	41,060	27	9,793,051	39,631	26	37,798,753	152,966
MZ V	2,033,547	8,229	11	4,317,304	17,472	23	5,363,839	21,707	28	7,288,409	29,495	38	19,003,098	76,903
MZ VI	876,498	3,547	35	621,157	2,514	25	508,757	2,059	20	500,605	2,026	20	2,507,016	10,146
MZ VII	114,492	463	10	386,027	1,562	33	532,736	2,156	45	147,250	596	12	1,180,506	4,777

B

Priority Areas for Conservation	Breeding Habitat Probability													
Management	High			Moderate			Low			Unsuitable			Total	
Zone	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres	km^2	%	Acres	km^2
MZ I PACs	3,914,390	15,841	33	5,328,819	21,565	46	2,170,323	8,783	19	291,090	1,178	2	11,704,623	47,367
MZ II PACs	5,285,823	21,391	31	7,406,972	29,975	43	3,564,243	14,424	21	882,906	3,573	5	17,139,944	69,363
MZ III PACs	5,085,621	20,581	34	4,950,779	20,035	33	3,439,187	13,918	23	1,509,144	6,107	10	14,984,731	60,641
MZ IV PACs	6,532,758	26,437	29	7,233,347	29,272	32	5,264,494	21,305	23	3,454,484	13,980	15	22,485,084	90,994
MZ V PACs	1,746,686	7,069	22	2,667,368	10,794	33	2,239,345	9,062	28	1,399,445	5,663	1	8,052,844	32,589
MZ VI PACs	861,457	3,486	35	609,859	2,468	25	497,192	2,012	20	480,956	1,946	20	2,449,464	9,913
MZ VII PACs	96,865	392	42	68,201	276	29	55,599	225	24	11,614	47	5	232,279	940

Table A12.3—Area and percentage of Greater sage-grouse breeding habitat probability category by resilience and resistance class for (A) the Management Zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone. Percentages for a Management Zone add to 100.

A

Breeding Habitat Probability	Resilience and Resistance					
	Low		Moderate		High	
	Acres	%	Acres	%	Acres	%
MZ I						
High	18,503	0	4,991,493	11	443,768	0
Moderate	69,366	0	12,986,234	29	720,665	2
Low	34,089	0	13,974,961	31	1,477,070	3
Unsuitable	12,319	0	7,503,099	17	3,241,274	7
Total	134,276	0	39,455,788	88	5,882,776	12
MZ II						
High	796,172	2	4,586,273	13	1,121,366	3
Moderate	2,144,299	6	8,979,738	25	1,975,062	5
Low	2,313,881	6	6,325,700	18	2,411,600	7
Unsuitable	2,328,125	6	1,574,251	4	1,571,550	4
Total	7,582,478	20	21,465,962	60	7,079,578	19
MZ III						
High	3,282,368	11	1,655,280	6	1,048,389	4
Moderate	4,343,197	15	2,033,276	7	1,345,451	5
Low	5,311,460	18	1,836,801	6	1,219,423	4
Unsuitable	5,488,860	19	748,057	3	902,338	3
Total	18,425,886	63	6,273,414	22	4,515,601	16
MZ IV						
High	1,827,805	5	2,723,165	7	2,688,714	7
Moderate	3,499,600	9	3,504,581	9	3,190,375	9
Low	4,293,957	12	2,823,101	8	2,774,042	8
Unsuitable	4,188,550	11	1,625,985	4	3,766,790	10
Total	13,809,912	37	10,676,833	28	12,419,922	34
MZ V						
High	542,091	3	1,330,346	7	138,436	1
Moderate	1,846,639	10	2,016,965	11	421,027	2
Low	2,321,041	13	2,278,551	13	622,480	3
Unsuitable	3,064,102	17	2,447,866	13	1,138,340	6
Total	7,773,873	43	8,073,728	44	2,320,283	12
MZ VI						
High	703,215	29	166,077	7	1,146	0
Moderate	466,683	19	124,915	5	982	0
Low	381,042	16	89,452	4	3,085	0
Unsuitable	447,209	19	29,210	1	875	0
Total	1,998,149	83	409,654	17	6,088	0
MZ VII						
High	1,530	0	4,277	0	108,532	9
Moderate	236,219	20	23,873	2	125,936	11
Low	173,717	15	102,109	9	256,693	22
Unsuitable	18,368	2	48,244	4	80,532	7
Total	429,833	37	178,503	15	571,693	49

(Continued)

Table A12.3—(Continued).

B **Breeding Habitat Probability**	**Resilience and Resistance**					
	Low		**Moderate**		**High**	
	Acres	**%**	**Acres**	**%**	**Acres**	**%**
MZ I PACs						
High	17,400	0	3,507,329	30	359,745	3
Moderate	59,363	1	4,882,662	42	301,332	3
Low	20,147	0	1,919,033	17	192,156	2
Unsuitable	911	0	238,578	2	47,959	0
Total	97,822	1	10,547,602	91	901,192	8
MZ II PACs						
High	673,119	4	3,547,203	21	993,466	6
Moderate	1,268,264	8	4,858,003	29	1,140,357	7
Low	799,051	5	1,734,161	10	881,707	5
Unsuitable	131,216	1	244,175	1	431,869	3
Total	2,871,650	18	10,383,542	61	21	
MZ III PACs						
High	2,714,174	19	1,434,391	10	839,004	6
Moderate	2,421,787	17	1,392,232	9	1,019,175	7
Low	1,667,920	11	962,210	7	738,129	5
Unsuitable	810,865	6	213,047	1	457,001	3
Total	7,614,745	53	4,001,880	27	3,053,309	21
MZ IV PACs						
High	1,647,168	7	2,445,083	11	2,328,631	11
Moderate	2,588,270	12	2,503,692	11	1,943,482	9
Low	2,085,224	9	1,648,712	7	1,439,786	7
Unsuitable	1,303,025	6	657,672	3	1,455,823	7
Total	7,623,687	34	7,255,160	32	7,167,721	34
MZ V PACs						
High	494,897	6	1,112,332	14	118,204	1
Moderate	1,325,037	17	1,105,710	14	219,886	3
Low	1,102,262	14	887,674	11	216,505	3
Unsuitable	569,967	7	453,059	6	343,722	4
Total	3,492,163	44	3,558,775	45	898,317	11
MZ VI PACs						
High	693,992	29	160,263	7	1,146	0
Moderate	458,613	19	121,744	5	982	0
Low	371,502	16	88,104	4	3,085	0
Unsuitable	435,285	18	28,762	1	875	0
Total	1,959,392	82	398,873	17	6,088	0
MZ VII PACs						
High	206	0	2,320	1	94,452	41
Moderate	1,591	1	3,512	2	63,245	27
Low	267	0	10,799	5	44,166	19
Unsuitable	25	0	3,384	1	8,156	4
Total	2,089	1	20,016	9	210,019	91

Table A12.4—Relative percentage of the Greater sage-grouse population by resilience and resistance class for (A) the Management Zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone.

A

Breeding Bird Density	Resilience and Resistance % Low	% Moderate	% High
MZ I			
High	0	72	8
Low	0	18	2
MZ II			
High	6	57	17
Low	4	13	3
MZ III			
High	38	23	19
Low	10	6	4
MZ IV			
High	15	28	37
Low	6	8	6
MZ V			
High	29	45	6
Low	8	9	3
MZ VI			
High	76	3	1
Low	16	3	1
MZ VII			
High	0	6	74
Low	0	5	15

B

Breeding Bird Density	Resilience and Resistance % Low	% Moderate	% High
MZ I PACs			
High	0	49	7
Low	0	6	0
MZ II PACs			
High	3	49	15
Low	2	6	1
MZ III PACs			
High	34	22	17
Low	3	4	6
MZ IV PACs			
High	34	26	14
Low	5	5	4
MZ V PACs			
High	5	43	28
Low	6	5	2
MZ VI PACs			
High	74	6	0
Low	15	5	0
MZ VII PACs			
High	0	1	67
Low	0	1	12

Appendix 13—Tables Summarizing Fire Area by Resilience and Resistance Category

This appendix was prepared by Jacob D. Hennig and Jeanne C. Chambers.

Table A13.1—Area and percentage of fires greater than1,000 acres (4 km^2) (MTBS 2014) that burned within the occupied range of Greater sage-grouse from 1984–1999 and from 2000–2015 by resilience and resistance category. Areas are included that may have burned more than once during the time span.

	Fire area					
Resilience and	**1984–1999**			**2000–2015**		
Resistance	**Acres**	**km^2**	**%**	**Acres**	**km^2**	**%**
MZ I						
High	113,935	461	21	147,621	597	14
Moderate	428,174	1,733	79	919,203	3,720	86
Low	0	0	0	0	0	0
Total	542,109	2,194	100	1,066,825	4,317	100
MZ II						
High	65,329	264	19	231,739	938	44
Moderate	154,704	626	44	275,368	1,114	52
Low	131,164	531	37	22,090	89	4
Total	351,198	1,421	100	529,197	2,142	100
MZ III						
High	106,223	430	5	161,181	652	7
Moderate	575,204	2,328	28	494,206	2,000	23
Low	1,380,173	5,585	67	1,529,378	6,189	70
Total	2,061,599	8,343	100	2,184,766	8,841	100
MZ IV						
High	914,415	3,701	24	1,537,599	6,222	20
Moderate	831,720	3,366	22	2,345,103	9,490	30
Low	2,044,719	8,275	54	3,989,292	16,144	50
Total	3,790,853	15,341	100	7,871,994	31,857	100
MZ V						
High	167,080	676	14	332,315	1,345	17
Moderate	456,263	1,846	37	865,852	3,504	42
Low	599,612	2,427	49	842,274	3,409	41
Total	1,222,955	4,949	100	2,040,441	8,257	100
MZ VI						
High	1,927	8	2	1,762	7	0
Moderate	29,802	121	26	106,284	430	32
Low	81,570	330	72	228,644	925	68
Total	113,299	459	100	336,691	1,363	100
MZ VII						
High	0	0	0	0	0	0
Moderate	0	0	0	0	0	0
Low	0	0	0	0	0	0
Total	0	0	0	0	0	0
Total						
High	1,368,908	5,540	17	2,412,217	9,762	17
Moderate	2,475,868	10,019	31	5,006,016	20,259	36
Low	4,237,237	17,148	52	6,611,679	26,757	47
Total	8,082,013	32,707	100	14,029,912	56,777	100

Table A13.2—Area and percentage of fires greater than 1,000 acres (4 km^2) (MTBS 2014) that burned within the Priority Areas for Conservation (PACs; FWS 2013) within each Management Zone (MZ; Stiver et al. 2006) from 1984−1999 and from 2000−2015 by resilience and resistance category. Areas are included that may have burned more than once during the time span.

Resilience and Resistance	Fire area 1984–1999 Acres	km^2	%	2000–2015 Acres	km^2	%
MZ I						
High	2,129	9	5	5,651	23	3
Moderate	40,590	164	95	159,219	644	97
Low	0	0	0	0	0	0
Total	42,719	173	100	164,870	667	100
MZ II						
High	32,978	133	14	35,245	143	22
Moderate	103,489	419	42	116,936	473	72
Low	106,843	432	44	10,147	41	6
Total	243,311	985	100	162,328	657	100
MZ III						
High	48,406	196	9	112,775	456	24
Moderate	192,863	780	35	162,367	657	34
Low	310,649	1,257	56	201,052	814	42
Total	551,918	2,234	100	476,194	1,927	100
MZ IV						
High	513,016	2,076	31	891,356	3,607	22
Moderate	442,928	1,792	26	1,611,892	6,523	41
Low	716,665	2,900	43	1,485,580	6,012	37
Total	1,672,609	6,769	100	3,988,828	16,142	100
MZ V						
High	39,151	158	9	208,092	842	16
Moderate	210,864	853	45	574,212	2,324	44
Low	214,153	867	46	518,924	2,100	40
Total	464,167	1,878	100	1,301,228	5,266	100
MZ VI						
High	1,927	8	2	1,762	7	0
Moderate	29,802	121	26	106,284	430	32
Low	80,836	327	72	227,592	921	68
Total	112,565	456	100	335,638	1,358	100
MZ VII						
High	0	0	0	0	0	0
Moderate	0	0	0	0	0	0
Low	0	0	0	0	0	0
Total	0	0	0	0	0	0
Total						
High	637,607	2,580	21	1,254,882	5,078	20
Moderate	1,020,536	4,130	33	2,730,910	11,052	42
Low	1,429,146	5,784	46	2,443,294	9,888	38
Total	3,087,289	12,494	100	6,429,086	26,018	100

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