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Using Resilience and Resistance Concepts to Manage Threats to Sagebrush Ecosystems, Gunnison Sage-Grouse, and Greater Sage-Grouse in Their Eastern Range: A Strategic Multi-Scale Approach

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Abstract

This report provides a strategic approach developed by a Western Association of Fish and Wildlife Agencies interagency working group for conservation of sagebrush ecosystems, Greater sage-grouse, and Gunnison sage-grouse. It uses information on (1) factors that influence sagebrush ecosystem resilience to disturbance and resistance to nonnative invasive annual grasses and (2) distribution and relative abundance of sage-grouse populations to address persistent ecosystem threats, such as invasive annual grasses and wildfire, and land use and development threats, such as oil and gas development and cropland conversion, to develop effective management strategies. A sage-grouse habitat matrix links relative resilience and resistance of sagebrush ecosystems with modeled sage-grouse breeding habitat probabilities to help decisionmakers assess risks and determine appropriate management strategies at both landscape and site scales. Areas for targeted management are assessed by overlaying matrix components with Greater sage-grouse Priority Areas for Conservation and Gunnison sage-grouse critical habitat and linkages, breeding bird concentration areas, and specific habitat threats. Decision tools are discussed for determining the suitability of target areas for management and the most appropriate management actions. A similar approach was developed for the Great Basin that was incorporated into the Federal land use plan amendments and served as the basis of a Bureau of Land Management Fire and Invasives Assessment Tool, which was used to prioritize sage-grouse habitat for targeted management activities.

Keywords: sagebrush habitat, Greater sage-grouse, Gunnison sage-grouse, persistent ecosystem threats, land use and development threats, climate change, management prioritization, conservation, restoration

Front Cover Photo. Expansive big sagebrush in sage-grouse Management Zone II (photo by M. Evans) with male Greater sage-grouse on road inset (photo by C.P. Kirol).
Inside Cover Photo. Sage-grouse lek in Sublette County, Wyoming (photo by T. Christiansen).
Back Cover Photo. Male Greater sage-grouse in a sagebrush ecosystem in Management Zone I (photo by C. Duchardt).

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Contents

1. Purpose and Use of this Document

The primary purpose of this report is to (1) facilitate large-scale prioritization of limited resources across administrative boundaries to address persistent ecosystem threats, (2) provide a unifying framework to communicate relative risks, and (3) assist in determining appropriate management strategies to promote both species and ecosystem persistence at multiple scales. An approach is provided that links information on ecosystem resilience to disturbance and resistance to invasive plant species with data on species habitat and population abundance. A key aspect of the process is prioritizing areas for management at the scale of ecoregions or Management Zones. Once these priority areas for management are determined, they are used to inform budget prioritization and to ensure consistent allocation of funds.

Ecoregion or Management Zone priorities are stepped down to local scales by engaging managers and stakeholders to refine priorities based on higher resolution geospatial products and more detailed species information and to identify opportunities to leverage partner resources. The ultimate goal is to ensure that enough of the right actions are implemented in the right places, consistently through time, to maintain the distribution and abundance of functioning sagebrush ecosystems and sage-grouse. This approach is consistent with prioritizations and management strategies already being applied by local land managers, but places those actions into a broader context and helps to justify the need to sustain or enhance conservation and restoration investments.

This document is divided into parts that can be used by the reader to gain an understanding of (1) the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems, Greater sage-grouse (*Centrocercus urophasianus,* hereafter GRSG), and Gunnison sage-grouse (*Centrocercus minimus*, hereafter GUSG), (2) the key concepts and approach used to prioritize areas for management and develop effective management strategies, and (3) the necessary information for determining appropriate management treatments. Users of the document will find the rationale for this report in section "2. Introduction." Individuals who are unfamiliar with the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems, GRSG, and GUSG can access that information in sections "3. Climatic Regimes and Vegetation Types," and "4. Threats to Sagebrush Ecosystems, Greater Sage-Grouse, and Gunnison Sage-Grouse," 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 "5. Resilience to Disturbance and Resistance to Nonnative Invasive Plant Species." The key elements of the approach are in sections "6. Integrating Resilience and Resistance Concepts with Sage-Grouse Habitat Requirements to Prioritize Areas for Management and Inform Management Strategies," and "7. Delineating Habitats for Targeted Management Intervention at the Ecoregional/Management Zone Scale," and will be of interest to all users. Section "8. Determining Appropriate Management Treatments at the Local Scales" provides information and examples and also will be of general interest.

Geospatial data, maps, and models are provided through the U.S. Geological Survey 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) to assist managers in implementing the resilience-based approach described herein. Handbooks and guides for implementing this approach are available for the western portion of the sagebrush biome that can be adapted to the eastern portion of the sagebrush biome (Miller et al. 2014, 2015; Pyke et al. 2015a,b).

2. Introduction

Sagebrush (*Artemisia* spp.) ecosystems are among the largest and most imperiled ecosystems in North America (Noss et al. 1995). Sage-grouse and the more than 350 other species that rely on sagebrush ecosystems (Suring et al. 2005) face widespread habitat loss due to multiple, interacting threats. The GRSG has been considered for Federal regulatory protections under the Endangered Species Act eight times (USFWS 2015). The GUSG was designated as threatened (USFWS 2014a) with 1.4 million acres (566,000 ha) designated as critical habitat under the Endangered Species Act in 2014 (USFWS 2014b). Concern over GRSG and GUSG and their associated habitats has set in motion Federal and State land management policy changes and proactive conservation actions to address threats within the realm of management control (Western Governors Association 2015). However, persistent ecosystem threats, such as invasive species and altered disturbance regimes, interact with land uses and development threats, such as oil and gas development and cropland conversion, and remain widespread issues that require sustained management effort (see Goble et al. 2012; Scott et al. 2010). To address these threats, a strategic, multi-scale approach based on resilience science has been developed for the western portion of the GRSG range (Chambers et al. 2014a). This approach provides the framework for wildland fire operations, post-fire rehabilitation, fuels management, and restoration/recovery strategies, and has been used as the basis for prioritization of GRSG conservation resources at national and regional scales (USDA NRCS 2015b; USDI BLM 2014). In this report, we develop a similar approach for the GUSG range and the eastern portion of GRSG range that can be used to help prioritize areas for management and determine the most effective management strategies based on an area's resilience to disturbance and resistance to nonnative invasive plants, particularly invasive annual grasses.

Two different types of threats impact sagebrush ecosystems and sage-grouse in the eastern portion of the range. Persistent ecosystem threats—invasion of nonnative invasive plants, altered fire regimes, conifer expansion, and climate change (Miller et al. 2011)—are difficult to regulate and must be managed using ecologically based approaches (Boyd et al. 2014b; Evans et al. 2013). In contrast, threats due to land uses and development—energy development, conversion to cropland, livestock grazing, mining, and urban, suburban, and exurban development—can be regulated on public land. These two 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 land use and development threats have been extensively studied or reviewed in recent years (see Hanser et al. 2011; Knick and Connelly 2011; Manier et al. 2014). In this report, we focus on persistent ecosystem threats and the secondary effects of land use and development on ecosystems such as invasion of nonnative plant species. Importantly, the same types of ecologically based approaches used to manage persistent ecosystem threats can be used to minimize impacts and increase restoration effectiveness of habitats affected by land use and development.

Resilience science has been used to provide a conceptual basis for conservation planning (Curtin and Parker 2014; Fischer et al. 2009). Spatially explicit knowledge of how ecosystem resilience and resistance vary across large landscapes can provide the basis for threat management (Rowland and Wisdom 2009; Wisdom and Chambers 2009). ***Resilient*** ecosystems have the capacity to ***reorganize and regain*** their fundamental structure, processes, and functioning when altered by stressors like invasive species, climatic factors such as drought, and disturbances such as overgrazing by livestock and altered fire regimes (Holling 1973). (See Appendix 1 for definitions used in this report.) ***Resistant*** ecosystems have the capacity to ***retain*** their fundamental structure, processes, and functioning when exposed to stressors, disturbances, or invasive species (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 limit 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 invasive plants, it is possible to assess and predict how they will respond to persistent threats and management actions over large planning areas.

Species are likely to be more resilient if connected populations exist in large blocks of high quality habitat across the full breadth of environmental conditions to which the species is adapted (Redford et al. 2011). Greater sage-grouse is a broadly distributed and wide ranging species that can move long distances between seasonal habitats (Connelly et al. 2011a,b; Fedy et al. 2012; Tack et al. 2011), and threat management necessarily requires a strategic, multi-scale approach that integrates both landscape prioritization and site-scale decision tools. Because of its widespread distribution and the broad range of sagebrush habitats that sage-grouse use, managers have considered GRSG an umbrella species for identifying ecological conditions required for a larger set of sagebrush-obligate species across large landscapes (Hanser and Knick 2011; Rowland et al. 2006). Holistic management approaches based on resilience science that address large-scale threats to GRSG and GUSG habitat should benefit sagebrush ecosystems and most sagebrush obligate species (see Evans et al. 2013).

The use of resilience science has recently been fully operationalized for conservation of sagebrush ecosystems and GRSG in the Cold Desert ecoregions of the western portion of the GRSG range (Management Zones III, IV, and V; Chambers et al. 2014a). Here, we expand the approach that was developed to include the eastern portion of the range (Management Zones I, II, and VII identified in Stiver et al. 2006), which differs from western GRSG range in the magnitude of ecosystem versus land use and development threats and encompasses a different set of climatic regimes and vegetation types. We first discuss the climatic regimes and vegetation types that characterize the ecoregions in Management Zones I, II, and VII and review the primary threats to sagebrush ecosystems, GRSG, and GUSG in these ecoregions. We then discuss factors that determine ecosystem resilience to stressors and disturbances and resistance to nonnative invasive annual grasses in these ecoregions, and we provide an overview of the relative resilience and resistance of the predominant ecological types. We develop a sage-grouse habitat matrix in which we link the information that we developed on relative resilience to disturbance and resistance to nonnative invasive annual grasses with breeding habitat probabilities (Doherty et al. 2016) to both identify priority areas for management and determine effective management strategies at landscape scales. We also provide an approach for targeting areas for habitat management that overlays Priority Areas for Conservation (USFWS 2013) for GRSG, critical habitat for GUSG (GSGRSC 2005, as updated; USFWS 2014a), and breeding bird population indices with resilience to disturbance and resistance to invasive annual grasses to spatially link sage-grouse populations with indicators of habitat conditions and risks. Finally, we review the tools and data available for assessing the suitability of targeted areas for treatment and determining the most appropriate management treatments. Throughout the report, we emphasize the importance of providing information that can help guide management and restoration strategies to maintain or enhance GRSG and GUSG habitat.

3. Climatic Regimes and Vegetation Types

The eastern portion of GRSG range is characterized by different ecoregions that vary with respect to the type and extent of sagebrush habitat and persistent ecosystem threats. Here, we use Level II and Level III Environmental Protection Agency Ecoregions as the basis for describing these differences. The eastern portion of the range encompasses three Level II and six Level III ecoregions: the Cold Desert, which includes the Wyoming Basin and Colorado Plateau; West-Central Semiarid Prairies, which includes the Northwestern Glaciated Plains and Northwestern Great Plains; and Western Cordillera, which includes the Middle Rockies and Southern Rockies (fig. 1; Griffith 2010). Each of these ecoregions is characterized by distinct temperature and precipitation regimes (fig. 2) and differs in the amount of precipitation received in winter vs. summer (fig. 3). Greater sage-grouse Management Zones were based largely on these ecoregional differences, and the relationships between the two land classifications are shown in figure 1.

Differences in overlap between seasonality of precipitation and temperature, and onset of the dry season, are of particular importance in determining ecoregional differences. These differences, especially when coupled with 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). Amount of precipitation that is received during the period when temperature and potential evapotranspiration are 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/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 factor influencing the balance between C3 and C4 (cool and warm season) species with C3 species such as wheatgrasses (e.g., *Agropyron* and *Elymus* spp.) dominating in areas with cool, wet springs and C4 species such as grama grasses (*Bouteloua* spp.) dominating in areas with warm, wet summers (Paruelo and Lauenroth 1996; Sala et al. 1997). These differences are reflected in the land cover of sagebrush for the eastern portion of the range (figs. 5, 6).

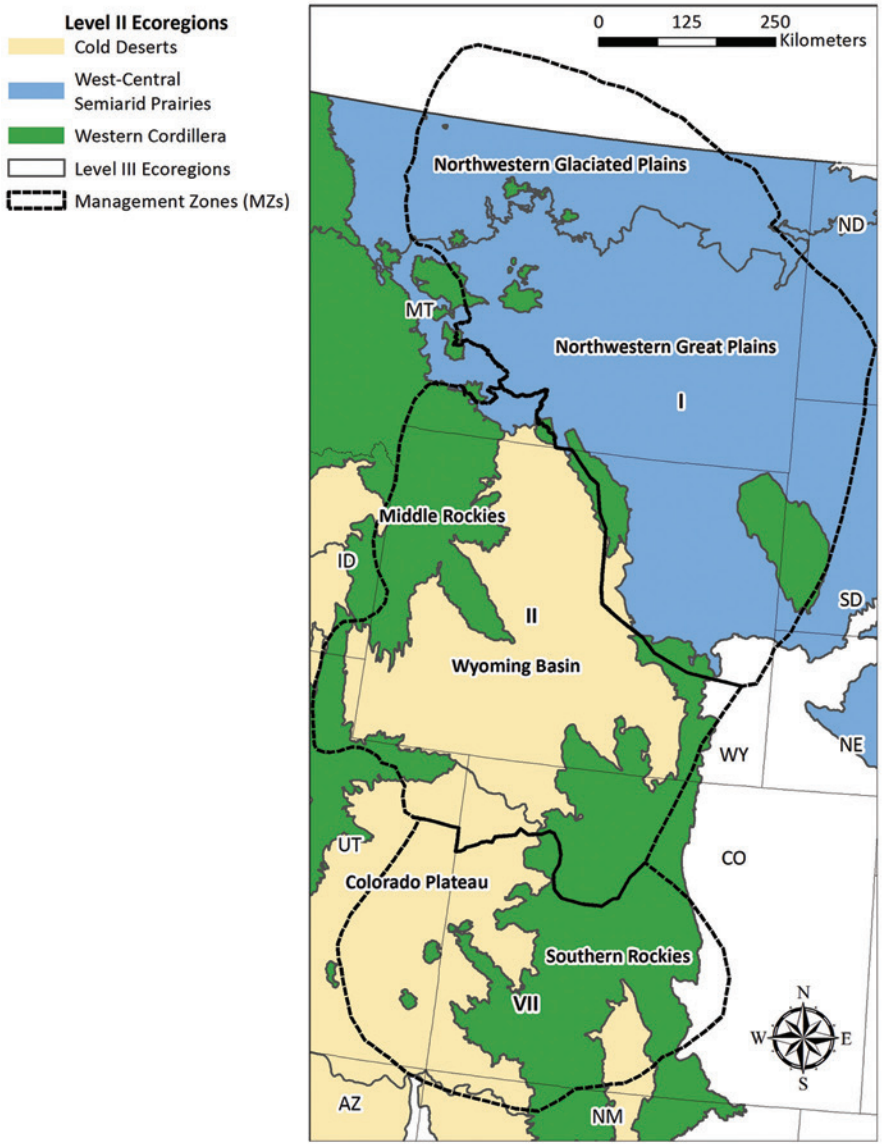


Figure 1—The Level II and Level III Ecoregions (EPA 2016) occurring in Management Zones I, II, and VII (Stiver et al. 2006).

Resistance to *Bromus* species generally increases as summer precipitation and amount of precipitation increase (fig. 4c) as a function of increasing 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 nonnative invasive plants (Bradford and Lauenroth 2006; Knight et al. 2014; Lauenroth et al. 2014).

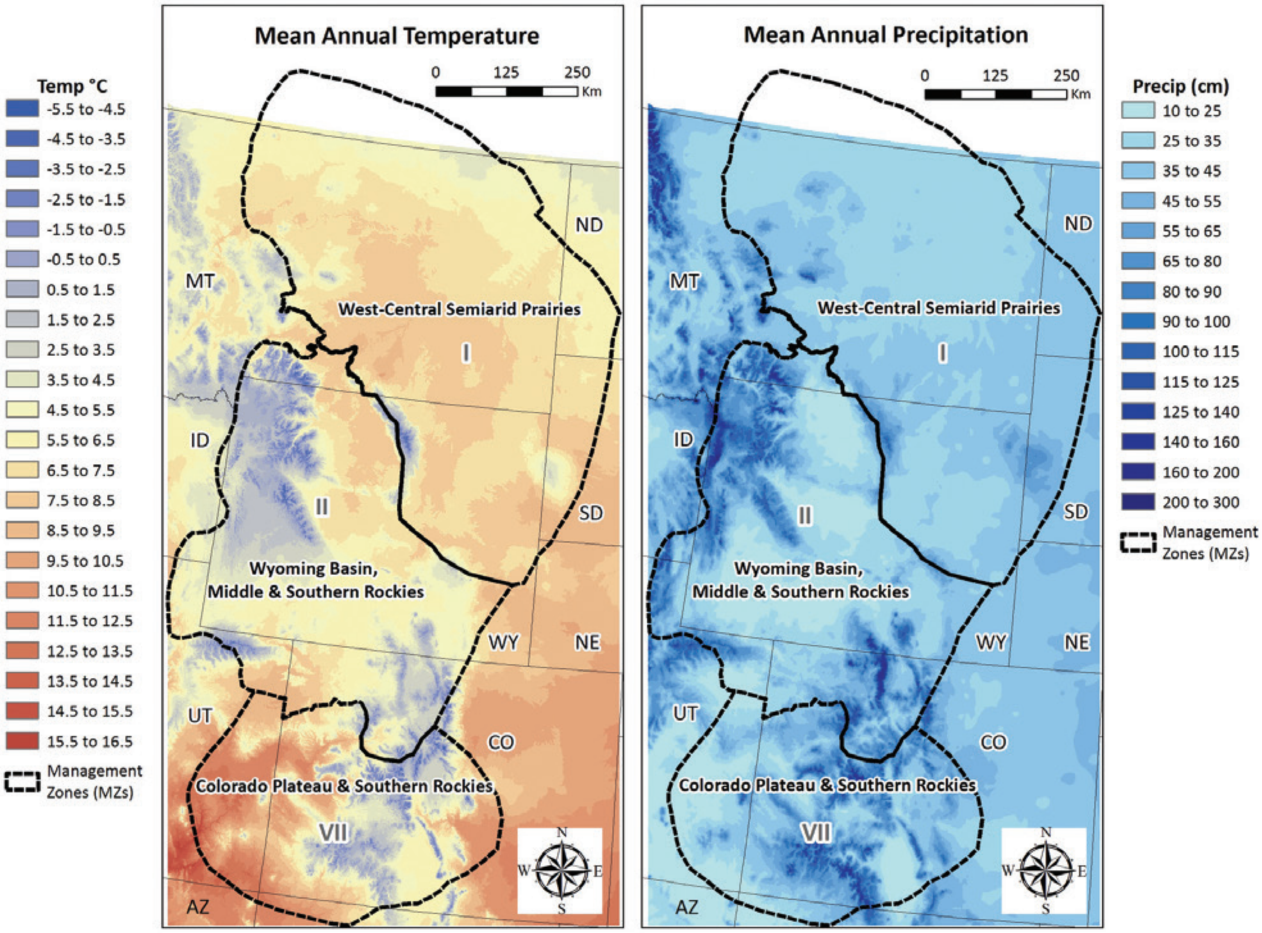


Figure 2—The 30-yr normal annual values for precipitation and temperature (PRISM) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

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 (USDA NRCS 2016) and thus can be used in large-scale analyses (Maestas et al. 2016). (See Appendix 2 for an explanation of soil temperature and moisture regimes.) Also, they are a key component of Ecological Site Descriptions— part of a widely used land classification system that describes the potential of a set of climatic, topographic, and soil characteristics to support a dynamic set of plant communities and provide necessary information for determining the most appropriate management actions at site scales (Caudle et al. 2013; USDA NRCS 2015a). The soil temperature and moisture regimes that characterize sagebrush ecosystems in the eastern range vary due to the large latitudinal difference and elevation gradients that the area encompasses as well as the variation in seasonality of precipitation (fig. 7).

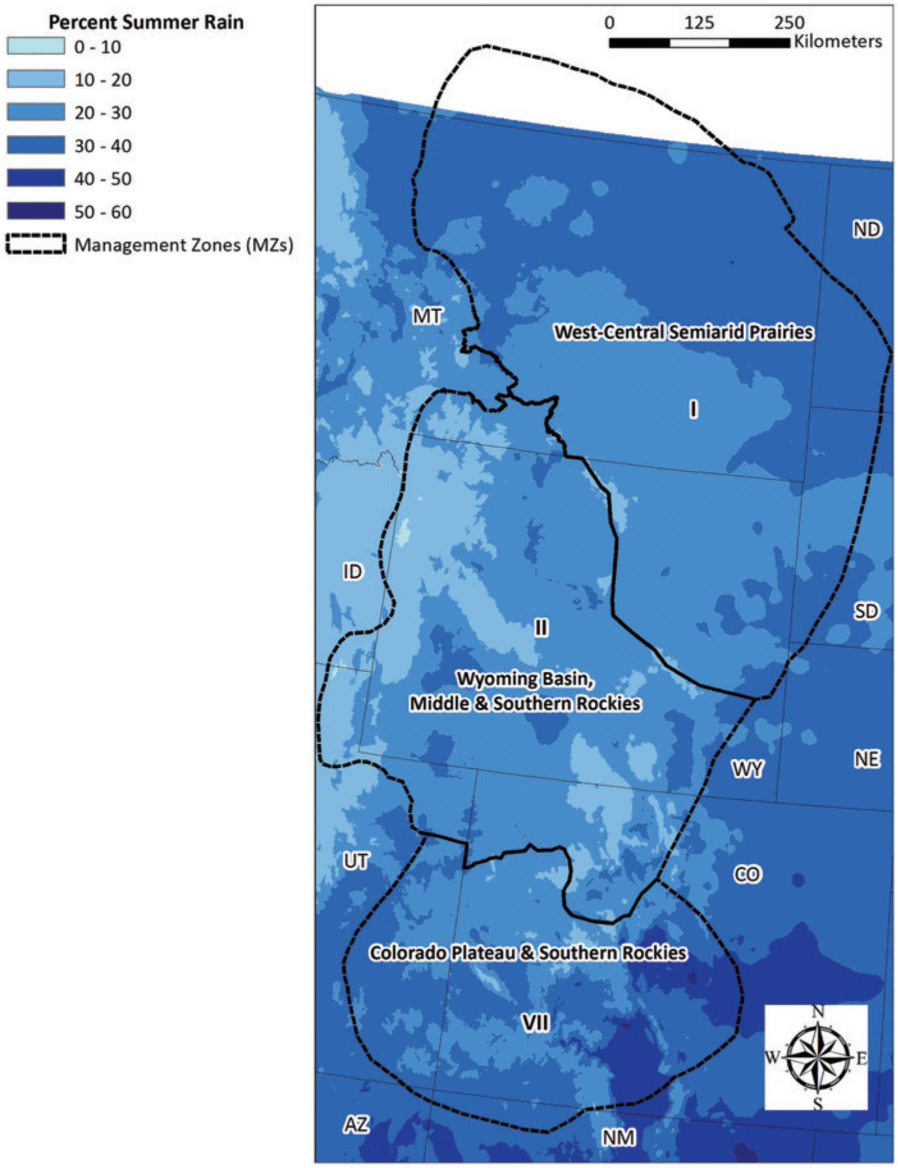


Figure 3—Percentage of annual precipitation occurring during the months of July, August, and September (PRISM) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

As with most large-scale mapping products, there are limitations in using Soil Survey information including incongruities in soil regime classifications, especially along mapping boundaries, and variation in the level of survey detail available. However, these areas represent a relatively minor component of the data set and have been taken into account in this report. Until improved products emerge, the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) still provides the most complete data set to advance understanding of resilience and resistance concepts across the sagebrush biome. Project level planning can be informed by local climate and soils data.

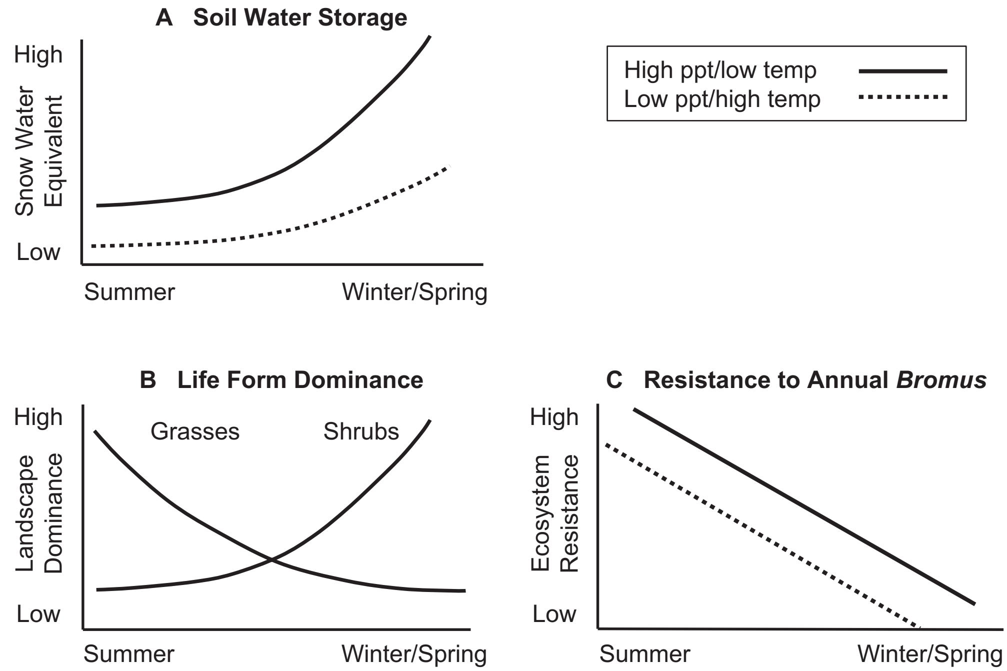


Figure 4—Changes in soil water storage, life form dominance, and resistance to annual *Bromus* as seasonality of precipitation transitions from primarily summer to winter. **A.** Soil water storage increases as winter/spring precipitation and snow water equivalent increase and these changes are relatively 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 (based on Chambers et al. 2016a).

West-Central Semiarid Prairies is represented by the Northwestern Glaciated Plains in northern Montana and the Northwestern Great Plains in the west and central Dakotas, southeast Montana, and northeast Wyoming (Griffith 2010). The Northwestern Glaciated Plains are comprised of rolling hills and gentle plains mantled by glacial till, outwash, and glaciolacustrine sediments, while 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. Mean annual temperatures range from 37.4 °F to 47.3 °F (3 °C to 8.5 °C), while mean annual precipitation ranges from 9.8 inches to 21.6 inches (25 cm to 55 cm). 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.

Cook and Irwin (1992) evaluated vegetation characteristics along a west to east gradient at 14 study sites between Idaho and the Dakotas. They found that shrub cover diminished and graminoid cover increased at relatively constant rates across

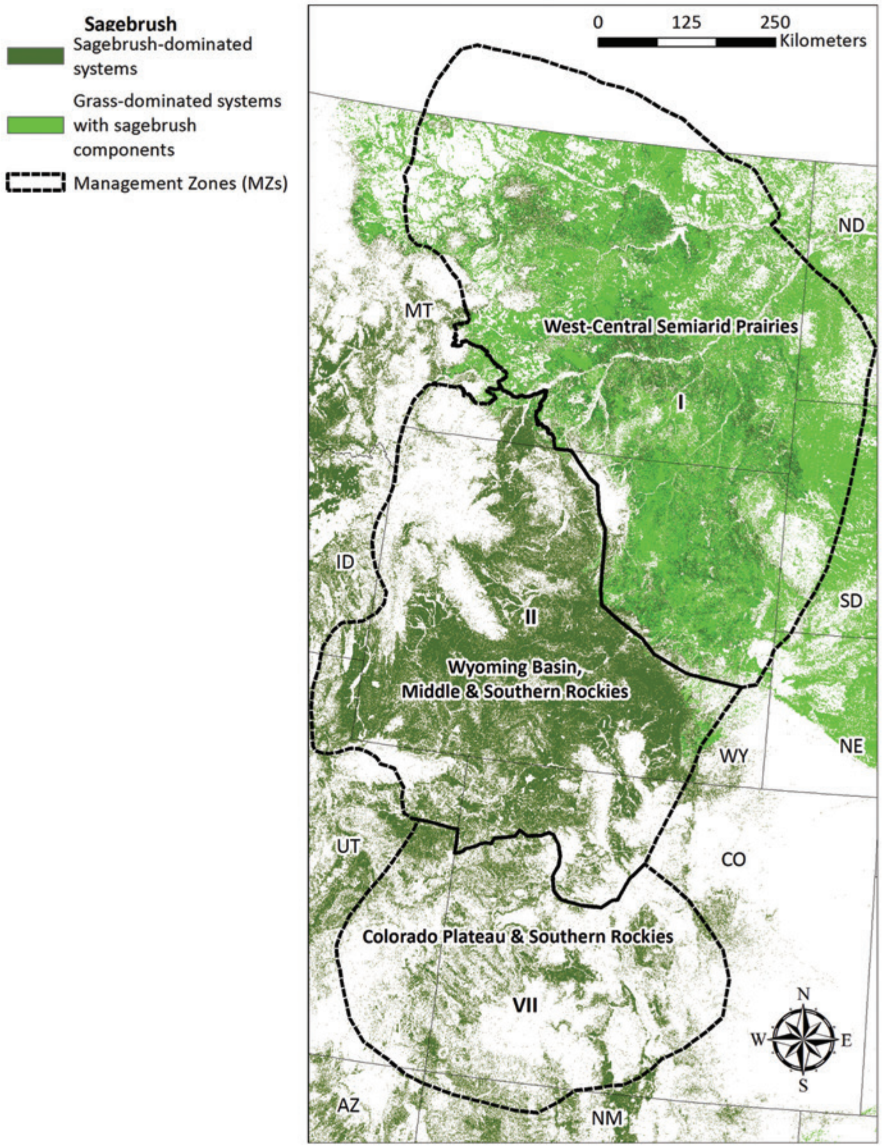


Figure 5—Sagebrush-dominated ecological systems and grass-dominated ecological systems with sagebrush components (USGS 2014) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

this west to east gradient. Graminoid cover was positively associated with increased summer precipitation, whereas shrub cover was positively correlated with winter precipitation. Thus, climate patterns of 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. tridentata* ssp. *tridentata*) (Miller et al. 2011; USGS 2013). Dominant grasses include wheatgrasses (*Pascopyrum smithii* and *Elymus* spp.), grama grasses (*Bouteloua* spp.), bluestem species (*Andropogon gerardii, Schizachyrium scoparium*), and needlegrasses (*Hesperostipa spp., Nasella spp.*, and *Achnatherum spp.*), which vary widely in relative abundance in response to climate, drought conditions, and grazing pressure (Barker and Whitman 1988).

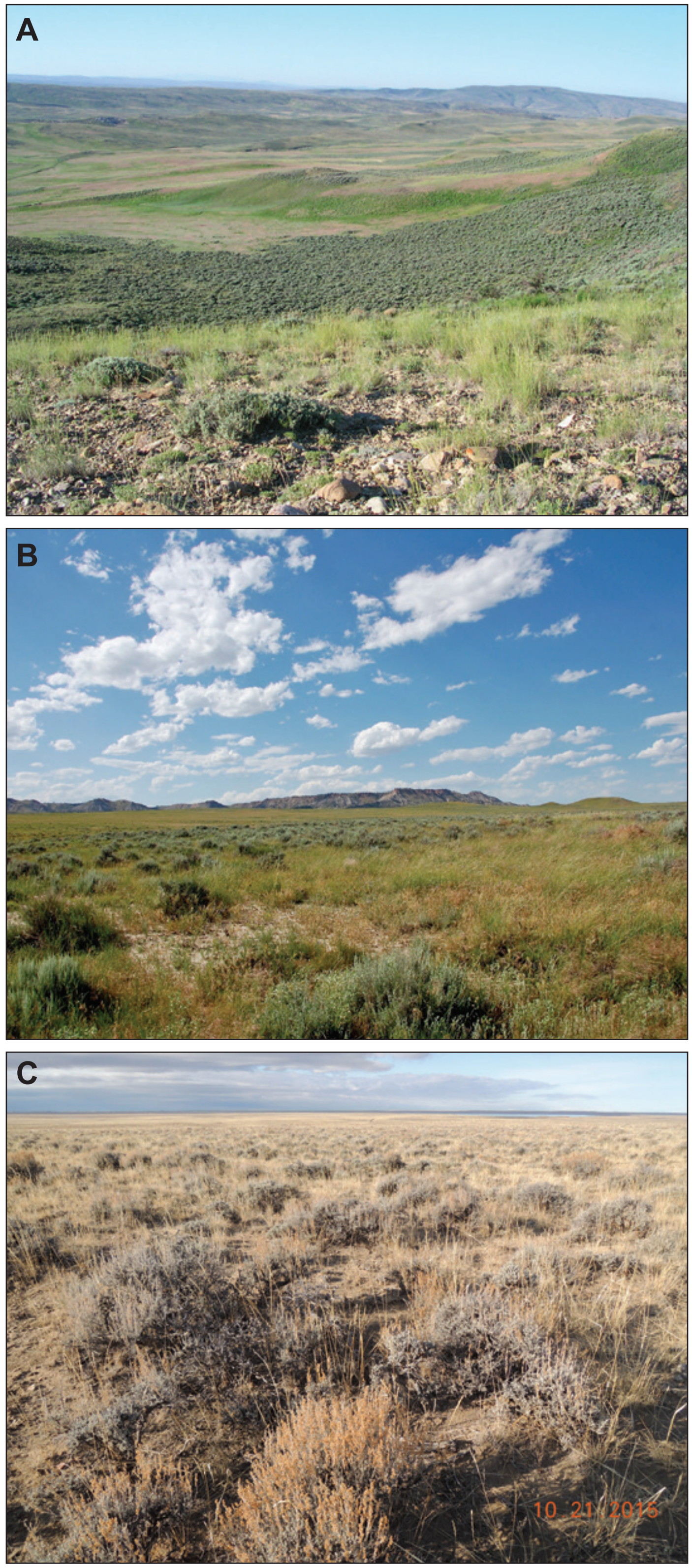


Figure 6—Representative Wyoming big sagebrush ecological types in (A) the Powder River Basin in the West-Central Semiarid Prairies (Management Zone I) (photo by C. P. Kirol), (B) the Rochelle hills in eastern Wyoming (Management Zone I) (photo by C. Duchardt), and (C) the Wyoming Basin in the Cold Desert (Management Zone II) (NRCS file photo).

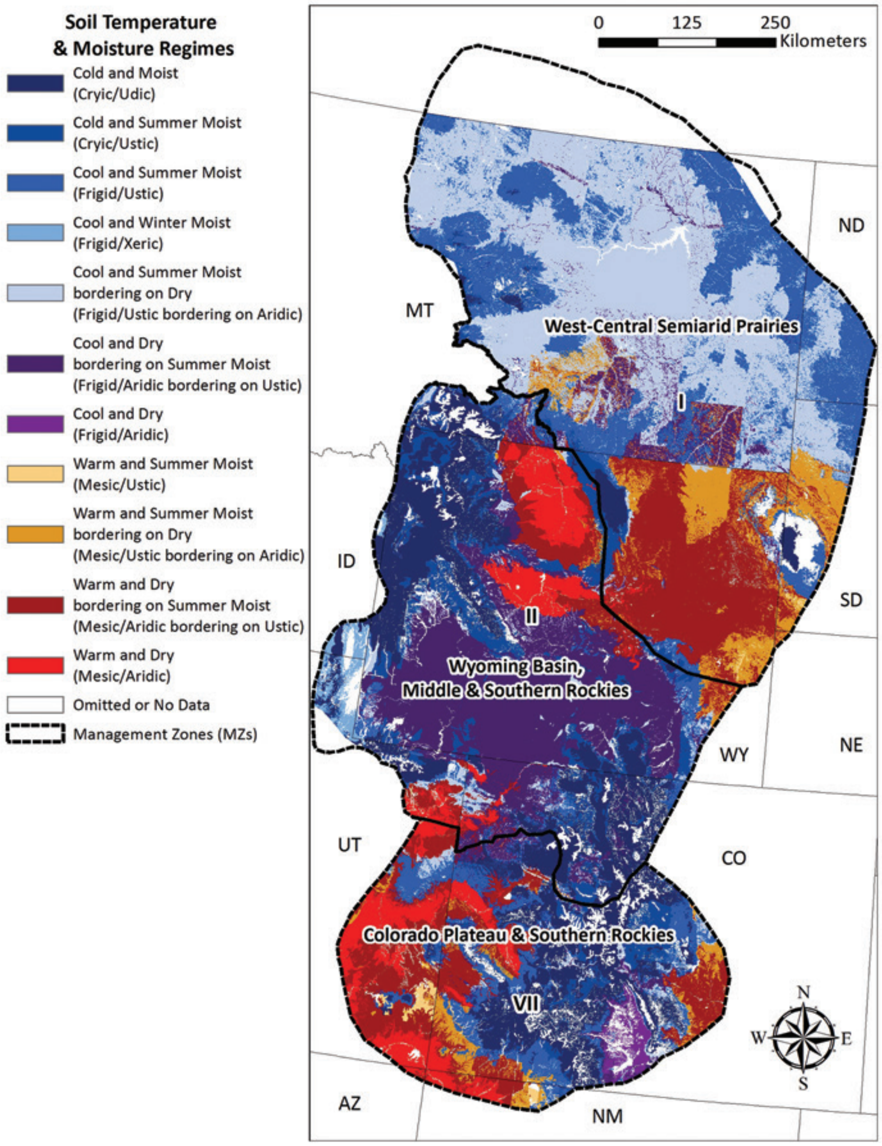


Figure 7—Soil temperature and moisture regimes by soil moisture subclass in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). See Appendix 2 for an explanation of the soil temperature and moisture regime data used in this report. The area near the border between southeastern Montana and northeastern Wyoming is in a transition zone between the frigid and mesic soil temperature regimes, which has resulted in an apparent abrupt change in temperature regime at the State border. Future updates to soil survey information will resolve these join issues along political boundaries, using current climate datasets and additional field data.

The Cold Desert in the eastern part of the sage-grouse range includes the Wyoming Basin in the western and central portions of Wyoming, and the Colorado Plateau in eastern and southern Utah and western Colorado. 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).

The Cold Desert ecoregion in general has a continental climate with warm to hot and dry summers and cool to cold and wet winters. In the Wyoming Basin, mean annual temperature ranges from about 32 °F to 46.4 °F (0 °C to 8 °C) and mean annual precipitation ranges from 5.1 in to 19.7 in (13 cm to 50 cm). In the warmer Colorado Plateau, mean annual temperature ranges from approximately 41 °F (5 °C) at high elevations in the north to 59 °F (15 °C) in southern canyons, and mean annual precipitation ranges from 5.1 in (13 cm) at lower elevations in the south to more than 31.5 in (80 cm) at high elevations. Cool and warm (frigid and mesic) soil temperature regimes and dry and summer moist (aridic and ustic) soil moisture regimes occur in the Cold Desert ecoregion.

Vegetation is characterized largely by arid to semiarid shrublands that transition from zero to a few warm season grasses west of the Continental Divide, to warm season grasses as a major component east of the Continental Divide (Griffith 2010). 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. arbuscular* ssp. *longiloba*) occurs on sites with higher precipitation and clay content. Basin big sagebrush (*A. tridentata* ssp. *tridentata*) 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 Desert and Western Cordillera Ecoregions at mid elevations, Wyoming big sagebrush transitions into mountain big sagebrush, and at higher elevations mountain big sagebrush co-occurs with mountain shrubs (e.g., Saskatoon serviceberry [*Amelanchier alnifolia*], 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*) co-mingles with Utah juniper.

The Western Cordillera is represented by the Middle Rockies (which 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) (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. In the Middle Rockies, mean annual temperatures range from approximately 23 °F to 46.4 °F (–5 °C to 8 °C) and precipitation ranges from 11.8 in (30 cm) to over 98.4 in (250 cm). Soil temperature regimes are cool to cold (frigid to cryic), and soil moisture regimes are summer moist and wet and humid (ustic and udic). In the Southern Rockies, mean annual temperatures range from about 24.8 °F to 51.8 °F (–4 °C to 11 °C), and precipitation ranges from 9.8 in (25 cm) to over 68.9 in (175 cm). Soil temperature regimes range from warm to cold (mesic to cryic), and moisture regimes range from dry to wet and humid (aridic to udic).

Dominant sagebrush species at higher elevations are mountain big sagebrush, low sagebrush (*A. arbuscula*), silver sagebrush, three-tip sage (*A. tripartita*), and spiked big sage (*A. tridentata* ssp. *spiciformis*), and at lower elevations are Wyoming big sagebrush and black sagebrush (Knight et al. 2014). 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. The Middle Rockies and Southern Rockies are characterized by many of the same grass species as the Cold Desert ecoregions (fig. 1) including wheatgrasses, needlegrasses, fescues, and bluegrasses.

4. Threats to Sagebrush Ecosystems, Greater Sage-Grouse, and Gunnison Sage-Grouse

The relative importance of persistent ecosystem threats versus land use and development threats for GRSG was summarized in the Sage-Grouse Conservation Objectives Final Report (COT Report; USFWS 2013) based on known occurrence of threats, existing management strategies, and professional experience. Threats to GUSG are summarized in the Gunnison Sage-grouse Rangewide Conservation Plan (GSGRSC 2005) and the final U.S. Fish and Wildlife Service listing decision (2014a). Here we discuss these threats for the GRSG habitat in the eastern portion of the range and for GUSG habitat range-wide to inform a resilience and resistance approach. We focus on the effects of persistent ecosystem threats and the secondary ecosystem threats of land use and development. Because the Cold Desert transitions into the Western Cordillera and have similar threats, we combine them for this discussion.

4.1 *Persistent Ecosystem Threats*

West-Central Semiarid Prairies (Management Zone I)

Herbivory, in conjunction with fire, has significantly influenced plant community composition, structure, and production of plant communities in the West-Central Semiarid Prairies (Knapp 1996). Historically, 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). Grazing by bison occurred across large areas as huge herds moved through, and the impacts of these herds on the vegetation, soils, and riparian areas were probably extensive. The interval between grazing episodes may have ranged from 1 to 8 years (Malainey and Sherriff 1996). Knopf (1996) suggests that the mixed and short-grass prairies comprising the West-Central Semiarid Prairies supported not only a significant portion of the North American bison population, but also the highest densities of black-tailed prairie dogs (*Cynomys ludovicianus*). 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 also presumed to be extensive (Lockwood and DeBrey 1990). Managed domestic livestock grazing (mostly cattle) has largely replaced these herbivores across the landscape and their impacts on grassland habitats are different in scale and duration.

Drought also played an important role in the composition of plant communities in this ecoregion, and it resulted in temporal changes in the dominant graminoid species (e.g., shifts from western wheatgrass to blue grama; Bragg and Steuter 1996). Large fires often occurred, but fire regimes were probably highly variable depending on rainfall and subsequent grass growth (Umbanhowar 1996). The burns removed much of the vegetation, which resulted in continual shifts in the abundance and distribution of herbivores across large areas. In turn, drought and grazing by bison and/or locusts mediated the direction and extent of vegetation response (Umbanhowar 1996).

Euro-American settlement had profound impacts on this ecoregion. Prior to settlement, fire likely limited expansion of shrub communities, including sagebrush and, along with herbivory, fire was considered a significant disturbance in the West-Central Semiarid Prairies. Anthropogenic changes in landscape patterns resulting from Euro-American settlement reduced the extent and distribution of fires and likely resulted in increased shrub abundance. Numerous fires have burned in this ecoregion in the past 15 years, but most large fires have occurred within conifer dominated ecosystems and outside of sage-grouse Priority Areas for Conservation (fig. 8).

After Euro-American settlement, bison were removed from the landscape and 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. These areas were the breeding habitat for the Rocky Mountain locust, and conversion to cropland was presumably a primary driver of their extinction (Lockwood and Debrey 1990).

A number of homestead claims were filed on lands that were not suitable for non-irrigated agricultural development. Following the severe drought ("dust-bowl") years of the 1930s, portions of the area with a high number of failed homesteads were reacquired by the Federal government under the Bankhead Jones Farm Tenant Act (1937, as amended). The Bankhead Jones Act included provisions for development of a land conservation and utilization program. Land considered submarginal for cropland was purchased, rehabilitated, and used for purposes for which it was better suited (Maddox 1937).

Under management of the U.S. Department of Agriculture, conservation measures were taken to restore water and soil resources that included planting non-native grass species. Several introduced seeded species became widely naturalized, including crested wheatgrass (*Agropyron cristatum*) (Lesica et al. 1996). More recently, sweet clover (*Melilotus officinalis*), Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*), timothy (*Phleum pratense*), annual bromes, and leafy spurge (*Euphorbia esula*) have altered native communities. Land use and development uses as well as climate change in this ecoregion may exacerbate effects of these species on sagebrush communities

The West-Central Semiarid Prairies align with Management Zone I and in a recent analysis included 12.4 percent of the total GRSG population based on lek counts from 2010 to 2014 (fig. 9; Doherty et al. 2016). In this analysis, variables showing the highest importance for predicting breeding habitat were: tree canopy cover (negatively associated), cover of all sagebrush species (positively associated), terrain roughness (quadratic relationship), topographic wetness (quadratic relationship), and gross primary productivity (quadratic relationship) (table 1; see Doherty et al. 2016). This analysis clearly showed the overarching importance of environmental variables in determining suitable GRSG habitat. Greater sage-grouse habitats in Management Zone I are characterized by patchy and often sparse sagebrush

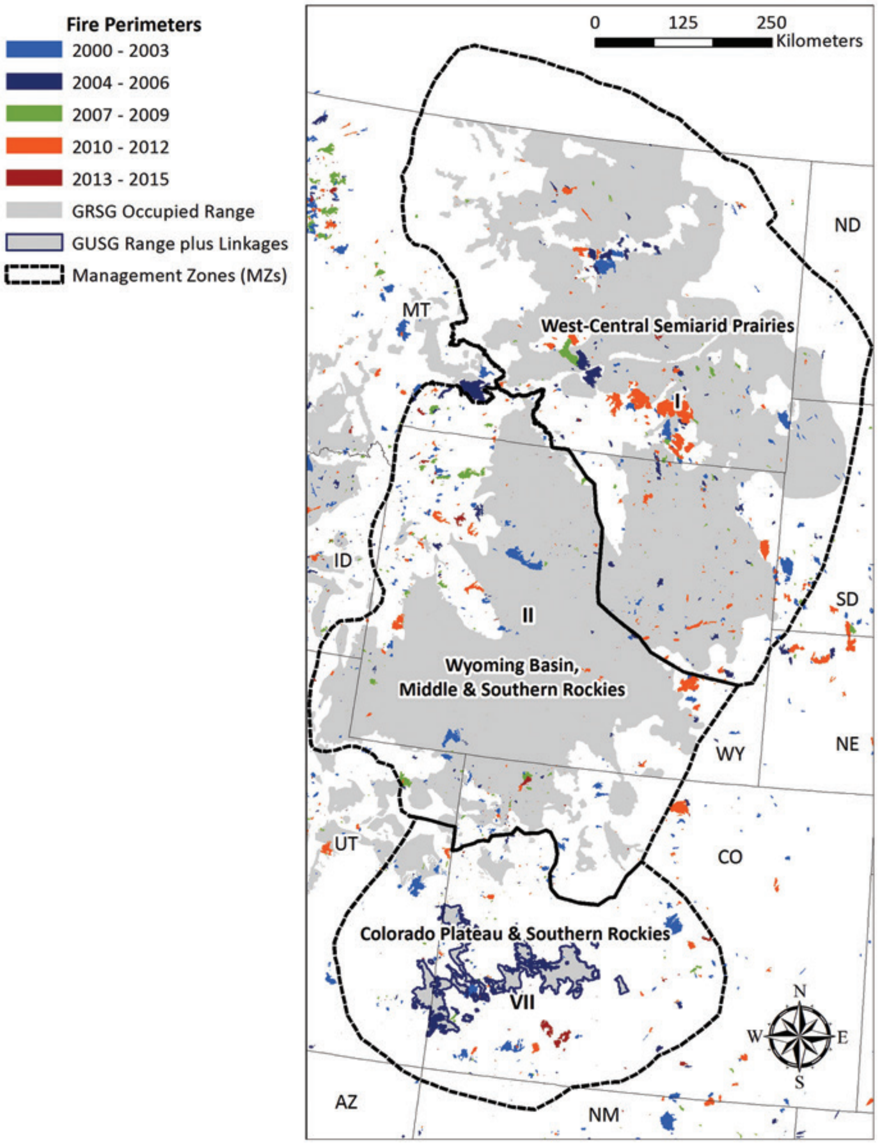


Figure 8—Perimeters of fires that have occurred since 2000 in Management Zones I, II, and VII (Stiver et al. 2006), the Gunnison sage-grouse critical range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a), and associated ecoregions (EPA 2016). Data for fires >1,000 acres are from MTBS (2014) and data for fires <1,000 acres are from GeoMAC (2015).

cover, and just 14 percent of the landscape is classified as sagebrush compared to 45 percent in Management Zone II (fig. 5; Knick 2011). Within this patchwork of sagebrush, sage-grouse select areas that contain high cover of sagebrush to winter and nest (Doherty et al. 2008, 2010a; Herman-Brunson et al. 2009; Moynahan et al. 2006; Swanson et al. 2013).

In the COT Report (USFWS 2013), persistent and widespread threats in the West-Central Semiarid Prairies (Management Zone I) included weeds and annual grasses in the Yellowstone Watershed and Powder River Basin, and fire in North and South Dakota. Conifers were a localized threat in parts of the region. Land use and development activities including cropland conversion in the Yellowstone Watershed that eliminates sagebrush cover, and energy development throughout the ecoregion,

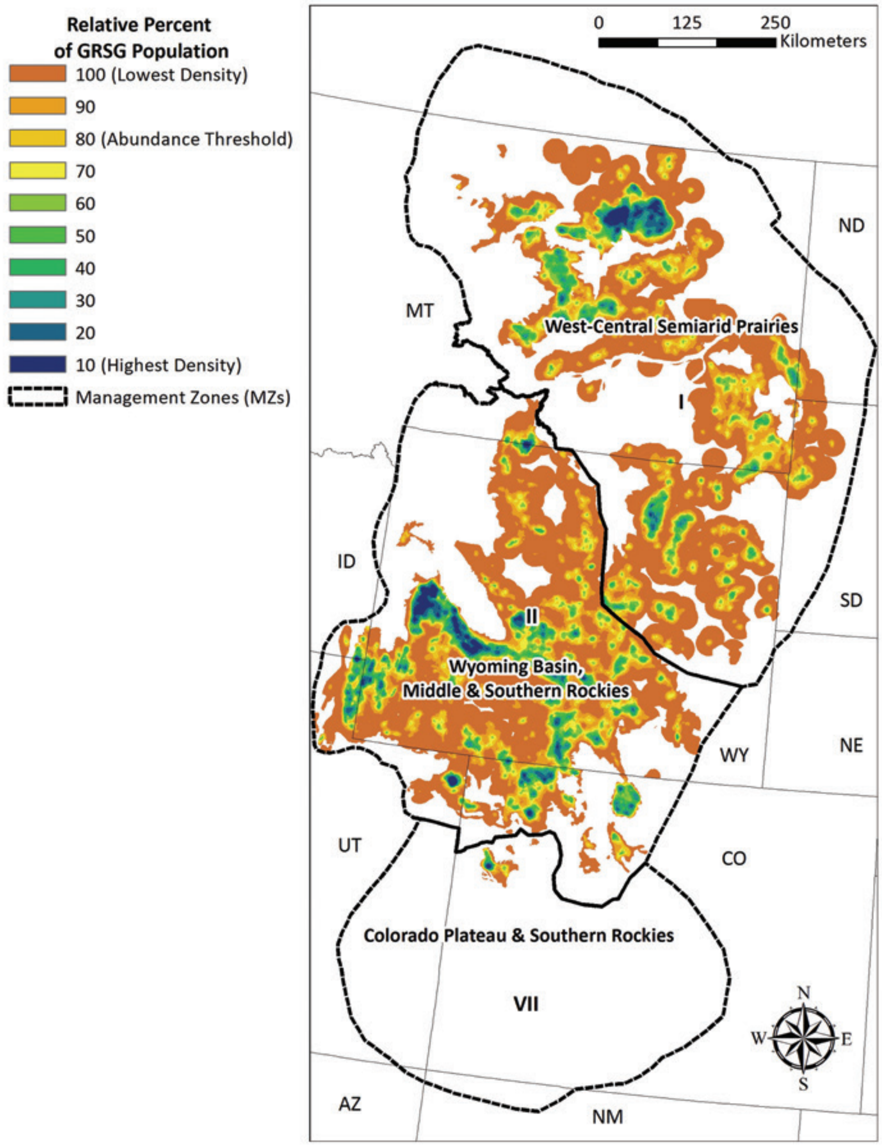


Figure 9—Relative percentage of the Greater sage-grouse population based on breeding bird abundance during 2010 to 2014 (Doherty et al. 2016) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). Population index values were calculated separately for each management zone. Population bins are additive.

were considered significant threats. Understanding the relative effects of invasive species, fire, and conifer expansion across the ecoregion can help in determining the most effective management and restoration strategies in areas being affected by land use and development activities as well as in relatively intact areas.

Cold Desert and Western Cordillera Ecoregions (Management Zones II and VII)

Euro-American arrival in the mid-1800s initiated a series of changes in vegetation composition and structure in the Cold Desert that had cumulative effects on sagebrush habitats. First, improper grazing by livestock led to a decrease in native perennial grasses and forbs (Miller and Eddleman 2001; Miller et al. 2011).

Table 1—Top predictor variables and relative importance values from Random Forest models for each Management Zone from Greater sage-grouse results (2010 to 2014) from Doherty et al. (2016) and Gunnison sage-grouse results (1995 to 2015) developed for this report.

Management zone	First variable	Second variable	Third variable	Fourth variable	Fifth variable
I	Conifer cover	All sagebrush	Roughness	Topographic wetness	Gross primary production
Importance	1.00	0.63	0.57	0.55	0.45
II	All sagebrush	Conifer cover	Annual drought index	Degree days >5 °C	Mean annual precipitation
Importance	1.00	0.73	0.68	0.59	0.49
VII (Greater sage-grouse)	All sagebrush	Low sagebrush index	Human disturbance	Oil and gas wells	
Importance	1.00	0.67	0.48	0.4	
VII (Gunnison sage-grouse)	All sagebrush (4.0 km)	All sagebrush (0.56 km)	Conifer cover (0.56 km)	Annual drought index	Conifer cover (4.0 km)
Importance	1.00	0.64	0.53	0.39	0.32

Decreased competition from perennial herbaceous species, in combination with ongoing climate change and favorable conditions for woody species establishment at the beginning of the 20th century, resulted in a widespread increase in shrub abundance (primarily *Artemisia* species) and at mid elevations more localized increases in Utah and Rocky Mountain juniper and two-needle piñon pine (Baker 2011; Miller et al. 2011; Romme et al. 2009).

Second, 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 land development (Mealor et al. 2013; Knight et al. 2014). These grasses spread with wildfire disturbance in both the Wyoming Basin (Knight et al. 2014) and western Colorado Plateau (Floyd et al. 2006). Annual grass/fire cycles and increases in fire frequency are not yet as problematic as in the Great Basin and western portion of the range, but conversion to invasive annual grasses is an increasing problem in some areas (Baker 2011; Brooks et al. 2015; Mealor et al. 2012). On sites with oil and gas drilling and mining disturbances, invasive annual grasses and a host of other annual invaders typically increase at the expense of native species diversity and cover (fig. 10; 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 an increase in invasive annuals if already present (Beck et al. 2012). This leads to slow recovery of sagebrush canopy cover and height required by nesting and brooding sage-grouse (Hess and Beck 2012a).

Third, expansion of juniper and piñon pine trees into sagebrush types at mid- to high elevations is occurring locally and is reducing the grass, forb, and shrub species associated with these types (fig. 11, 12; Romme et al. 2009). For example, infill of persistent woodlands and wooded shrublands and expansion of piñon and juniper into shrublands is occurring on portions of the Uncompahgre Plateau and Mesa Verde in southwestern Colorado (Eisenhart 2004; Floyd et al. 2004, 2006; Shinneman and Baker 2009). Infilling of trees increases woody fuels but reduces fine fuels that can result in less frequent fires than occurred historically in sagebrush dominated ecosystems (Miller et al. 2013). Fires in piñon and juniper stands at or

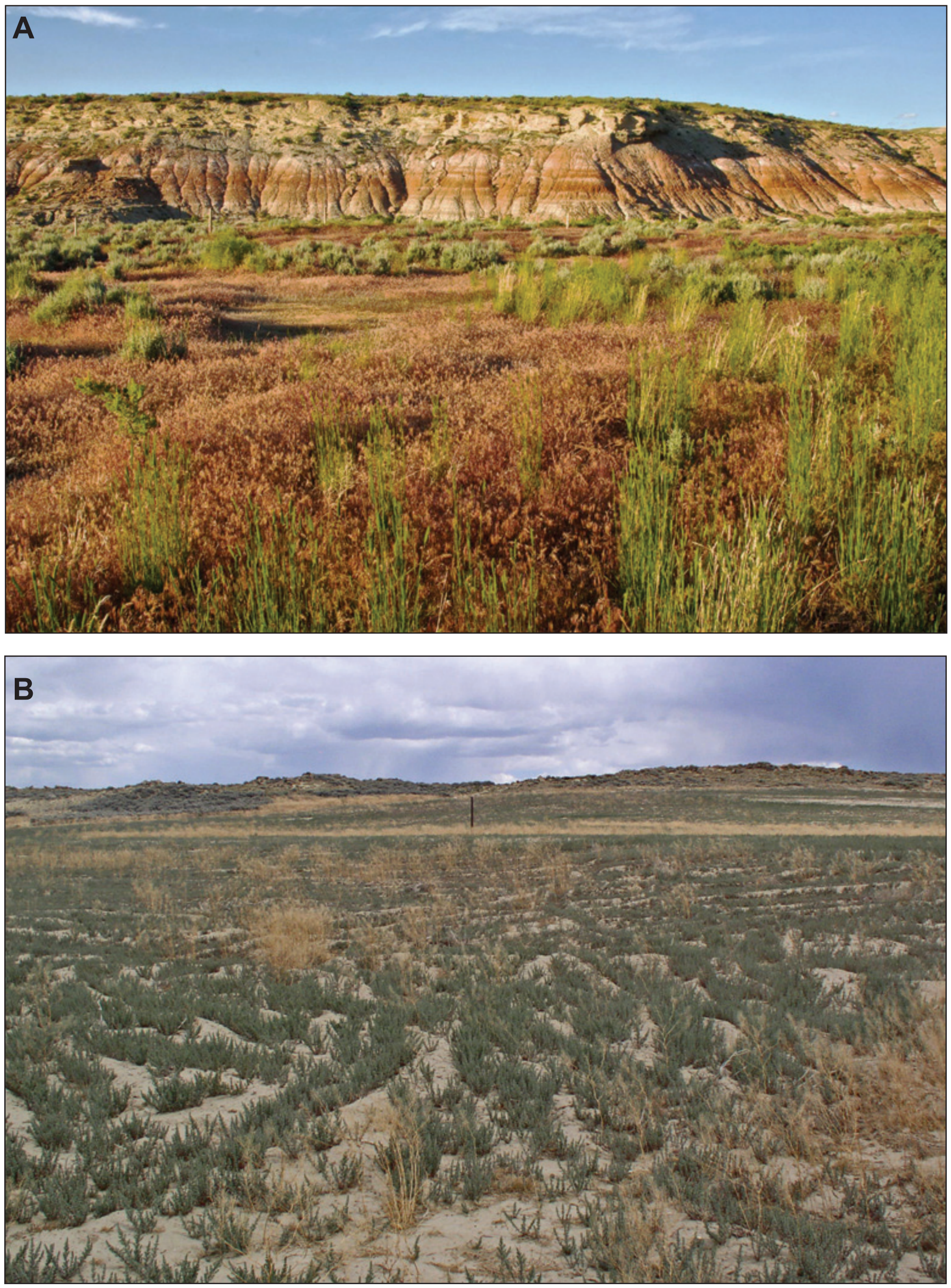


Figure 10—Annual invasive species established on disturbed sites in Wyoming: (A) cheatgrass (*Bromus tectorum*) and (B) saltlover (*Halogeton glomeratatus*) (photos by K. Henke).

near full tree stocking are typically high severity (Baker and Shinneman 2004) and consequently result in significant losses of above- and below-ground organic matter with detrimental ecosystem effects (Miller et al. 2013).

Warmer temperatures and prolonged droughts may be increasing the risk of wildfire and invasive annual grasses in many of these ecosystems (Littell et al. 2009). Multiple fires have burned in Management Zones II and VII since 2000, often with uncharacteristically large sizes and severity (fig. 8). Although not within GUSG range, in southwestern Colorado in Mesa Verde National Park, a greater proportion of the piñon-juniper 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).

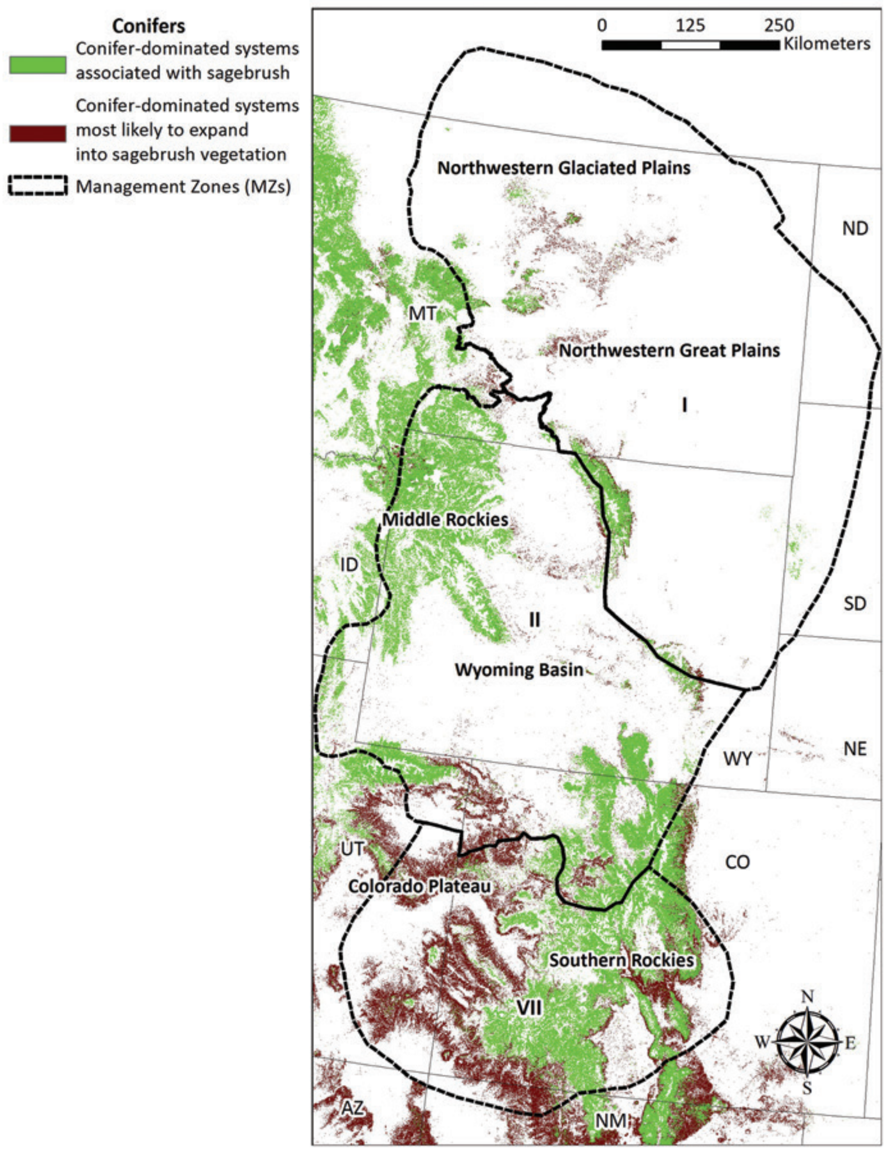


Figure 11—Conifer-dominated ecological systems (USGS 2014) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). The dark brown colors represent conifer-dominated systems most likely to expand into sagebrush-dominated systems (USDI BLM 2014), and are not intended to indicate areas with ongoing conifer expansion.

Figure 12—Conifer expansion in the Big Horn Basin of the Cold Desert (Management Zone II) (photo by T. Christiansen).

In the COT Report (USFWS 2013), persistent ecosystem threats to GRSG were ranked high for much of the Wyoming Basin and Middle Rockies (Management Zone II). Fire was considered a persistent and widespread threat in six of the nine populations (North Park, Colorado; Northwest, Colorado; Middle Park, Colorado; Laramie, Wyoming; Rich-Morgan Summit, Wyoming and Utah; Uintah, Utah) and a localized threat in the remaining three (Eagle-South Routt, Colorado; Jackson Hole, Wyoming; Wyoming Basin, Wyoming) (fig. 8). Weeds and annual grasses were a persistent and widespread threat in eight populations and a low-ranked threat in one (Wyoming Basin, Wyoming). Conifers were a persistent and widespread threat in the Laramie and two Utah populations (Rich-Morgan-Summit and Uintah), and a localized threat in the remaining populations, except for Middle Park and North Park, Colorado, where conifers were not considered a threat (fig. 11).

In Doherty et al.'s (2016) analysis, Management Zone II included 36.8 percent of the range-wide total of male GRSG attending leks from 2010 to 2014 (fig. 9). Variables showing the highest importance for predicting breeding habitat were: cover of all sagebrush species (positively associated), tree canopy cover (negatively associated), annual drought index (quadratic relationship), degree days greater than 5 ^{o}C (quadratic relationship), and mean annual precipitation (quadratic relationship) (table 1; see Doherty et al. 2016). Similar to Management Zone I, these variables indicate the importance of environmental variables to sage-grouse habitats. Habitats in Management Zone II are characterized by broad expanses of sagebrush ecosystems, which provide resources for all life history needs of GRSG (Doherty et al. 2016; Fedy et al. 2014; Kirol et al. 2015a; Smith et al. 2014). Lek sites are an important predictor of GRSG populations, with approximately 95 percent of nests within 10 km from lek capture (Doherty et al. 2010a; Holloran and Anderson 2005).

In addition, individual GRSG from many populations in Management Zone II migrate between seasonal sagebrush habitats (Fedy et al. 2014).

Studies on the impacts of conifer expansion on GRSG and GUSG from across the eastern portion of the range indicate both species avoid or are negatively associated with conifer cover during lekking and nesting as well as during summer and winter (Aldridge et al. 2012; Doherty et al. 2008, 2016; Fedy et al. 2014; Walker et al. 2016). But Kirol et al. (2015a) reported a positive response for non-brooding female GRSG in summer in south-central Wyoming. Furthermore, summer survival of females in Wyoming was negatively associated with proximity to forested areas (deciduous and conifer stands), where on average, GRSG mortality was higher closer to woodlands than for locations farther from woodlands (Dinkins et al. 2014b). In the Gunnison Basin, GUSG also selected nest sites farther from conifer (including juniper) cover, and nesting habitat quality was lower within 350 m of forested habitat (Aldridge et al. 2012). A doubling of GUSG males occurred on three leks in southwestern Colorado 2 to 3 years after piñon-juniper reduction near the leks (Commons et al. 1999). Outside the eastern region, GRSG have been shown to incur population-level impacts at a very low level of conifer expansion and the likelihood of maintaining breeding activity is severely compromised when conifer canopy exceeds 4 percent in the immediate vicinity of the lek (Baruch-Mordo et al. 2013).

Persistent ecosystem threats coupled with land use and development threats can exacerbate potential impacts to sage-grouse. For example, environmental conditions such as sagebrush cover and availability of riparian areas interact with other stressors including land use and development and predatory birds such as *Buteo* hawks, common ravens (*Corvus corax*), and golden eagles (*Aquila chrysaetos*) in Management Zone II (Dinkins et al. 2012, 2014a). In turn, these stressors influence survival rates for GRSG (Dinkins et al. 2014b; Kirol et al. 2015b; LeBeau et al. 2014).

Also, increasing land use and development in the Wyoming Basins fragments habitat and promotes establishment of invasive species such as cheatgrass, which may lead to increasing wildfire (Hess and Beck 2012b). Numbers of oil and gas well pads, percent area of wildfire, and variability of shrub height within 1 km of leks were all correlated with GRSG lek abandonment in the Bighorn Basin of north-central Wyoming (Hess and Beck 2012b). These additive factors, all related to increasing disturbance, were reported to be connected to reduction in habitat quality, partly related to establishment and spread of cheatgrass and increasing wildfire (Hess and Beck 2012b). Although annual grasses do not yet dominate GRSG habitats in the Wyoming Basin, results from a microhabitat selection study in the south-central portion of this region indicate female sage-grouse nest site selection was negatively correlated with presence of cheatgrass and positively with canopy cover of mountain and Wyoming big sagebrush (Kirol et al. 2012).

In the COT Report (USFWS 2013), persistent ecosystem threats varied in importance for GRSG populations in the Colorado Plateau and Southern Rockies (Management Zone VII). Fire was a persistent and widespread threat in both populations (Parachute-Piceance-Roan Basin and Meeker-White River, Colorado) (fig. 8), weeds and annual grasses were a localized threat in both populations (fig. 10), and conifers were a persistent and widespread threat in the Parachute-Piceance-Roan Basin, Colorado, population and not a threat in the Meeker-White River, Colorado, population (fig. 11).

In Doherty et al.'s (2016) analysis, Management Zone VII included 0.3 percent of the rangewide total of GRSG males on leks from 2010 to 2014 (fig. 9). The four variables important for predicting breeding habitat of these small populations were: cover of all sagebrush species (positively associated), cover of low sagebrush (positively associated), human disturbance index (negatively associated), and oil and gas wells (negatively associated) (table 1; see Doherty et al. 2016).

The Colorado Plateau and adjacent Southern Rockies (Management Zone VII) encompass the entire population of GUSG, which was estimated at 4,700 birds rangewide in 2014 (fig. 13; USFWS 2014a). About 85 percent of the entire population of GUSG occurs in the Gunnison Basin while the remaining birds occur in six satellite populations in southwestern Colorado and southeastern Utah.

Invasive plants, piñon and juniper expansion, and wildfire are considered to be secondary and/or localized threats to GUSG. Some GUSG habitat has been affected by invasive plants, especially cheatgrass, but the impacts do not currently appear to be threatening individual populations or the species rangewide (GSGRSC 2005; USFWS 2014a). However, invasive plants continue to expand their range, facilitated by ground disturbances such as wildfire, grazing, and human infrastructure. Climate change will likely alter the range of individual invasive species, accelerating the decline of sagebrush communities (USFWS 2014a). Drought impacts are already considered a high to very high level of threat in two satellite populations (San Miguel, Colorado and Dove Creek/Monticello, Utah and Colorado; GSGRSC 2005). Most populations are experiencing low to moderate levels of piñon-juniper expansion although piñon-juniper expansion has been considerable in the Crawford and Piñon Mesa populations (GSGRCS 2005; USFWS 2104a).

The models developed for this report indicate that the five variables important for predicting breeding habitat of the GUSG populations were: cover of all sagebrush species at the 4.0 km scale (positively associated); conifer cover (negatively associated) at both the 0.56 km and 4.0 km scales; cover of all sagebrush species at the 0.56 km scale (positively associated); and annual drought index (quadratic relationship) (table 1).

4.2 Climate Change

Climate change projections and the likely effects of global warming differ among ecoregions in the eastern portion of GRSG range (U.S. National Climate Assessment, Kunkel et al. 2013a,b). In the Western Great Plains as a whole, average temperatures have increased throughout the region in the last few decades, with the largest changes occurring in winter months (Kunkel et al. 2013a). Also, the number of frost-free days has increased (Kunkel et al. 2013a). There have been no significant trends in precipitation, but there has been a significant increase in extreme precipitation events.

Future temperature projections are based on Global Circulation Models and depend on the models used, the carbon dioxide emissions scenario, and the time frame. Downscaled models are rare for the eastern portion of the range, but temperature values are generally similar for ensemble Global Circulation Models (CMIP3) with a reference period of 1980 to 2000 for the Great Plains and the Southwest United States (Kunkel et al. 2013a,b). Warming projections for low (B1) and high emissions (A2), respectively, range from 2.5 °F to 3.0 °F (4.5 °C to 5.4 °C) for 2035, 3.5 °F to 5.0 °F (6.3 °C to 9 °C) for 2055, and 5.0 °F to 8.0 °F (9.0 °C to 14.4 °C) for 2085. Notably, recent increases in temperature follow predicted trend

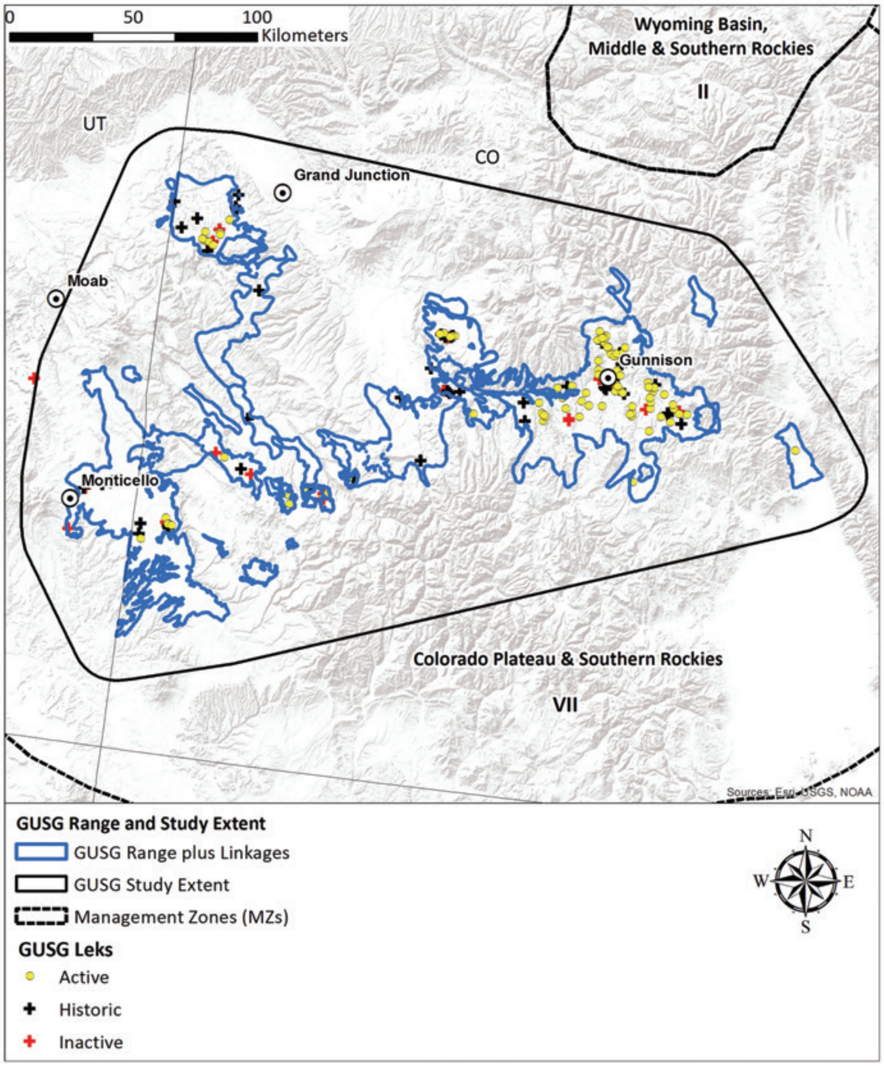


Figure 13—Gunnison sage-grouse critical range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) as well as active, inactive, and historic Gunnison sage-grouse leks.

lines from the Global Circulation Models. Precipitation in general is more difficult to forecast (and therefore has higher uncertainty), but for the Western Great Plains is predicted to change by about 0 to –6 percent in the west and increase by 3 to 9 percent in the east by 2070 (Kunkel et al. 2013a).

In the Cold Desert, including the Wyoming Basins and Colorado Plateau, annual temperature has generally increased over the past 115 years, and in the southern portion of the ecoregion the recent 10-year averages surpass any previous decadal value. Nighttime temperatures show the greatest increase and the recent period of elevated temperatures is most prominent in spring and summer. Precipitation is highly variable and shows no long-term trend. As in the Western Great Plains, the freeze-free season length has increased especially in the south. Ensemble Global Circulation Models project a change in precipitation of 0 to –9 percent by 2070 depending on location with winter months receiving relatively more precipitation and remaining seasons less than current (Kunkel et al. 2013b).

Within both ecoregions, evapotranspiration is predicted to increase whether or not precipitation increases and even those projections that indicate increases in precipitation show decreases in water availability (Seager et al. 2007). More precipitation is falling as rain instead of snow, snowmelt is occurring earlier, and consequently there is a shift towards earlier runoff (Knowles et al. 2006). Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change and rainfall becomes more concentrated into heavy events with longer, hotter dry periods in between events.

The changes in precipitation and temperature regimes described above are predicted 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 poleward 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 (*A. tridentata* spp.) and other sagebrush species project large decreases 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 (66 million hectares) in suitable climate is predicted by mid-century (Still and Richardson 2015). Areas in these regions that retain or gain climate suitability include higher elevations in the Cold Desert and the Northern Great Plains overall. 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 predicted to have significant effects on invasive annual grasses. Cheatgrass will likely spread upwards in elevation and possibly shift to northeast facing slopes; red brome (*B. rubens*) might expand northward and/or increase its abundance in the Cold Desert and Colorado Plateau (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 (Mealor et al. 2012; Bradley et al. 2016). 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).

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 and/or recovery potential of native ecosystems following disturbances such as improper livestock grazing and uncharacteristic wildfire (Chambers et al. 2014a,b). In turn, decreased resilience can lower resistance of these ecosystems to invasive annual grasses like cheatgrass, red brome, and field brome (Chambers et al. 2014b).

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. 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 GRSG and GUSG (Schrag et al. 2010; USFWS 2014a).

4.3 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. We include land fragmentation because of its importance to ecosystem processes such as species movements and gene flow. More detailed reviews of land use and development effects on sage-grouse are in Hanser et al. (2011) and Knick et al. (2011).

Livestock Grazing

Livestock grazing is the most widespread land use in the eastern portion of GRSG range. Grazing has well-recognized effects on ecosystem composition, pattern, and function (Beck and Mitchell 2000; Boyd et al. 2014a; Cagney et al. 2010; Freilich et al. 2003; Fuhlendorf and Engle 2001; Knick et al. 2011). In the COT Report (USFWS 2013), improper livestock grazing was considered a persistent and widespread threat to GRSG in Management Zones II and VII, except for three GRSG populations in Management Zone II (Jackson Hole, Wyoming, Rich-Morgan-Summit and Uintah, Utah) where it was not considered a threat. Livestock grazing occurs throughout Management Zone VII in the GUSG range and is considered a current and future threat to grouse where grazing occurs in a manner incompatible with local ecological conditions (USFWS 2014a).

The potential landscape effects of livestock grazing have been difficult to evaluate until recently because of a lack of area-wide spatial data (Knick et al. 2011). To address this lack of data, Veblen et al. (2011) 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) 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) 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 male GRSG reproductive success to the multivariate effects of livestock grazing on management units (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 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 able to 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.

Livestock effects on sagebrush ecosystems are likely more pronounced in Cold Deserts where stocking rates (Briske et al. 2011) and grazing season together can affect plant responses to grazing (Briske and Richards 1995). In Cold Deserts, defoliation of perennial grasses during inflorescence development (late spring) is the time when moisture is becoming limited and plant regrowth and recovery may 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. Care must be exercised regarding grazing season of use and stocking rates to maintain combinations of phenologically diverse plants where they should occur in these ecosystems.

The greatest potential for livestock grazing to affect sage-grouse habitat is by changing composition, structure, and productivity of herbaceous plants used for nesting/early brood-rearing (Beck and Mitchell 2000; Boyd et al. 2014a; Cagney et al. 2010; Hockett 2002). Empirical studies and meta-analysis indicate that sage-grouse nesting 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). Grass height in particular has been shown to influence nest success for GRSG in Management Zone I (Doherty et al. 2011a; 2014). However, Holloran et al. (2005) and Dinkins et al. (2016) reported weak, if any, effects of grass height on GRSG nest success in Management Zone II. Most recently, Gibson et al. (2016) demonstrated sampling bias based on the timing of grass height data collection. Their results suggest previously published grass height results based on data collected when nest fate was determined rather than the predicted hatch date were biased towards higher grass height relative to the true effect. In some cases, this bias was enough to change the overall direction of the effect as well as its magnitude. Therefore, revisiting management prescriptions based on specific grass heights within nesting habitat is advised. Nevertheless, repeated heavy grazing of sagebrush bunchgrass communities in Management Zone II removes bunchgrasses and leads to a sagebrush/rhizomatous grass or bluegrass state, which has reduced resource value for nesting and brood-rearing GRSG (Cagney et al. 2010). Sagebrush cover is inherently lower in the West-Central Semiarid Prairies than in other portions of the species range (Doherty et al. 2016; Herman-Brunson et al. 2009), suggesting greater reliance by breeding GRSG on herbaceous cover in Management Zone I 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 on western rangelands can contribute to collision related mortality, particularly when located on flat terrain close to leks (Stevens et al. 2012; Coates et al. 2016).

Urban and Exurban Development

Loss of sagebrush due to urban and exurban (residential) development since Anglo-American settlement is estimated at 16.0 percent for the West-Central Semiarid Prairies (Management Zone I), 18.4 percent for the Wyoming Basin and adjacent Rockies (Management Zone II), and 29.2 percent for the Colorado Plateau and adjacent Rockies (figs. 14, 15; Knick et al. 2011). In the COT Report (USFWS 2013), urban and exurban development was not considered a threat to GRSG in Management Zone I except for the Powder River Basin, Wyoming, where it was considered a localized threat. Development was considered a persistent and widespread threat in Management Zone II, particularly in outlying populations (Eagle South-Routt and Middle Park, Colorado; Laramie, Wyoming; Rich-Morgan Summit and Uintahs, Utah; and North Park, Colorado) and in Management Zone VII (Meeker-White River, Colorado). 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 (fig. 16; Knick et al. 2011).

Doherty et al.'s (2016) analysis showed that human disturbance was a major factor in predicting GRSG breeding habitat in Management Zone VII (ranked #3) and a minor factor in Management Zone I (ranked #12) and Management Zone II (ranked #11). For GUSG in Management Zone VII, residential and exurban development and associated infrastructure are considered a current or potential issue in all populations (USFWS 2014a). Nesting female GUSG avoided high-density development at the landscape scale and chose to nest farther away from any single development at the patch scale (Aldridge et al. 2012). A subsequent study showed that avoidance of development resulted in no observed effects on nest survival, and it indicated that other unknown factors may be driving nest survival (Stanley et al. 2015). In general, low-density exurban developments support lower native species abundance and more human-commensal bird and mammal species and invasive plants, than comparable unfragmented rangelands (Maestas et al. 2003).

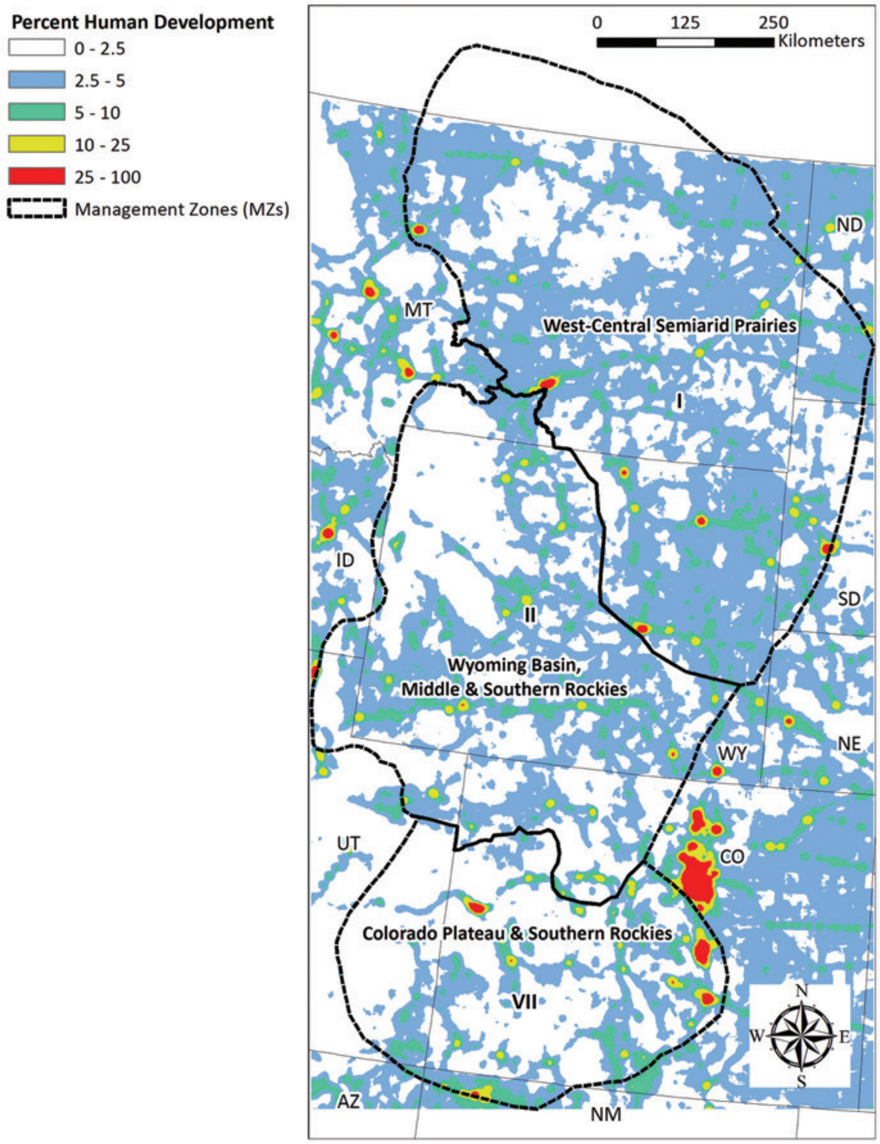


Figure 14—Percentage of developed land (NLCD 2011) within 5.0 km of each pixel in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

Figure 15—Rural subdivision in Sublette County, Wyoming (photo by T. Christiansen).

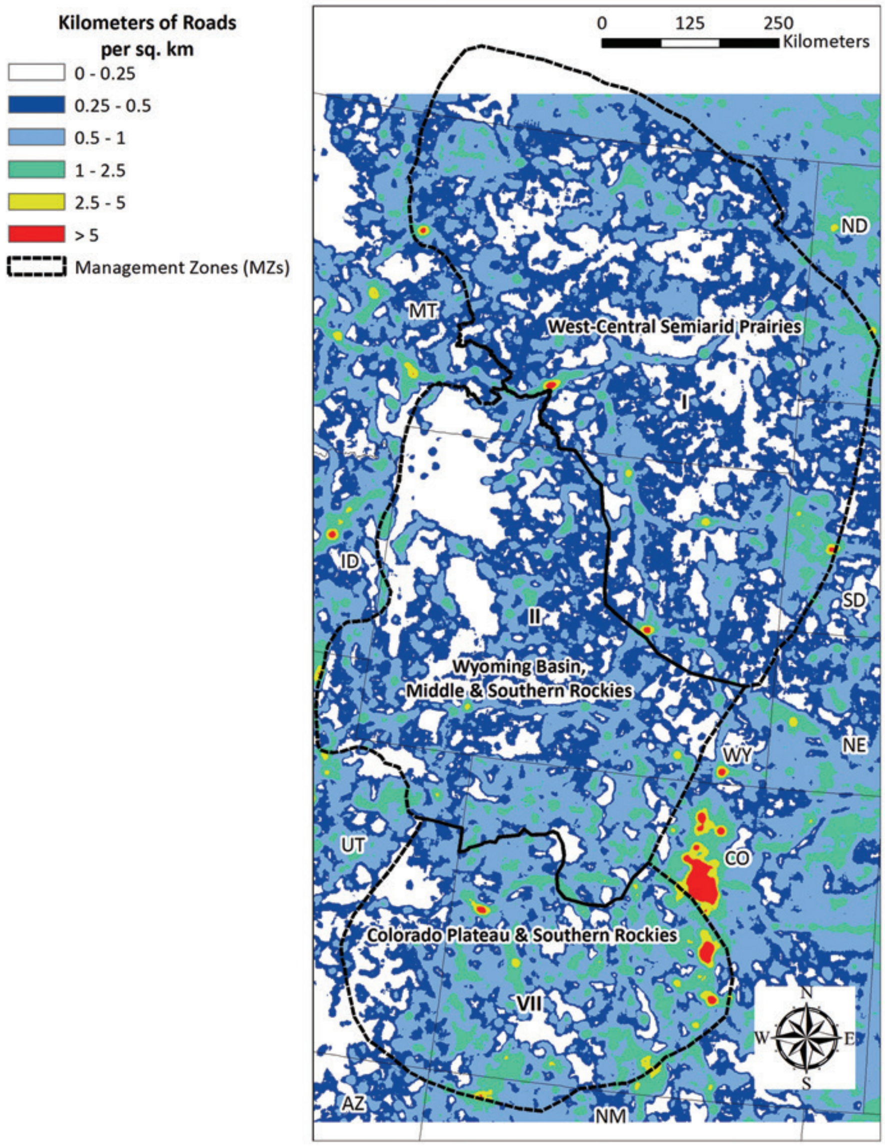


Figure 16—Density of all roads (surface roads, major roads, and interstate highways; ESRI Street Map Premium) in kilometers per square kilometer in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

Energy Development

Loss of sagebrush cover associated with energy, primarily oil and gas development, has been well-documented in recent analyses. The Wyoming Basin Ecoregional Assessment (Hanser et al. 2011)—which included south-central Montana, western and central Wyoming, northeastern 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. This is due to construction of well pads and supporting infrastructure, such as roads, power lines, and pipelines (Finn and Knick 2011). It is considered a persistent and widespread threat to almost all GRSG populations in the eastern range (figs. 17, 18; USFWS 2013). In the COT Report (USFWS

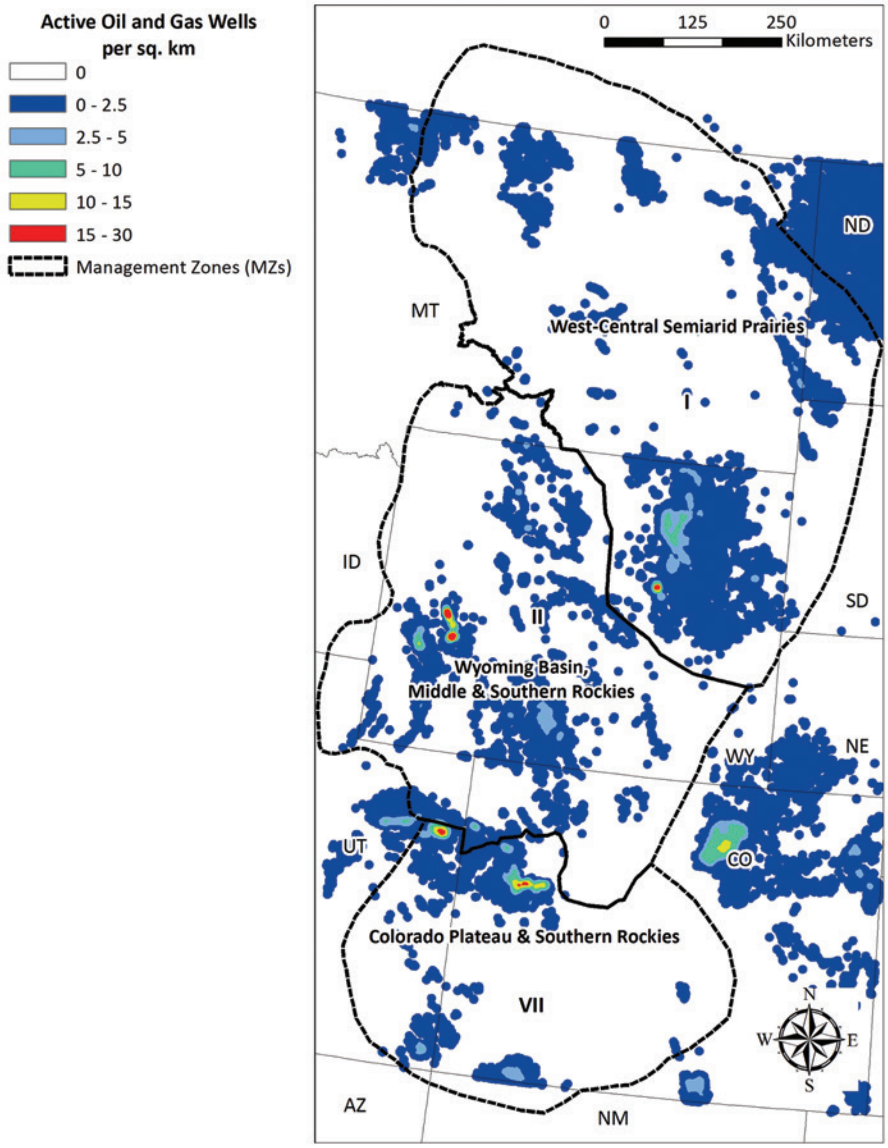


Figure 17—Number of active oil and gas wells per square kilometer (IHS; BLM [AFMSS]) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

2013), energy development was considered a persistent and widespread threat to GRSG in Management Zones I, II, and VII except in two GRSG populations in Management Zone II, where it is a localized threat (Jackson Hole, Wyoming, and Uintah, Utah). Energy development is limited in the GUSG range of Management Zone VII. Only two populations, San Miguel, Colorado, and Dove Creek/Monticello, Utah, currently have a moderate level of oil and gas development and a high level of future development potential. A medium level of potential development occurs in the Crawford, Colorado, population and no other populations have potential for energy development (GSGRSC 2005; USFWS 2014a).

Removal of sagebrush vegetation as a function of energy development can increase soil resources, such as available nitrogen, and alter soil properties that can favor various invasive species (Bergquist et al. 2007; Nielson et al. 2011). When compared to sites not influenced by development activities, sites disturbed by

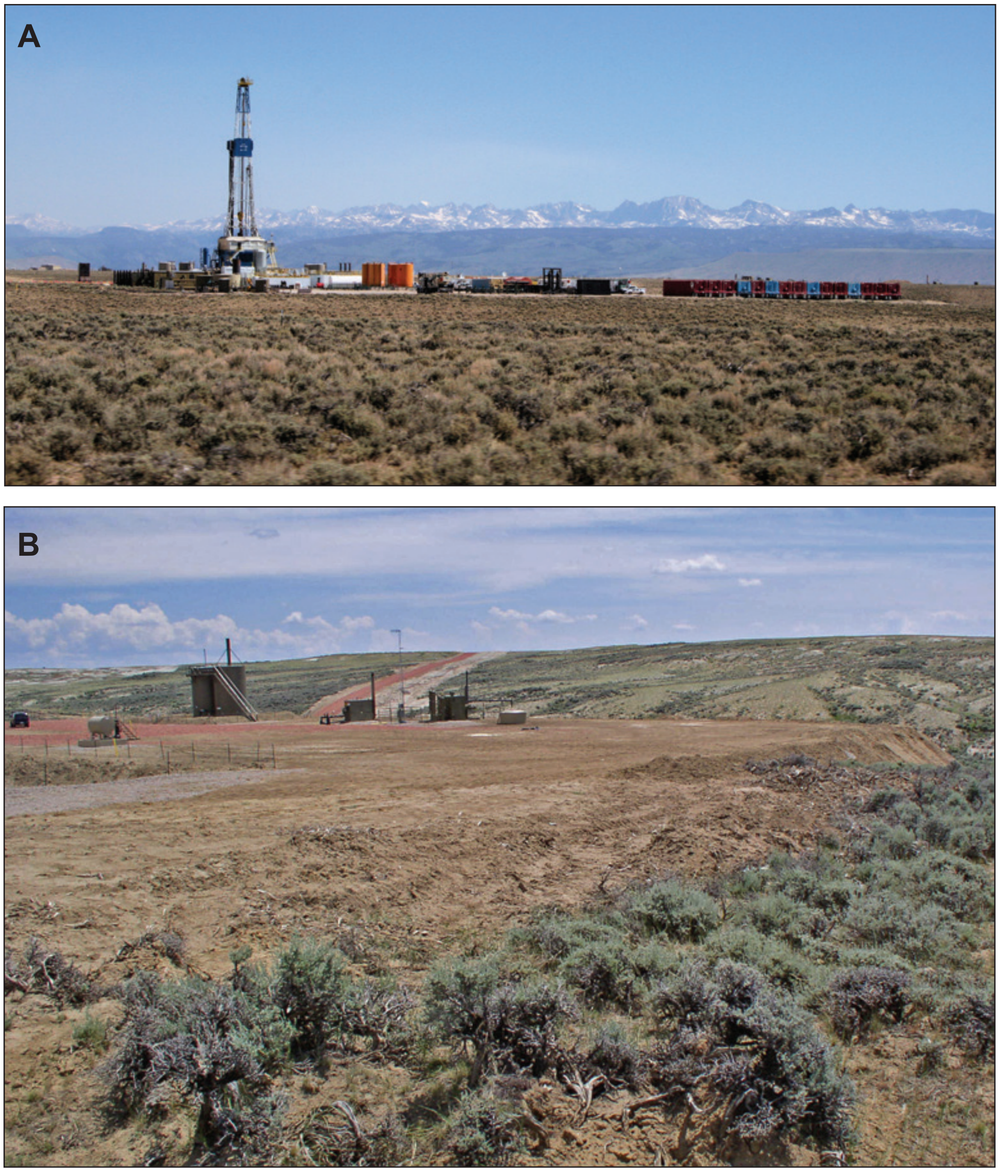


Figure 18—Deep gas drill rig (A) outside of Pinedale, Wyoming (photo by T. Christiansen), and well pad (B) (photo by K. Henke).

energy development had higher species richness (numbers) of exotic than native 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; 2014; Nielson et al. 2011). Although many invasive species decline at distances beyond 164 to 328 ft (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). 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 effectiveness of sagebrush communities for GRSG and GUSG 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 land use and development 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). This suggests that land use and development can decrease ecosystem resilience by reducing resistance to invasive species, which in turn may increase fire frequency and extent. These effects may be most evident for sites with relatively warm or dry soil temperature and moisture regimes, and may increase as the climate warms.

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; Kirol et al. 2015a; LeBeau et al. 2014; Lyon and Anderson 2003). Greater sage-grouse hens with successful nests located their nests farther from roads in oil and gas fields than unsuccessful hens (Lyon and Anderson 2003). Transmission towers potentially provide perches and nesting structures for raptors and ravens, and may also contribute to collision mortalities (Beck et al. 2006; Borell 1939; Coates et al. 2014; Howe et al. 2014). Proximity to distribution and transmission lines was related to lower adult female survival for GRSG, which was most likely related to increased raptor densities rather than collision mortalities (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). Thus, measures to decrease fragmentation and maintain areas with greater sagebrush cover in higher ecological condition are primary management objectives (Aldridge and Boyce 2007; Kirol et al. 2015b).

Cropland Conversion

Cropland conversion (changing rangeland to cropland) was ranked a persistent and widespread threat in areas with higher precipitation and more productive soils across the eastern range in the COT Report (USFWS 2013; Yellowstone Watershed, Montana; Eagle South-Routt and Middle Park, Colorado; North Park and Northwest Colorado [Wyoming Basin in Colorado]; Meeker-White River, Colorado) (figs. 19, 20). It was not a threat for most other populations. In Doherty et al.'s (2016) analysis, amount of tilled cropland was a minor factor in predicting GRSG breeding habitat in Management Zone I (ranked #7) and Management Zone II (ranked #14). Effects of cropland conversion may be underestimated 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). These lands are no longer considered in analyses of GRSG within their current range. Throughout GUSG range in Management Zone VII, the amount of land in cropland is declining except in the Dove Creek/Monticello, Utah, population (GSGRSC 2005) and is not expected to be a future threat in any of the other populations (USFWS 2104a).

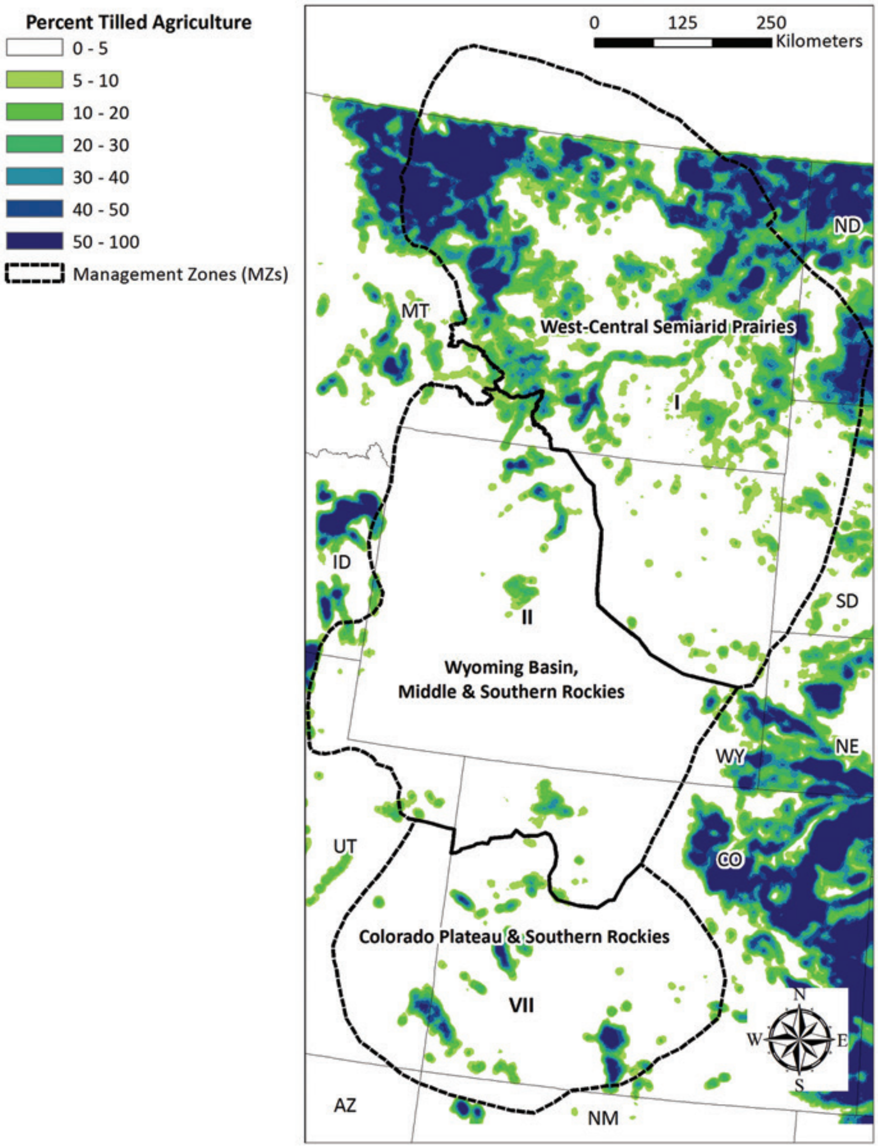


Figure 19—Percent annually tilled agricultural land (cropland; NASS 2014) within 5.0 km of each pixel in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016).

Figure 20—Conversion of a sagebrush ecosystem in the West-Central Semiarid Prairies to agricultural land (photo by J. Carlson, used with permission).

Extensive cultivation and fragmentation of native habitats have been associated with sage-grouse population declines. The West-Central Semiarid Prairies (Management Zone I) have the highest percentage of private lands and highest amount of tilled cropland (Doherty et al. 2016). 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 landscape surrounding agricultural fields influence 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). Greater sage-grouse extirpations have occurred in areas where cultivated crops exceeded 25 percent (Aldridge et al. 2008), and recent studies show that 96 percent of active leks are surrounded by less than 15 percent cropland in Management Zone I (SGI 2015; Smith et al. 2016). Management aimed at maintaining existing functional patches of sagebrush habitat at landscape scales is fundamental to the persistence of GRSG in Management Zone I.

Recreation

Recreational activities (off-highway vehicle [OHV] use, mountain biking, camping, snowmobiling, etc.) can have both direct and indirect impacts on sagebrush ecosystems and sage-grouse (USDI BLM 2009). Recreational use of OHVs is one of the fastest growing outdoor activities, although the effects of OHV use on sagebrush and sage-grouse have not been studied (Knick et al. 2011). Motorized access for recreation has a variety of effects, including removal of sagebrush cover, modification of animal behavior because of habitat changes or noise, alteration of the physical and chemical environment, and spread of invasive plants (Knick et al. 2011). In the COT Report (USFWS 2013) recreation is considered a persistent and widespread threat or a localized threat in every population in Management Zone I and Management Zone II, except the Meeker-White River and Parachute-Piceance-Roan populations in Colorado. Recreational use within the GUSG range is widespread, occurs throughout the year, and has expanded as more people move into the area or travel to recreate (Connelly et al. 2004). Recreation uses have affected large areas of GUSG range, especially portions of the Gunnison Basin and Piñon Mesa populations (USFWS 2014a).

Habitat Fragmentation

Land use and development can affect both habitat loss and habitat fragmentation. In its 2010 listing decision, the U.S. Fish and Wildlife Service determined that the greatest threat to GRSG was habitat loss and fragmentation (USFWS 2010). The USFWS noted in its 2015 decision (USFWS 2015) that the configuration of sagebrush mosaics across the range of GRSG has changed, resulting in risk of increased population isolation, exposure to predators in areas of edge habitat, and invasive plants (Gelbard and Belnap 2003; Knick and Connelly 2011; Saunders et al. 1991).

Habitat fragmentation is a function of habitat configuration (e.g., number of habitat fragments, edge density, patch shape), rather than total amount of habitat in a landscape. “Fragmentation” represents the dissection of large expanses of habitat via various mechanisms (Manier et al. 2013). Greater sage-grouse populations generally rely on large, interconnected expanses of sagebrush for local migrations and access to seasonal habitats (Connelly et al. 2004, 2011a,b). While conclusive data establishing minimum sizes of sagebrush-dominated landscapes necessary to support populations of GRSG are unavailable (Connelly et al. 2011a,b), some quantitative indications exist. For example, research in Wyoming and Montana suggest that the size of a sagebrush dominated landscape needed to support breeding habitats of an interspersed population may exceed 386 mi^2 (1,000 km^2) (Doherty et al. 2008). Investigations from Idaho and Wyoming suggest that relatively large blocks of sagebrush habitat (>9,884 acres [4,000 ha]) are critical to successful reproduction and overwinter survival (Leonard et al. 2000; Walker et al. 2007; Wisdom et al. 2011). More recently, Doherty et al. (2016) developed a spatial model of occupied GRSG breeding habitat based on biophysical habitat, climate, landform, and anthropogenic development. This model clearly shows the importance of ecological context in determining both habitat selection and response to disturbance.

Reduction and fragmentation of sagebrush habitats can decrease GRSG abundance and reduce the distribution of GRSG across the landscape (Knick et al. 2011; Leu and Hanser 2011). Greater sage-grouse avoid habitats near anthropogenic infrastructure associated with energy development (Naugle et al. 2011), interstate highways (Connelly et al. 2004; Knick et al. 2013), cropland (Aldridge and Boyce 2007; Smith et al. 2005; Walker et al. 2007,) and urban and exurban subdivision development (Aldridge and Boyce 2007). Indirect effects such as increased mortality and reduced reproductive success have also been documented.

The historic distribution of GUSG was naturally fragmented by piñon-juniper and rocky canyons (Braun et al. 2014; Rogers 1964). In 2014, the GUSG was listed as threatened by the U.S. Fish and Wildlife Service. In the determination document for the listing, habitat loss, degradation, and anthropogenic fragmentation of sagebrush habitats were considered the primary causes of GUSG decline in abundance and distribution (USFWS 2014a). Between 1958 and 1993 substantial sagebrush was lost; Gunnison Basin showed an 11 percent loss in sagebrush acreage, with a 28 percent loss combined for satellite populations (Oyler-McCance et al. 2001). This resulted in considerable habitat fragmentation with remnant sagebrush patches surrounded by a matrix of unsuitable habitat for GUSG. Due to habitat loss and fragmentation, the seven populations have become isolated with limited migration and gene flow thus increasing the likelihood of extirpation (USFWS 2014a).

Current climate and climate change are important factors determining the negative effects of habitat loss and fragmentation on species density and/or diversity (Mantyka-Pringle 2011). Most studies indicate that current habitat loss and fragmentation outweigh the responses of climate warming 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 may exacerbate land-use modifications in determining 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). Also, the threshold of climate change below which species extinction occurs or populations severely decline is likely to be determined by the pattern of habitat loss (Opdam and Wascher 2004).

5. Resilience to Disturbance and Resistance to Nonnative Invasive Plant Species

Our ability to address persistent ecosystem and land use and development threats to sagebrush habitats can be greatly enhanced by understanding the effects of environmental conditions on resilience to stress and disturbance and resistance to invasion by nonnative plants (Chambers et al. 2014a,b; Wisdom and Chambers 2009). In the West-Central Semiarid Prairies, Western Cordillera, and Cold Deserts, resilience of native ecosystems to stress and disturbance changes along climatic and topographic gradients at both landscape and local scales. At landscape scales, higher precipitation and cooler temperatures, along with greater soil development and plant productivity, typically result in greater resource availability and more favorable environmental conditions for plant growth and reproduction (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 disturbances and management treatments (Chambers et al. 2014a,b). More resilient ecosystems typically exhibit smaller changes following perturbations and recover more rapidly than less resilient ecosystems (Chambers et al. 2014a,b; Davies et al. 2012). These relationships also are observed at local or site scales where aspect, slope, and topographic position affect solar radiation, erosion processes, and effective precipitation, and thus soil development and vegetation composition and structure (Condon et al. 2011; Johnson and Miller 2006).

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 plant species distributions and relative abundances. The importance of these factors 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, 22; Brooks et al. 2016; Chambers et al. 2014b; 2016a). 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 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. 2013; 2014; Reisner et al. 2013; 2015; Salo 2005).

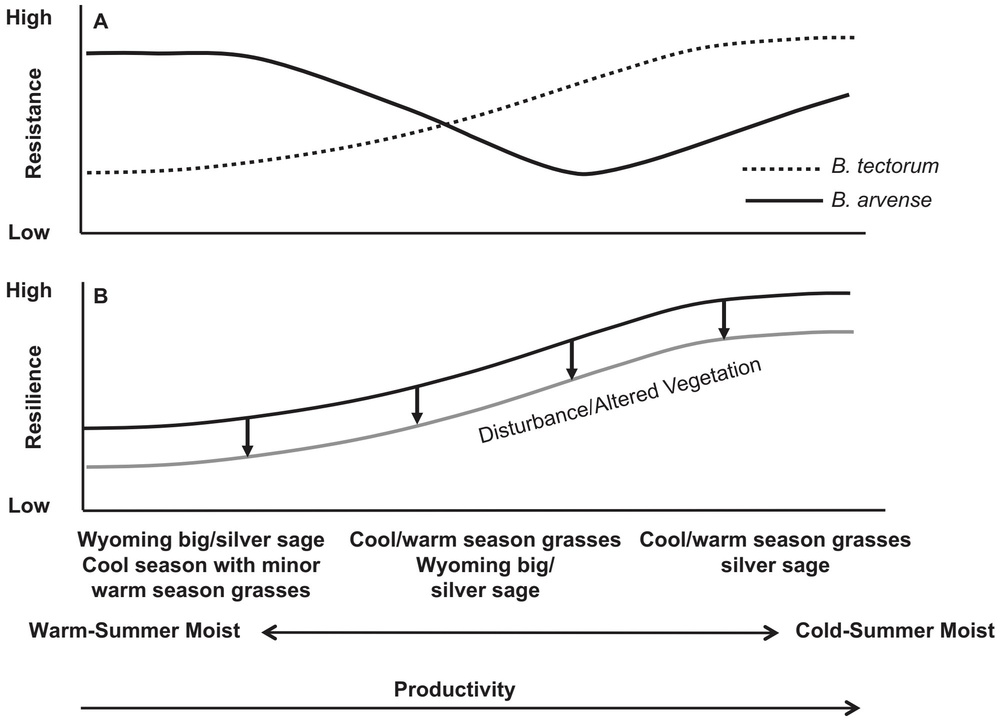


Figure 21—Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil moisture and temperature gradient in the West-Central Semiarid Prairies. Dominant ecological sites occur along a continuum from relatively warm and summer moist with Wyoming big sagebrush, silver sagebrush, and cool season grasses with 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 (based on Chambers et al. 2014b).

The occurrence and persistence of invasive annual grasses 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 native 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 adults of native, perennial grasses and forbs, 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 result in 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

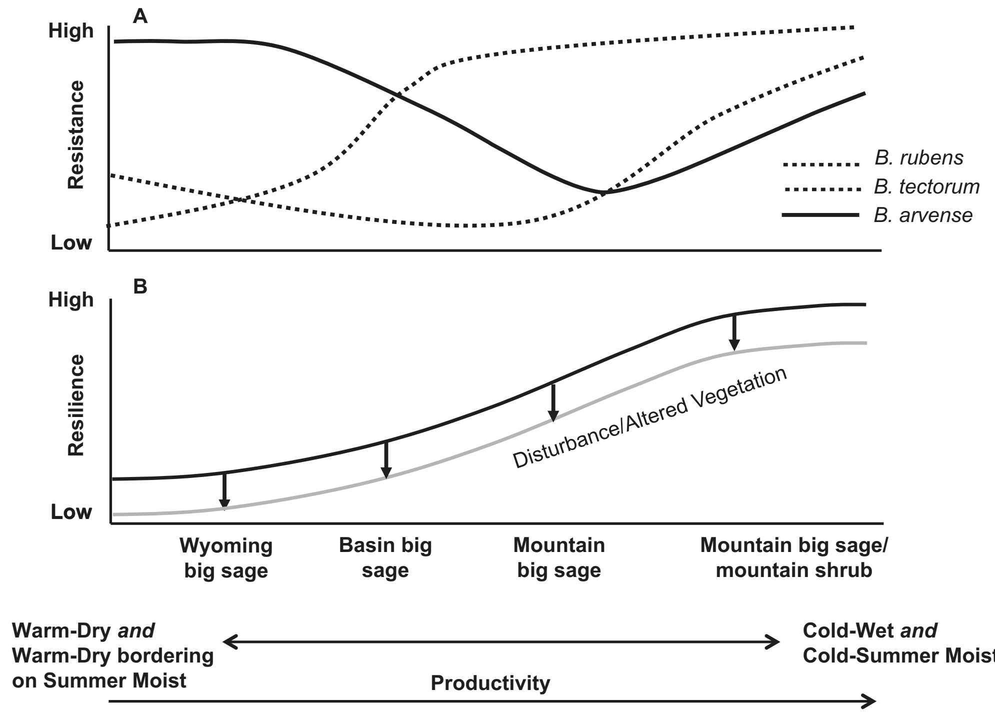


Figure 22—Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil temperature and moisture gradient in the Cold Desert. Dominant ecological sites occur along a continuum from relatively warm and dry to cold and wet conditions that includes salt desert shrub, 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 (based on Chambers et al. 2014b).

and elevated resources result in increased abundances of red brome (Salo 2005), field brome (Collins et al. 1985), and also species like spotted knapweed (*Centauria stoebe* ssp. *micranthos* syn. *C. maculosa*) (Willard et al. 1988).

The type, characteristics, and natural range of variability of stress and disturbance strongly influence both resilience and resistance. Disturbances like overgrazing of perennial plants by livestock and atypical fire regimes are outside of the historical range of variability and can reduce the resilience of sagebrush ecosystems. 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. 2014b) and cover of biological soil crusts (Reisner et al. 2013). Resistance to an invasive species can change when alterations in abiotic and biotic attributes result in increased resource availability or altered habitat suitability that influences an invasive species' ability to establish and persist and/or compete with native species (Chambers et al. 2014b,c). Progressive reduction of resilience and resistance can result in the crossing of abiotic and/or biotic thresholds and an inability of the system to recover to the reference state (Briske et al. 2008).

6. Integrating Resilience and Resistance Concepts with Sage-Grouse Habitat Requirements to Prioritize Areas for Management and Inform Management Strategies

Widespread persistent ecosystem and land use and development threats coupled with large and diverse ecoregions require a strategic approach to conserve sage-grouse habitats (Meinke et al. 2009; Pyke 2011; Wisdom and Chambers 2009; Wisdom et al. 2005). This strategic approach requires the ability to (1) identify those locations that provide current or potential habitat for sage-grouse, (2) prioritize management actions based on relative resilience and resistance, and (3) effectively allocate resources to achieve desired objectives. Recently, probabilistic models of GRSG occupied breeding habitat have been developed that account for general habitat characteristics, climate, landform, and disturbance. Spatially explicit models have been developed that quantify the relative density of breeding male GRSG across Management Zones (Doherty et al. 2016). And information on the relationships of environmental characteristics to ecological types and their inherent resilience and resistance has been developed. Coupling species distribution and abundance information with relative habitat resilience and resistance provides the foundation to (1) prioritize areas for management that sustain viable populations of birds and (2) determine the most appropriate treatments based on the area's capacity to respond to management actions (Chambers et al. 2014c).

6.1 Sage-grouse Breeding Habitat Probabilities and Population Indices

Sage-Grouse Breeding Habitat Model

We used two sets of models developed for the U.S. Fish and Wildlife Service status assessment (Doherty et al. 2016) to develop sage-grouse breeding habitat probabilities and population indices. 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) primarily because information available to the USFWS regarding occupied GRSG range was developed at a broad spatial scale and included large areas of unsuitable habitat. The breeding habitat model uses GRSG lek data as a proxy for landscapes important to breeding birds, because leks are central to the breeding ecology of sage-grouse (Coates et al. 2013; Holloran and Anderson 2005). The breeding habitat model evaluates characteristics such as vegetation (i.e., land cover), climate, landform, and disturbance variables around leks, which is where most nests occur (Holloran and Anderson 2005), i.e., within a radius of 4 mi (6.4 km; 13,010 ha; Doherty et al. 2016). The model provides an estimate of the probability of occupied breeding habitat at a spatial resolution of 120 x 120 m based on habitat characteristics for each sage-grouse Management Zone (fig. 23).

For this report, we modeled breeding habitat for GUSG in Management Zone VII following the same methodology used by Doherty et al. (2016) for GRSG. We used lek designations for active, inactive, and historic GUSG leks provided by Colorado Parks and Wildlife (GSRSC 2005) and by Utah Division of Wildlife Resources for Utah from 1995–2015. As with the GRSG breeding habitat analysis, we performed a geographic range analysis (i.e., Johnson's [1980] first order scale) to evaluate breeding habitat represented by active GUSG leks. The extent of this analysis was

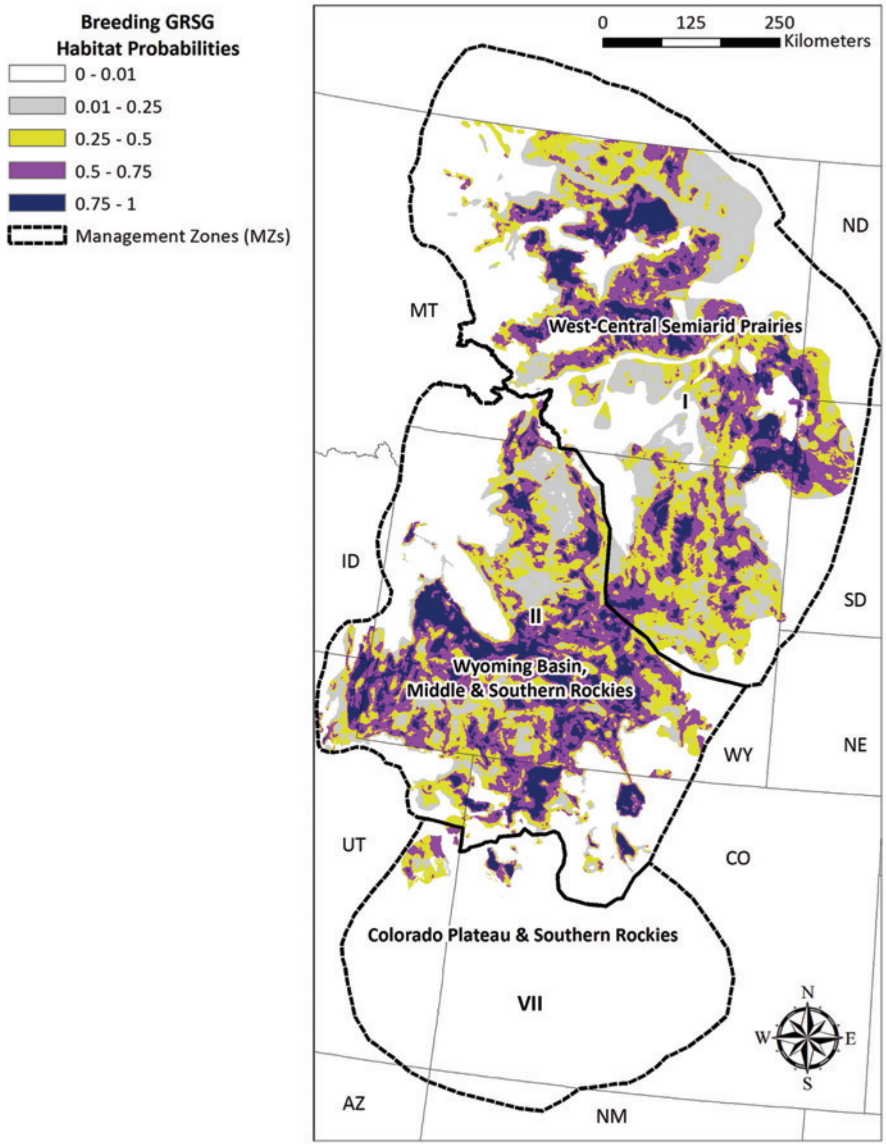


Figure 23—Greater sage-grouse breeding habitat probabilities based on 2010 to 2014 lek data (Doherty et al. 2016) in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). Active leks are overlaid.

delineated by placing a minimum convex polygon around range-wide GUSG habitat defined by Colorado Parks and Wildlife as occupied range and linkage habitat, Utah Division of Wildlife Resources as occupied and unoccupied habitat, and the U.S. Fish and Wildlife Service as critical habitat. We then buffered the polygon by 11 mi (18 km) as a reasonable approximation for the average distance an individual GUSG might move during the year to access seasonal resources based on several GRSG studies from Wyoming (Fedy et al. 2012). We quantified habitat, landform, and disturbance variables within two spatial scales, 2.5 mi (4.0 km) and 0.35 mi (0.56 km) of each lek. The median distance of an active GUSG lek from non-habitat as defined by Colorado Parks and Wildlife, Utah Division of Wildlife Resources, and the U.S. Fish and Wildlife Service (e.g., forested areas) was approximately 2.5 mi (4.0 km). We believed the smaller buffer size for GUSG compared to GRSG was warranted because a 4 mi (6.4 km) buffer placed around active GUSG leks included approximately 37 percent non-habitat (e.g., forested). We also considered a second lek buffer distance of 0.56 km (100 ha) for GUSG, which coincided with the avoidance distance of nesting GUSG from conifer in the western portion of the Gunnison Basin (Aldridge et al. 2012). Climatic variables were evaluated within 30 m x 30 m pixels. Similar to the GRSG breeding habitat model, the GUSG breeding habitat model generated an estimate of the probability of occupied breeding habitat at a spatial resolution of 30 x 30 m based on habitat characteristics within the GUSG range (fig. 24).

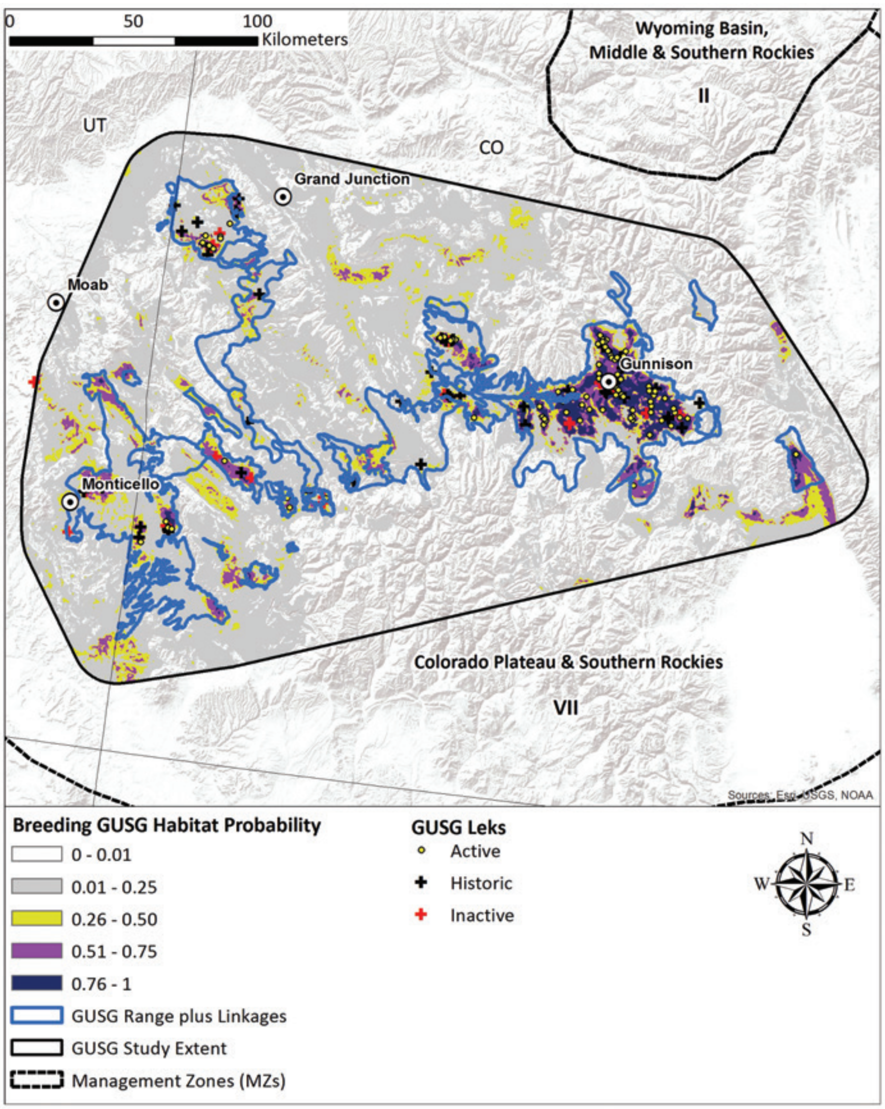


Figure 24—Gunnison sage-grouse breeding habitat probabilities for the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) based on lek data from 1995 to 2015. The breeding habitat probabilities were developed for this report based on Doherty et al. 2016. Active, historic, and inactive leks are overlaid.

We used the breeding habitat probabilities for GRSG (Doherty et al. 2016) and GUSG (see above) to develop three categories of breeding habitat suitability for areas near leks that can be used to prioritize management actions on the landscape: low (0.25 to <0.50); moderate (0.50 to <0.75); and high (0.75 to 1.00). Areas with very low probabilities (0.01 to <0.25) were considered to be unsuitable for breeding habitat, but may provide habitat during other life stages or linkages between suitable breeding habitat. Greater sage-grouse leks were defined as active if more than two males were counted in a single year from 2010 to 2014 and the last count was not zero (Doherty et al. 2016). Inactive GRSG leks were defined as those where no males were observed for more than four of the last lek counts. For GUSG, we combined inactive and historic leks. We relied on the probability values at existing active lek locations for GRSG and GUSG to define thresholds in breeding habitat probabilities. We then used the probability values at inactive lek locations for GRSG and inactive and historic lek locations (combined) for GUSG to conduct an accuracy assessment of our categorization of habitat probabilities (table 2). Our goal was to categorize breeding habitat so that less than 10 percent of active leks and more than 50 percent of the inactive leks would occur in the low and moderate probability ranges. This approach clearly differentiates where management actions to improve habitat are warranted (table 2). Inactive leks in the high habitat probability range (29.7 percent for GRSG and 45.6 percent for GUSG; table 2) may reflect site-specific issues such as a small wildfire that burned habitat surrounding a lek or a road or single oil and gas well placed close to a lek that resulted in its collapse. In contrast, active GRSG leks in the unsuitable (0.1 percent of active leks) and low (0.8 percent of active leks) probability ranges would indicate leks that are at high

Table 2—Breeding habitat model probabilities for Greater sage-grouse leks in Management Zones I, II, and VII and Gunnison sage-grouse leks in Management Zone VII grouped into ranges relative to their probability of supporting sage-grouse leks. Percentage (sample size) of active and inactive Greater sage-grouse leks from Colorado, Idaho, Montana, North Dakota, South Dakota, Utah, and Wyoming are included as an illustration of the distribution of current active and inactive leks within these probability ranges. Percentage (sample size) of active and inactive Greater sage-grouse leks from all States and active and inactive/historic Gunnison sage-grouse leks from Colorado and Utah are included as justification of probability breaks for these probability ranges. Habitat probabilities for Greater sage-grouse were modeled by comparing habitat characteristics within 4 mi (6.4 km) around active leks and pseudo-absence locations (Doherty et al. 2016). Habitat probabilities for Gunnison sage-grouse were modeled by comparing habitat characteristics within 2.5 mi (4.0 km) and 0.35 mi (0.56 km) around active leks and pseudo-absence locations (this report).

	Breeding habitat probability			
Percentage of leks	**Unsuitable 0.01 to <0.25**	**Low 0.25 to <0.50**	**Moderate 0.50 to <0.75**	**High 0.75 to 1.0**
Greater sage-grouse				
Active (%)	0.1 (*n* = 1)	0.8 (*n* = 14)	7.2 (*n* = 131)	92.0 (*n* = 1,680)
Inactive (%)	6.2 (*n* = 51)	24.5 (*n* = 202)	39.6 (*n* = 326)	29.7 (*n* = 244)
Gunnison sage-grouse				
Active (%)	0.0	0.0	1.1 (*n* = 1)	98.9 (*n* = 93)
Inactive/historic (%)	7.3 (*n* = 5)	22.1 (*n* = 15)	25.0 (*n* = 17)	45.6 (*n* = 31)

risk of collapse (table 2). Habitat managers should consult table 1 to identify the top predictor variables for GRSG breeding habitat in each Management Zone and for GUSG in Management Zone VII to identify specific issues. Identifying these issues may help explain why some leks occur in low, moderate, and high probability ranges. For example, there may be specific issues such as energy development structures or wildfire that eliminated sagebrush near inactive leks in the moderate probability range.

Sage-Grouse Population Index Model

Doherty et al. (2016) also developed a population index model (hereafter, population index) to identify areas on the landscape that contain population centers of male GRSG. Past work has shown that sage-grouse populations are highly clumped and that relatively small areas can contain a disproportionate number of males attending leks (Doherty et al. 2011a). This model is important because there are very large differences in the density of birds even within the identified high sage-grouse breeding habitat probability threshold described above. The population index serves as a proxy for relative abundance, which allows for better understanding of how risks, such as development or conifer expansion, and management strategies can be aligned spatially with population centers of sage-grouse. The population index model provides spatial insight into the importance of specific areas to the overall relative number of male GRSG during 2010 to 2014. Because of its threatened status under the Endangered Species Act (USFWS 2014a) and its limited distribution and abundance, we believe all GUSG range is important to the conservation of the species. However, lek locations can provide spatial insight into the relative importance of specific areas within the satellite populations of GUSG (fig. 13).

The population index model follows logic similar to previous published work by the U. S. Geological Survey on the Bi-State Greater sage-grouse population (Coates et al. 2016). To create the population index model, lek data were used to identify hotspots using kernel density functions. The kernel density function was linked with the breeding habitat model to develop a final population index model. The model created grids that represent an index to the relative abundance of breeding males in each 120 x 120 m pixel within each Management Zone. The final population index models incorporated spatial patterns of sage-grouse habitat selection with contemporary information of abundance within each Management Zone (fig. 9). Similar to the breeding habitat model, the population index model can be linked with other spatially explicit risk models or conservation actions to understand spatial overlap of habitat with sage-grouse populations. We did not develop a population index model for GUSG.

Use and Limitations of the Breeding Habitat Models

We used partial probability plots to elucidate habitat relationships of the variables in the final breeding habitat model for GRSG (Doherty et al. 2016) and GUSG. These figures demonstrate how the probability of the landscape to support a breeding population of sage-grouse changes relative to specific habitat variables (fig. 25). To improve interpretability and show variation across the GRSG range, we plotted each covariate for all Management Zones on the same plot. The partial probability plots were derived using the rfUtilities library (Evans and Murphy 2014).

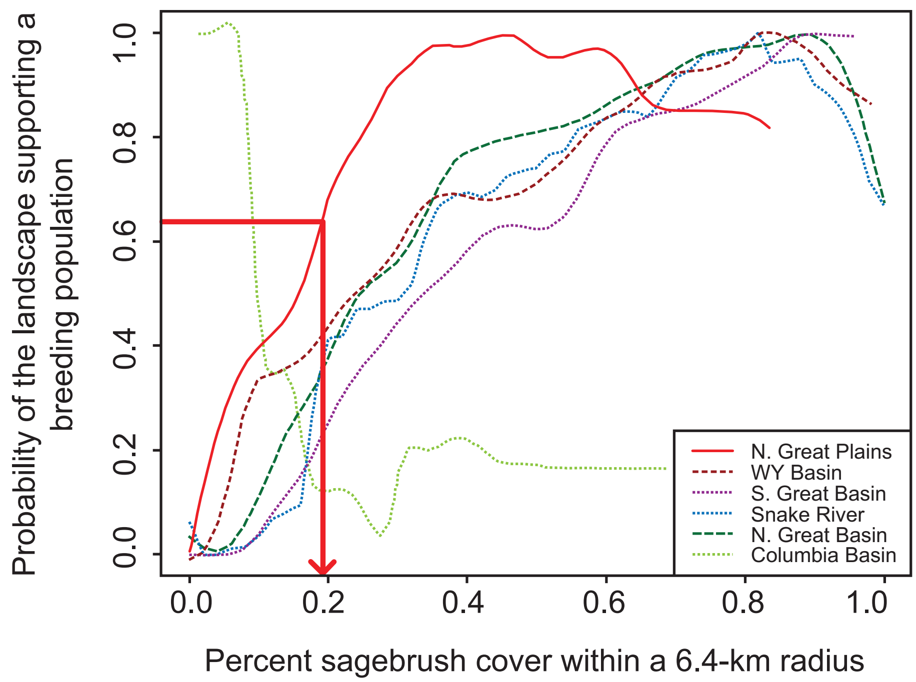
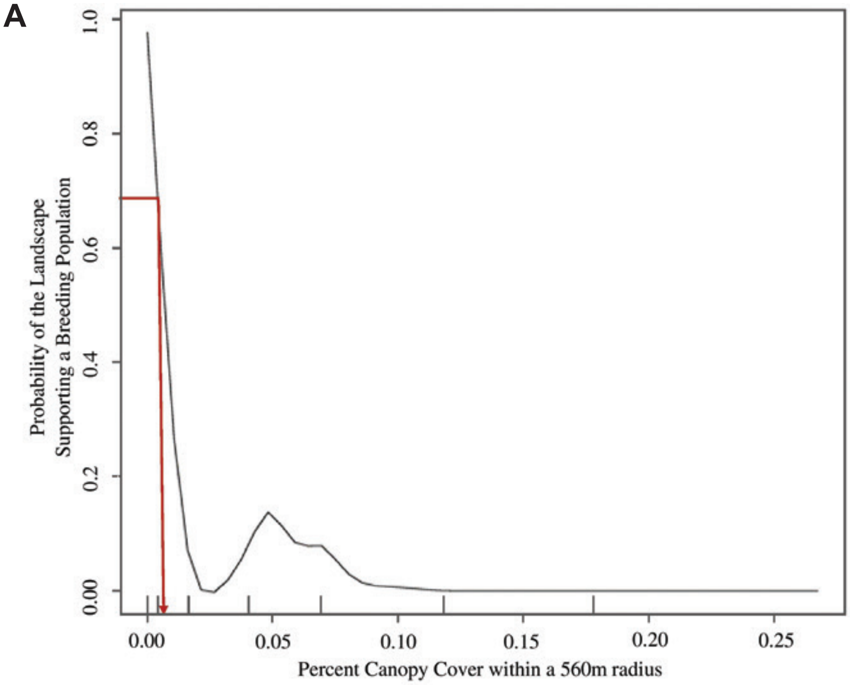


Figure 25—Partial probability plot depicting the effect of landscape cover of sagebrush on the probability of a landscape supporting a breeding population of Greater sage-grouse (modified from Doherty et al. 2016). The thick red line shows the minimum level of sagebrush landscape cover needed to support a breeding population of Greater sage-grouse based on a 4 mi (6.4 km) radius of a lek. Landscape cover of sagebrush was derived from Landfire (USGS 2014).

Partial probability plots of habitat relationships can also be used to identify thresholds in which non-habitat features exceed the tolerance of a species. For example, within the GUSG range, steep declines in the probability of an area supporting breeding habitat were associated with greater proportion of landscape cover of conifers within 0.35 mi (0.56 km) of leks (fig. 26A). The relationship of habitat characteristics can be mapped in a Geographical Information System (GIS) to display areas that have exceeded the GUSG threshold for the probability of lek occurrence in relation to a particular habitat characteristic. To illustrate this point, we have used habitat values associated with a probability threshold of 0.65 (identified in fig. 25 for GRSG) to predict the probability of lek occurrence across the entire range of GUSG (fig. 26B). We used this threshold because the original models developed by Doherty et al. (in press) indicated that all active GRSG leks existed in areas with estimated occupied habitat probabilities greater than 0.65, and our GUSG modeling for this report indicated all active GUSG leks were in areas with estimated breeding habitat probabilities greater than 0.66.

Use of a spatially explicit model that predicts occurrence based on multiple habitat features simultaneously is preferred over using a single habitat variable such as sagebrush cover to define priority habitat areas. This is because environmental niches of species are defined by multiple variables (e.g., James 1971). However, when multi-variable, spatially explicit models do not exist, then using threshold values of a single habitat variable from the literature, such as those identified in fig. 25, can be a useful starting place for defining priority areas. For example, Donnelly et al. (in press) showed an apparent threshold value of sagebrush cover of 40 percent above which the occurrence of three sagebrush obligate passerines increased (fig. 27).

A



B

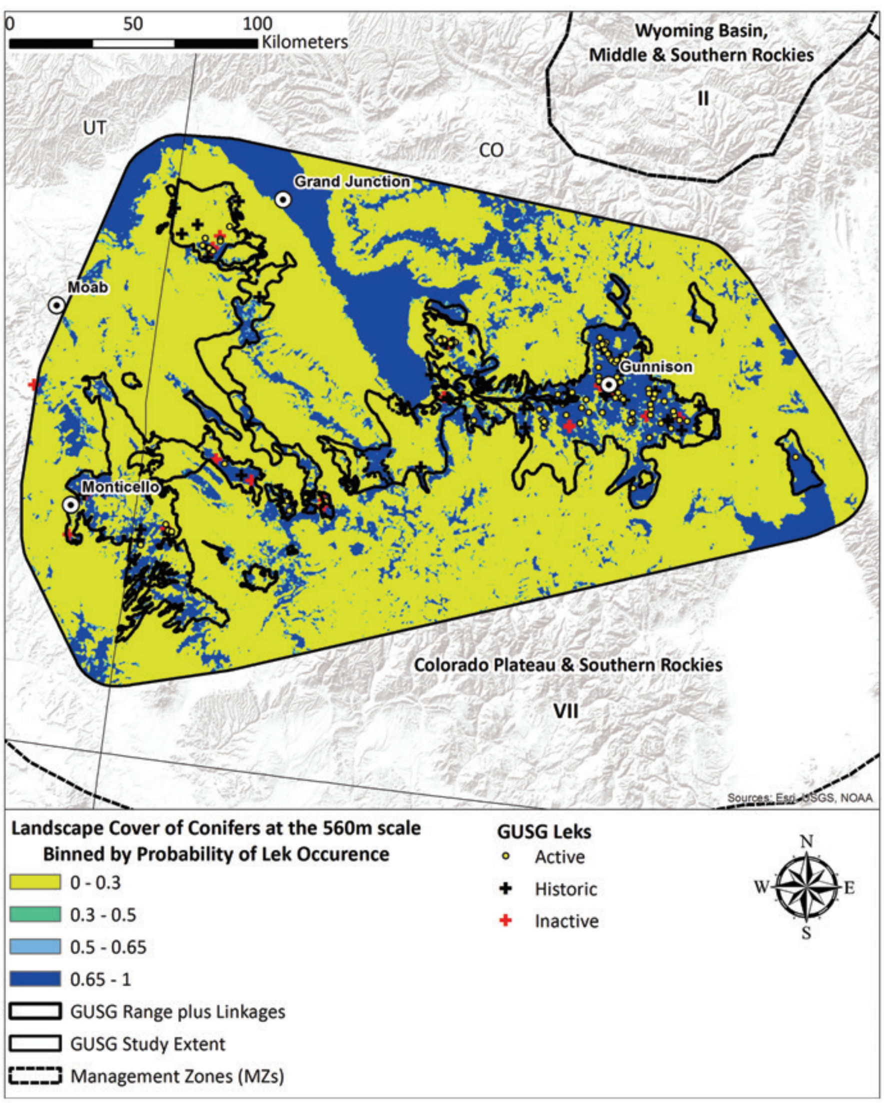


Figure 26—(A) Partial probability plot depicting the effect of landscape cover of conifers on the probability of a landscape supporting a breeding population of Gunnison sage-grouse. The red line shows the maximum level of conifer land cover that can support a breeding population of Gunnison sage-grouse based on a 0.35 mi (0.56 km) radius of a lek. (B) Spatial depiction of the landscape cover of conifers binned by the predicted probability of Gunnison sage-grouse lek occurrence using a 0.35 mi (0.56 km) radius of a lek. Conifer land cover was derived from Falkowski et al. (in press). The Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) is based on lek data from 1995 to 2015. Active, historic, and inactive leks are overlaid.

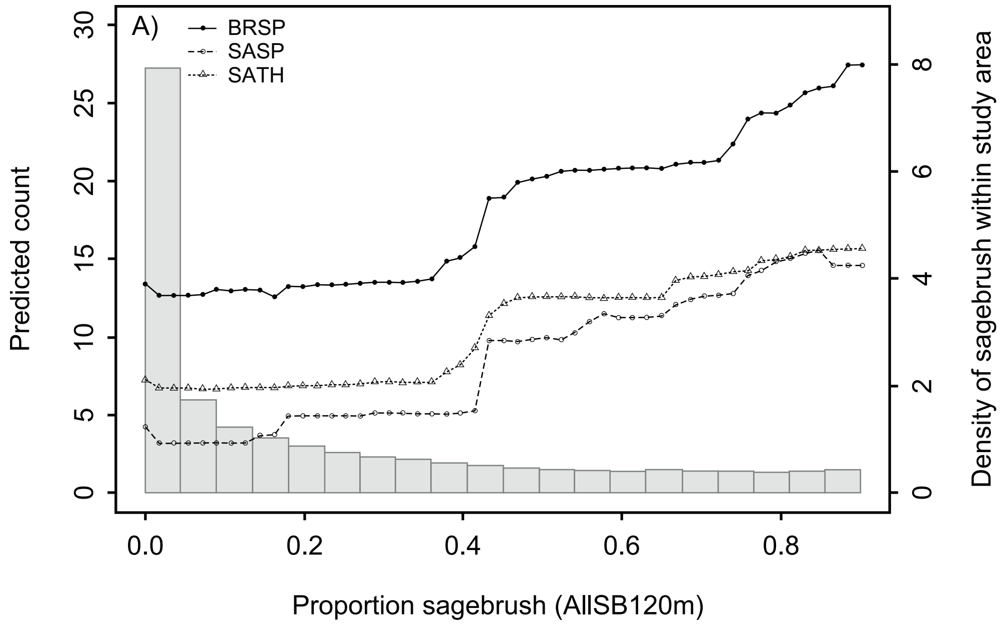


Figure 27—Partial dependence plot showing the predicted relationships among the proportion of sagebrush within a 120-m buffer and counts of Brewer's sparrow (BRSP), sagebrush sparrow (SASP), and sage thrasher (SATH) (Donnelly et al., in press). There is an apparent threshold value of 40 percent landscape 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).

6.2 Soil Temperature and Moisture Regimes as Indicators of Ecosystem Resilience and Resistance

Once suitable habitat for sage-grouse is identified, appropriate conservation and restoration actions are determined by assessing the likely ecological response to disturbances and management treatments. Soil temperature and moisture regimes can be used as indicators of resilience to disturbance and resistance to invasive annual species like cheatgrass in sagebrush ecosystems (Chambers et al. 2007; Chambers et al. 2014a,b,c; Maestas et al. 2016). In general, higher potential 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 potential 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. 21, 22; Chambers et al. 2014a,b; Maestas et al. 2016). An explanation of soil temperature and moisture regimes is in Appendix 2.

High soil moisture typically equates to elevated productivity and thus increased resilience (Chambers et al. 2014b), whereas cold soil temperatures typically limit growth and reproduction of nonnative invasive annual grasses and thus increase resistance (Chambers et al. 2007). The timing of precipitation also is important because cheatgrass and many other invasive annual grasses are particularly well-adapted to climates with cool and wet winters and warm and dry summers (fig. 4; Bradford and Lauenroth 2006; Bradley 2009). In contrast, areas that receive regular and relatively abundant summer precipitation (ustic soil moisture regimes at the high end of the precipitation gradient) often are dominated by warm and/or cool season grasses (Sala et al. 1997). These grasses likely create a more competitive environment and result in greater resistance to annual grass invasion and spread (Bradford and Lauenroth 2006; Bradley 2009).

For this report, we describe the predominant sagebrush ecological types in relation to soil temperature and moisture regimes, typical vegetation, and resilience to disturbance and resistance to invasive annual grass (table 3). To facilitate landscape analyses and prioritization, we categorized relative resilience and resistance based on soil temperature regime and moisture regime subclasses (fig. 7) and the predominant sagebrush ecological types (table 3; Appendix 3). We assigned each soil temperature regime and moisture regime subclass to one of three categories of relative resilience and resistance: high, moderate, and low. An explanation of soil temperature and moisture regimes and cross-walks between soil temperature and moisture regimes and relative resilience and resistance are in Appendix 2. To facilitate assessments across scales, we developed state-and-transitions models for the predominant ecological types based on soil temperature and moisture regimes and relative resilience and resistance of the sagebrush ecosystem types (Appendix 6). 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.

Much of the West-Central Semiarid Prairies (Management Zone I) is characterized by moderate to high resilience and resistance as indicated by relatively cool and summer moist regimes (fig. 7; table 3). However, the southeastern part of this ecoregion has low to moderate resilience and resistance as indicated by warm (mesic) and drier regimes (ustic bordering on aridic) (table 3). The dominant ecological types are comprised of varying amounts of cool season and warm season grasses, Wyoming big sagebrush, and plains silver sagebrush (table 3). The Western Cordillera in Management Zones 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. 7; table 3). Ecological types are typically comprised of mountain big sagebrush, snowberry, other shrubs, and cool season grasses (table 3). The Cold Deserts in Management Zones 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. 7; table 3). 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 3—Predominant sagebrush ecological types in the West-Central Semiarid Prairies (MZ I), Western Cordillera, and Cold Deserts Ecoregions (MZ II, VII) based on soil temperature and moisture regimes (to moisture subclass), typical characteristics, and 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 type. Definitions of MLRAs, state-and-transition models, ecological types, and ecological sites are in Appendix 1. The methods used to determine the predominant ecological types and a map that intersects the MLRAs, ecoregions, and management zones are found in Appendix 3. State-and-transition models were developed for most of these ecological types for this report (Appendix 6). A detailed description of how to use this information is in the section on "Determining Appropriate Management Treatments at Local Scales" in this report.

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) 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 South Dakota, 58C in North Dakota	Precipitation: 10-14 inches Typical Vegetation: *Wyoming big sage, plains silver sage, 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 minor and increases on warmer and drier sites.
Warm/Summer moist (Mesic/Ustic) 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.

Table 3—(Continued)

Western Cordillera (Middle and Southern Rockies)

Ecological Type	Characteristics	Resilience and Resistance
Cold/Wet (Cryic/Udic) Representative Area: Middle and Southern Rockies—MLRA 43B in Wyoming and Montana; 48A in Colorado; MLRA 47 in Utah **Applies to both Gunnison and Greater sage-grouse habitats**	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) 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 **Applies to both Gunnison and Greater sage-grouse habitats**	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. High variability due to aspect with lower resistance on south-facing aspects.
Cool/Summer moist (Frigid/Ustic) Representative Area: Uinta Mountains (MLRA 47, LRU C) in Utah and Wyoming; Southern Rockies in Colorado and Utah—MLRA 48A **Applies to both Gunnison and Greater sage-grouse habitats**	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) Described in Chambers et al. 2014b. Representative Area: Wasatch and Uinta Mountains in Utah (MLRA 47)	Precipitation: 12-22 inches Typical vegetation: m*ountain big sagebrush, antelope bitterbrush, snowberry, 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 can decrease resilience. *Resistance*—**Moderate**. Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.

Cold Deserts (Wyoming Basin and Colorado Plateau)

Ecological Type	Characteristics	Resilience and Resistance
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. **Applies to both Gunnison and Greater sage-grouse habitats**	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 can decrease resilience. *Resistance*—**Moderate.** Climate suitability to invasive annual bromes is relatively low, but increases with temperature and soil sand content.

Table 3—(Continued)

Cold Deserts (Wyoming Basin and Colorado Plateau)

Ecological Type	Characteristics	Resilience and Resistance
Cool bordering on warm/ Summer moist (Frigid bordering on Mesic/Ustic) Representative Area: Colorado Plateau – MLRA 48A/34A Piceance Basin-Book Cliffs in Colorado and Utah **Applies to both Gunnison and Greater sage-grouse habitats**	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 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 productivity, perennial herbs, 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 **Applies to both Gunnison and Greater sage-grouse habitats**	Precipitation: 10-14 inches in Wyoming; 12-16 inches in Utah and Colorado Typical Vegetation: *Wyoming big sagebrush, Utah juniper and twoneedle pinyon, wheatgrasses, needleandthread, Indian ricegrass* Shrub dominated—cool season grasses with warm season grasses increasing in the 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.
Warm/Dry bordering on summer moist (Mesic/Aridic bordering on Ustic) Representative Area: Wyoming Basin and Colorado Plateau—MLRAs 32 foothills in Wyoming and MLRA 34B and36 in Colorado and Utah **Applies to both Gunnison and Greater sage-grouse habitats**	Precipitation: 8-12 inches Typical Vegetation: *Wyoming big sagebrush, fourwing saltbush, Utah juniper, black sagebrush, shadscale, needleandthread, Indian ricegrass, wheatgrasses, galleta,* Shrub dominated—cool season grasses with some warm season grasses	*Resilience*—**Moderate to low.** Effective precipitation and productivity are moderately low, and vary with soil temperature and texture. *Resistance*—**Low.** Climate suitability to invasive annuals is high. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resistance.
Warm/Dry (Mesic/Aridic) Representative Area: Wyoming Basin—MLRA 32 in Wyoming (Bighorn and Wind River Basins)	Precipitation: 5-9 inches Typical Vegetation: *Wyoming big sagebrush, salt desert shrubs, wheatgrasses, needleandthread, Indian ricegrass* Shrub dominated—cool season grasses with some warm season grasses	*Resilience*—**Low.** Effective precipitation and productivity are low resulting in low resilience. *Resistance*—**Low.** Climate suitability to invasive annual grasses is high. Decreases in site productivity, herbaceous perennial species, and ecological conditions decrease resistance.

6.3 Sage-Grouse Habitat Resilience and Resistance Matrix

Knowledge of the potential resilience and resistance of sagebrush ecosystems can be linked with the probability that an area will provide sage-grouse breeding habitat to determine priority areas for management and identify effective management strategies (Chambers et al. 2014a; Wisdom and Chambers 2009). The sage-grouse habitat matrix (table 4) illustrates an area's relative resilience to disturbance and resistance to invasive annual grasses in relation to its probability of providing habitat for sage-grouse. As resilience and resistance go from high to low, timeframes required for sagebrush regeneration and perennial grass and forb abundance progressively limit the capacity of sagebrush ecosystems to recover after disturbances without management assistance. The risk of annual invasives increases and the ability to successfully restore burned or otherwise disturbed areas decrease as resilience and resistance decrease. As the probability of sage-grouse breeding habitat goes from low to high within these same ecosystems, the capacity to sustain populations of sage-grouse increases. Areas with breeding habitat probabilities of 0.25 to less than 0.5 are unlikely to provide adequate breeding habitat for sage-grouse. Areas with breeding habitat probabilities of 0.5 to less than 0.75 can provide breeding habitat for sage-grouse, but are at risk if sagebrush loss occurs without recovery or if other factors negatively impact the area, such as conifer expansion, development, or infrastructure. Areas with breeding habitat probabilities greater than or equal to 0.75 can provide the necessary breeding habitat conditions for sage-grouse to persist.

Management strategies can be determined by considering (1) resilience to disturbance and resistance to nonnative invasive plants, (2) sage-grouse breeding habitat probabilities, and (3) the predominant threats to both sagebrush ecosystems and their associated sage-grouse populations. Management strategies for the West-Central Semiarid Prairies (Management Zone I), Cold Deserts (Management Zone II), and Western Cordillera Ecoregions (Management Zone VII) are found in table 5. Because management strategies often cross-cut multiple program areas for land management agencies, 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, and wildlife, may all contribute to vegetation management strategies designed to address persistent ecosystem and land use and development threats.

The sage-grouse habitat matrix is a decision support tool that allows land managers to better evaluate risks and decide where to focus specific activities to promote desired species and ecosystem conditions (table 4; Chambers et al. 2014a). Areas with high sage-grouse breeding habitat probabilities and high concentrations of birds are typically comprised of intact habitats and thus are high priorities for management (table 4 cells 1C, 2C, 3C). Protective management can be used in and adjacent to these areas to maintain habitat connectivity and ecosystem resilience and resistance. A diverse set of strategies can be used for protective management such as reducing or eliminating disturbances from land uses and development, establishing conservation easements, utilizing an early detection and rapid response approach (EDRR; USDI 2016) to invasive plant species management, or suppressing fires (table 5). Areas with high sage-grouse 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. 2014c).

Table 4—Sage-grouse habitat resilience and resistance matrix based on resilience and resistance concepts from Chambers et al. (2014a,b), and breeding habitat probabilities based on Doherty et al. (2016) for Greater sage-grouse and developed in this report for Gunnison sage-grouse. 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. 2016) and relate to the sagebrush ecological types in table 3. Columns show the landscape-scale sage-grouse breeding habitat probability based on table 1 (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, land use and development threats, and climate change are in table 5 for the West-Central Semiarid Prairies (Management Zone I), Western Cordillera, and Cold Deserts (Management Zones II, VII).

Landscape-Scale Sage-Grouse Breeding Habitat Probability

Ecosystem Resilience to Disturbance and Resistance to Invasion (Low----Moderate----High)	**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 annual invasive plants becoming dominant is relatively low. Early detections/rapid response can be used to address problematic invasive plants. Conifer expansion is a localized issue. Tree removal can increase 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 annual invasive plants becoming dominant is moderate, especially on warmer sites. EDRR can be used to address problematic invasive plants. Conifer expansion is a localized issue. Tree removal can increase 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 annual invasive plants becoming dominant is high. Early detections and rapid response can be used to address problematic invasive plants. 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.		

Table 5—Management strategies for persistent ecosystem threats, land use and development threats, and climate change in the West-Central Semiarid Prairies (MZ I), Western Cordillera, and Cold Deserts (MZ II and VII). Recommendations are provided for prioritizing and targeting strategies based on cells in the sage-grouse habitat resilience and resistance matrix (table 4). Threats and strategies are cross-cutting and affect multiple program areas. While many of these fall under the broad umbrella of vegetation management, an integrated approach will likely be used in addressing threats. For example, it is expected that multiple agency program areas such as invasive plant management, fuels management, range management, wildlife, and others will contribute to strategies that use vegetation manipulation to address persistent ecosystem and land use and development threats.

Threat—Nonnative Invasive Species

Management Strategies

- 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 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.
    - 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.
    - Attempt proactive management of invasive annual grasses in the understory of sagebrush stands to reduce wildfire risk where proven methods exist (rather than focusing efforts exclusively on postfire annual grass control). Restrict spread of large weed infestations located in lower 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 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 fire 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 perennial grasses and forbs exist to promote recovery.

Threat – Wildfire

Management strategies

Fire Operations: Protection of areas supporting sagebrush is important for maintaining sage-grouse habitat. The West-Central Semiarid Prairies (MZ I) have limited availability of sagebrush and all areas with moderate and especially low resilience and resistance have longer recovery periods. If resources become limiting, consider the following prioritization:

- Fire suppression typically shifts from low to moderate priority when resistance and resilience categories shift from high to moderate, but it varies with large fire risk and landscape condition (cells 1B, 1C, 2B, 2C). In low resistance and resilience 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 connectivity for sage-grouse.
  - Areas where sagebrush communities have been successfully reestablished through seedings or other rehabilitation investments.
  - 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 includes vegetation projects that mitigate wildfire risk, improve resilience to disturbance, and restore habitat, as well as actions intended to protect intact sage-grouse habitat. Mechanical treatments are typically applied to reduce fuel loading or to alter species composition consistent with Land Use Plan objectives. Prescribed fire 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 species and to 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</u>

- Mechanical treatments conducted to minimize sagebrush loss (e.g., conifer reduction) is a high priority in areas with high breeding habitat probabilities and moderate to high resilience and resistance (cells 1B, 1C, 2B, 2C), and shifts to low in areas with low breeding habitat probabilities (cells 1A and 2A).
- In areas of low resilience and resistance, mechanical treatments to minimize sagebrush loss shifts in priority from low to high as the sage-grouse habitat probability increases (cells 3B, 3C). However, treatments intended to decrease fuel loads and increase perennial herbaceous species may be ineffective if insufficient perennial grasses and forbs exist to promote recovery and resist invasive plant species.
- Management activities may include:
  - Tree removal in early to mid-phase (Phases I, II) post-settlement conifers to maintain shrub/herbaceous cover and reduce fuel loads.
  - Removal of mountain shrub species that encroach into sagebrush communities (e.g., gambel oak, curlleaf mountain mahogany, snowberry, serviceberry.)
  - Tree removal in later phase (Phase III) post-settlement conifers to reduce risks or large or high severity fires.
  - Herbicide and/or seeding associated with mechanical treatments to reduce invasive species and restore native perennial species in areas with insufficient native perennial grasses and forbs for recovery.

Table 5—(Continued).

<u>Prescribed Fire</u>

- Consider alternatives to prescribed fire 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:
    - o 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 (30.5 cm) of precipitation do not respond favorably to burning.
    - o Burning is part of multi-stage restoration projects where burning is required to remove biomass following chemical treatments for site preparation.
    - o Monitoring data validates that the preburn composition will lead to successful, native plant dominance postburn.
- Use prescribed fire 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:
    - o Preburn community composition.
    - o Probability of invasive species establishment.
    - o Historic fire regime, and patch size/pattern to be created by burning.
    - o Wildfire risk and desired fuel loading to protect intact sagebrush; and
    - o Alternative treatments that may meet objectives.
- Prescribed fire activities may include:
    - o Burning piles or concentrations of woody biomass resulting from mechanical treatments.
    - o Broadcast burning in areas having conifer concentrations that interface with sagebrush communities, while intentionally avoiding burning intact sagebrush that is not fire tolerant.
    - o Creating fuel conditions that constrain future fire spread.
    - o Prescribed fire adjacent to intact habitat where treatment will aid in wildfire suppression.
    - o Prescribed fire to create landscape patterns that improve resilience and desired species composition.

Chemical Treatment and Seeding: Herbicide treatments and seedings are used to decrease invasive species composition and increase native species dominance where perennial native grasses and forbs are insufficient for site recovery. Herbicide 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.

Postfire Rehabilitation: Postfire rehabilitation is a cross-cutting effort involving range, wildlife, soils, fire, and fuels subject matter expertise. General considerations for prioritization of postfire rehabilitation efforts are:

- Priority shifts from generally low priority (cells 1A, 2A, 3A, 1B, and 1C) to moderate priority in moderate resilience and resistance areas (cells 2B, 2C). Areas of low resilience/resistance shift in priority from low priority to high priority with increasing habitat probability for sage-grouse (cells 3B to 3C).
- Areas of higher priority include:
    - o Areas where perennial herbaceous cover, density, and species composition is inadequate for recovery.
    - o Areas where seeding or transplanting sagebrush is needed to maintain habitat connectivity for sage-grouse.
    - o Areas threatened by nonnative invasive plants.
    - o Steep slopes and soils with erosion potential.

Threat—Climate Change

Management strategies

- Where effects of climate change and its interactions with stressors are expected to be relatively small and knowledge and capacity high, continue to use best management practices.

Table 5—(Continued).

- Where climate change and stress interactions are expected to be severe, proactive management such as assisted migration may be necessary to facilitate transition to a new site potential.
- Practice drought adaption measures such as reduced grazing during droughts, conservation actions to facilitate species persistence, and seeding and transplanting techniques proven to work during drought.
- Use species and ecotypes for seeding and out-planting that are adapted to both site conditions and drought, and resilient to episodic drought where projections indicate long-term climate change.
- Monitor transition zones between climatic regimes (the edges). Plant community shifts that affect management decisions often occur between Major Land Resource Areas or Level III Ecoregions.

Threat—Grazing

Management strategies

- Manage livestock grazing to maintain a balance of perennial native grasses (warm and/or cool season species as described in ESDs for that area), forbs, and biological soil crusts to allow natural regeneration and to maintain resilience. 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 rest 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 species. 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.

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 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
    - Using certified weed-free (including annual bromes) gravel and fill material
    - Assessing and treating weed populations, if necessary, prior to surface disturbing activities
    - Removing mud, dirt, and plant parts from construction equipment
    - Addressing weed risk and spread factors in travel management plans
    - Ensuring timely establishment of desired native plant species on reclamation sites
    - Using locally adapted native seed, if possible

Table 5—(Continued).

- Intensively monitoring reclamation sites to ensure seeding success and to determine presence of weeds
- Using mulch, soil amendments, or other practices to expedite reclamation success when necessary
- Ensuring 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—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 Sage Grouse Initiative Cultivation Risk layer).
- Offer alternatives to farming on expired USDA Conservation Reserve Program 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 Conservation Reserve Program 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—Sagebrush Reduction

Management strategies

- Avoid intentional sagebrush removal (prescribed fire, chemical, 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 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 annual grasses after treatment in lower resistance and resilience areas (Miller et al. 2014, 2015).

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 among the highest priorities for protective management (table 4 cell 3C; Chambers et al. 2014c).

Areas with moderate sage-grouse breeding habitat probabilities are comprised of habitat that supported a higher proportion of leks in the past than currently (table 2) and that may be improved through various management strategies (table 4 cells 1B, 2B, 3B). Management objectives may include increasing resilience and resistance by promoting perennial grasses and forbs through conifer removal or improved livestock management, reducing or eliminating new infestations of invasive plants through EDDR approaches, or restoring sagebrush habitat through seeding or transplanting (table 5). Management strategies often have synergistic effects. Increasing 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) and, in turn, 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 expansion areas, can increase the functional capacity of plant communities to resist invasive annual grasses (Chambers et al. 2014b) 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 post-fire rehabilitation and the likelihood of nonnative annual grass invasion (Chambers et al. 2014b; Miller et al. 2013, 2014, 2015). Areas with lower resilience and resistance may still be among the highest priorities for management in areas with moderate breeding habitat probabilities, but they may require greater investment and repeated interventions to achieve management objectives (table 4 cell 3B; Chambers et al. 2014a).

Areas with low sage-grouse breeding habitat probabilities are characterized by habitat that supported active sage-grouse leks in the past, but that currently support few leks (table 4 cells 1A, 2A, 3A). If land use and development threats such as oil and gas development or cropland conversion are causing low sage-grouse 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. 2014a,c). Consequently, substantial investment and repeated interventions may be required to achieve objectives.

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, and have differing land use histories and species composition (Miller et al. 2014, 2015; Pyke et al. 2015a,b). Also, areas with low sage-grouse 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 also benefit these other resources and species.

7. Delineating Habitats for Targeted Management Intervention at the Ecoregional/Management Zone Scale

Effective management and restoration of sage-grouse habitat prioritizes the best management practices in the most appropriate places. This section describes an approach for targeting areas for sage-grouse habitat management based on widely available data, including (1) Priority Areas for Conservation for GRSG and critical habitat and linkages for GUSG, (2) breeding habitat probabilities and population indices, (3) ecosystem resilience and resistance, and (4) persistent ecosystem and land use and development threats. 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. Datasets used to conduct the analyses and create the maps are in Appendix 4.

7.1 Assessing Target Areas for Sage-Grouse Habitat Management—Key Data Layers

Priority Areas for Conservation and Critical Habitat

Sage-grouse priority areas for conservation have been delineated using available habitat and population data to identify areas critical for conserving GRSG populations (USFWS 2013). Similarly, critical habitat has been delineated for conserving GUSG populations (GSGRSC 2005; USFWS 2014a). These areas can be used as a first filter in prioritizing management actions. Habitats outside of priority areas for conservation and critical habitat areas are also important to consider where they provide genetic and habitat linkages and capture important seasonal habitats (USFWS 2013).

Breeding Habitat Probabilities and Population Indices

Further prioritization can be achieved by mapping areas with high breeding habitat probabilities and population indices. The breeding habitat models provide information on habitat characteristics (figs. 23, 24; table 1; Doherty et al. 2016). The categorical break points show the proportion of active and inactive leks in each sage-grouse Management Zone for GRSG and GUSG (table 2). These areas can be used to prioritize areas for management based on the probability of an area providing suitable habitat. The categorized breeding habitat probabilities overlaid with lek locations shows the relationship of modeled breeding habitat and active breeding locations (figs. 23, 24).

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. 9; 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 sage-grouse populations identified by stakeholders (e.g., highest 25 percent or 85 percent of the population). For the purposes of this report, the population index model was classified into two categories (0–80 percent and 80–100 percent of the relative population). Because of the large area currently occupied by GRSG, the population index model can be used to better focus appropriate management actions on areas that: (1) currently support viable populations, (2) provide connectivity between population centers, and (3) occur close enough to breeding concentration areas to allow successful recolonization of reclaimed habitat (Coates et al. 2016).

Resilience to Disturbance and Resistance to Nonnative Invasive Annual Grasses

Resilience and resistance predictions coupled with sage-grouse breeding habitat probabilities and population indices provide critical information for determining areas for targeted management actions (table 5). Soil temperature and moisture regimes are strong indicators of ecological types as well as resilience to disturbance and resistance to nonnative invasive annual grasses figs. 7, 21, 22; table 3). The available data for soil temperature and moisture regimes were recently compiled for the western and eastern ranges of sage-grouse (Maestas et al. 2016; Appendix 2). Relative resilience and resistance categories were assigned to each soil temperature and soil moisture subclass to create a simplified index (table 3; figs. 28, 29;

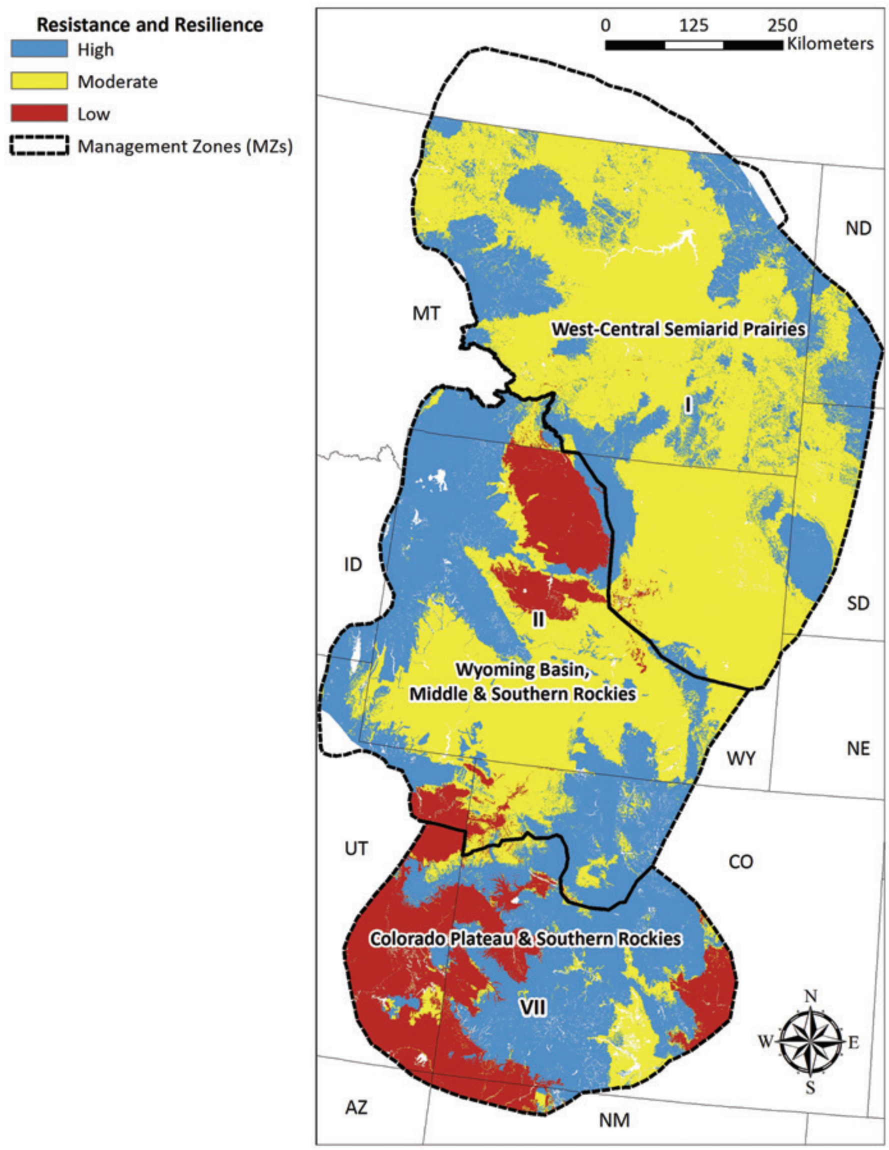


Figure 28—The soil temperature and moisture regimes categorized according to high, moderate, and low resilience and resistance in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

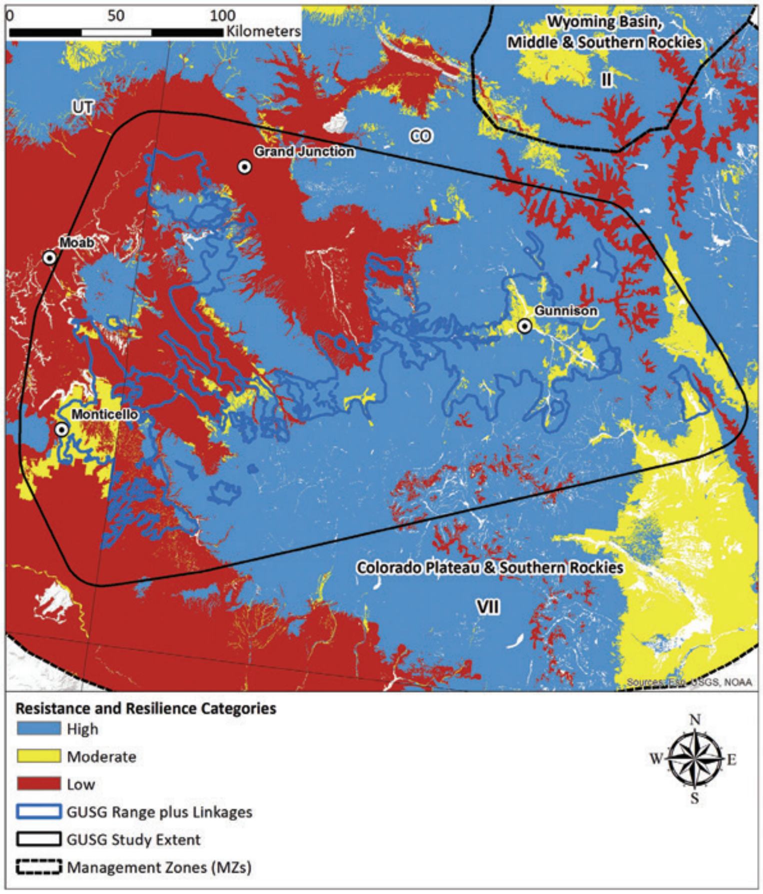


Figure 29—The soil temperature and moisture regimes categorized according to low, moderate, and high resilience and resistance in the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) and surrounding area. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

Appendix 2) that allows managers to predict the ecological responses of sagebrush ecosystems to both disturbance and management actions.

Habitat Threats

Assessing the magnitude of persistent ecosystem and land use and development threats can provide important insights into targeting areas for treatment and the most appropriate management strategies (e.g., Hanser et al. 2011). Although habitat threats are considered in the breeding habitat and population index models (Doherty et al. 2016), depicting threats to different populations is necessary to assess their magnitude and evaluate viable management strategies. The threats and data sources considered in this report largely follow those in the Interagency Greater Sage-Grouse Disturbance and Monitoring Subteam Report (IGSDMS 2014) and are in Appendix 4. More refined data products are often available at regional to local scales. For example, Bureau of Land Management 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 sage-grouse (https://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html). Also, high resolution geospatial data for cultivation risk layers are available and piñon and/or juniper landscape cover will soon be available for the eastern portion of the range (http://map.sagegrouseinitiative.com/). Land managers can evaluate the available land cover datasets for the targeted area and select those datasets with the highest resolution and accuracy.

Other Relevant Data Layers

Use of spatially explicit habitat models like those developed by Doherty et al. (2016) for GRSG is generally preferred over using threshold values for specific habitat variables like landscape cover of sagebrush (Cushman et al. 2013). However, in the absence of these models, individual habitat variables can provide important information on habitat characteristics and may provide a viable approach for assessing the probability of suitable habitat (Vojta et al. 2013). Landscape cover of sagebrush has been shown to be an important predictor of persistence of sage-grouse and other sagebrush obligate species and can help inform management decisions. Landscape cover of sagebrush is typically derived from remotely sensed land cover data such as LANDFIRE (USGS 2013) using a moving window analysis (see Appendix 5). Because of the difficulty of using remote sensing to assess landscape cover of sagebrush in the West-Central Semiarid Prairies (Management Zone I), landscape cover of sagebrush is less informative for this ecoregion than for the Wyoming Basin and Middle Rockies (Management Zone II) or for the Colorado Plateau and Southern Rockies (Management Zone VII). Areas containing sagebrush are commonly mapped as grassland types, because sagebrush is either an understory component or grass cover dominates the signature during the mapping process.

Analyses of the landscape cover of sagebrush around leks in various portions of the range (Aldridge et al. 2008; Knick et al. 2013; Wisdom et al. 2011) indicate that the relative probability of lek persistence can be estimated using percentage sagebrush landscape cover. In general, low lek persistence occurs with less than 25 percent landscape cover of sagebrush; intermediate persistence with 25–65 percent; and high persistence with more than 65 percent (see Chambers et al. 2014a for a detailed explanation). However, analyses conducted in Management Zone I for this report show that active leks are distributed across all of these sagebrush landscape cover categories (measured within 6.4 km of leks) indicating that GRSG select breeding habitat across a broader range of sagebrush landscape cover in Management Zone I than in other Management Zones. This finding reflects the relatively lower percentage of sagebrush landscape cover in Management Zone I (14 percent) than in Management Zone II (45 percent; Knick et al. 2011) where most active GRSG leks occurred in areas of high sagebrush cover. Similar relationships exist for other species in the region (Aldridge et al. 2011), and 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. 27; Donnelly et al., in press).

7.2 Assessing Target Areas for Sage-Grouse Habitat Management—Overlaying Data Layers

Assessments of priority areas for management are typically conducted at the scale of ecoregions or Management Zones for GRSG because of similarities in biophysical characteristics and thus management strategies and treatments. Landscape scale analyses for GUSG are typically conducted at the scale of the range plus linkages. 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 from this process are an essential component of prioritizing areas for management actions and developing management strategies.

The sage-grouse habitat resilience and resistance matrix (table 4) is based on the relative resilience and resistance of an area and the probability that the area provides suitable breeding habitat. The matrix provides the basis for interpreting the overlays and analyses and for selecting priority areas for management. Specific management strategies (table 5) address the predominant threats in sagebrush ecosystems and are linked directly to the cells in the matrix. These strategies are used to determine appropriate management actions for priority areas for management.

The steps in the geospatial analysis are identified below. The maps used to illustrate the steps are from the GRSG eastern range and the GUSG range and linkages.

1. Determine the best information available for the analyses. For GRSG, this includes Priority Areas for Conservation, breeding habitat probabilities, the population index (Doherty et al. 2016), and breeding bird densities (figs. 9, 23). For GUSG, this includes the range plus linkages, breeding habitat probabilities, and breeding bird densities (fig. 24).
2. Determine the probability of suitable habitat. For GRSG and GUSG, this is the breeding habitat probability (table 2; low = 0.25 to <0.50, moderate = 0.50 to <0.75, high = 0.75 to 1.0).
3. Create the resilience and resistance layer using categorized soil temperature and moisture regimes (figs. 7, 28, 29; Appendix 2; Maestas et al. 2016).
4. Overlay resilience and resistance categories with the probability of suitable habitat for the assessment area (figs. 30, 31). This layer provides information on how areas that can support sage-grouse will respond to both disturbance and management treatments, specifically the likelihood of recovery and risk of conversion to undesirable states. Calculating the areas in the different categories by ecoregion, Priority Areas for Conservation within Management Zones for GRSG, or the range plus linkages for GUSG can help identify priority areas for management.
5. Overlay resilience and resistance with species population abundance measures. For GRSG and GUSG, this is the breeding bird densities (figs. 32). 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 that the species can recolonize reclaimed habitats. Calculating the areas in the different categories by ecoregion, Priority Areas for Conservation within Management Zones for GRSG, or the range plus linkages for GUSG can further refine areas for management.

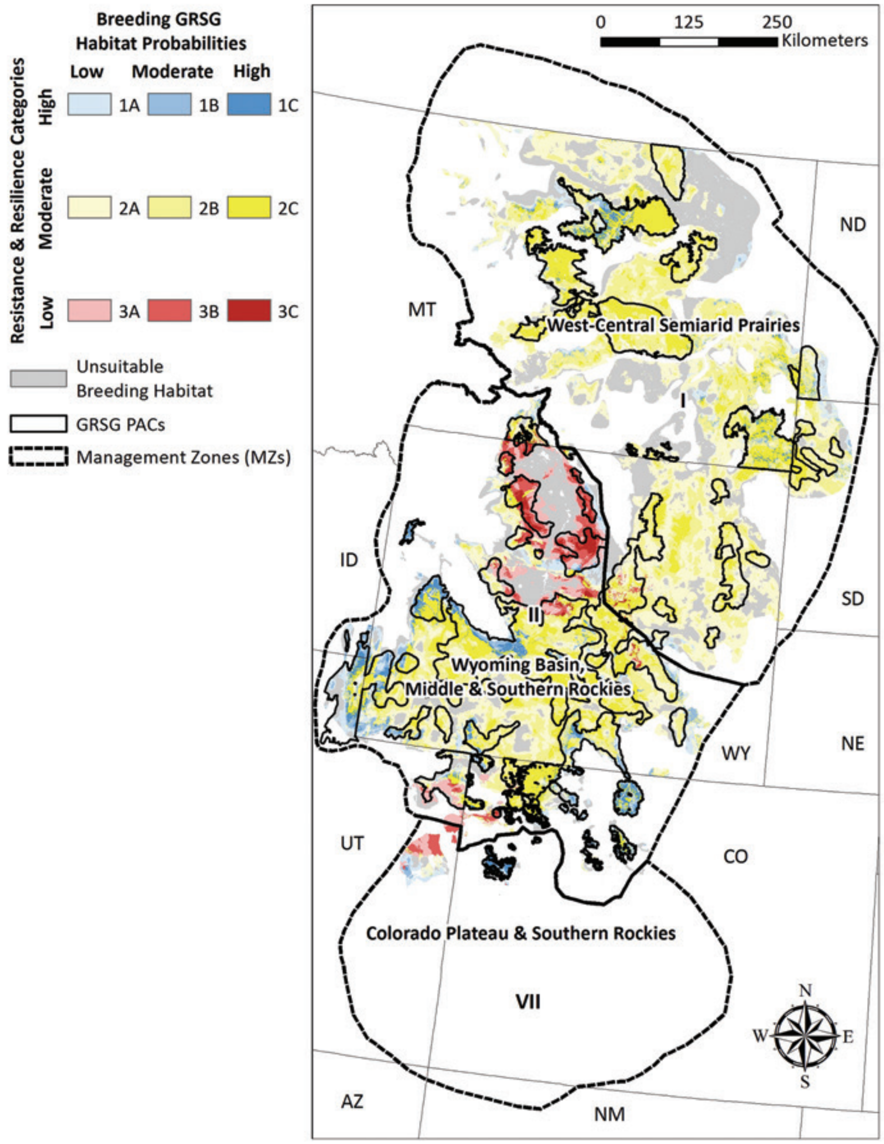


Figure 30—Greater sage-grouse breeding habitat probabilities based on 2010 to 2014 lek data (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

6. 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/Management Zone for GRSG and within the range plus linkages for GUSG. Developing thresholds (ecological minimums) for the extent and magnitude of the threat (e.g., land cover of piñon and juniper and invasive annual grasses, density of oil and gas wells, road density, etc.) above which the habitat can no longer support sage-grouse 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

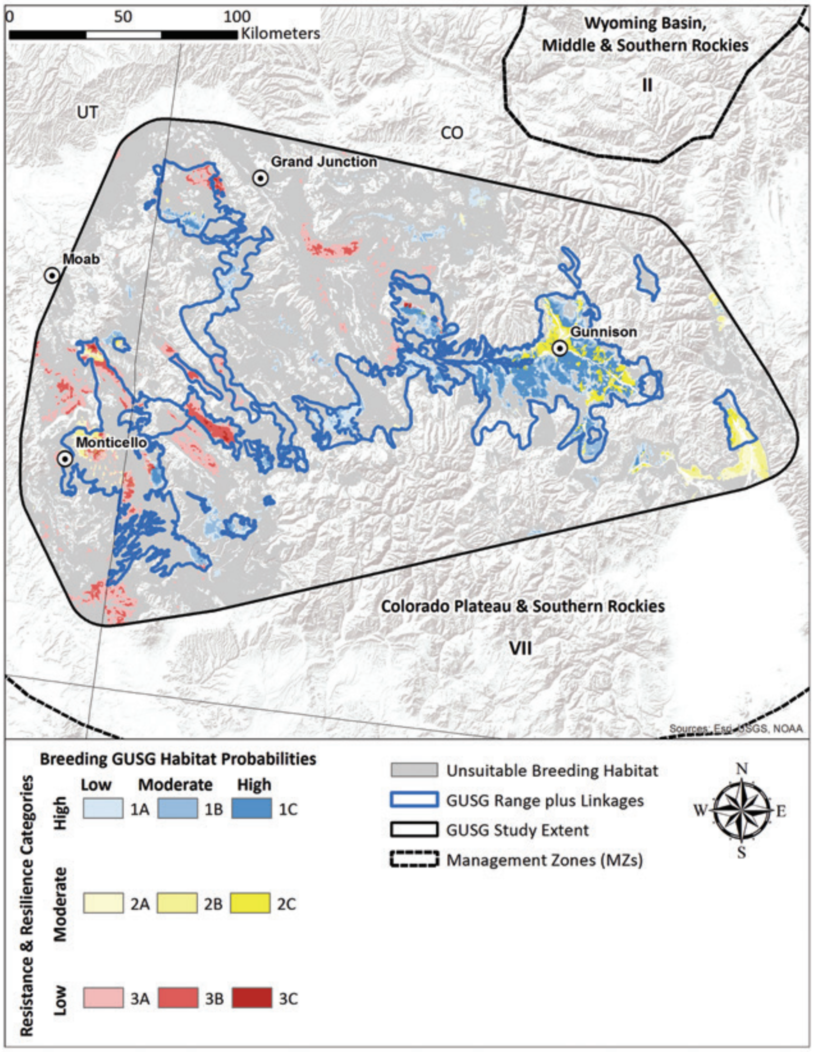


Figure 31—Gunnison sage-grouse breeding habitat probabilities for the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) based on lek data from 1995 to 2015 intersected with resilience and resistance categories developed from soil temperature and moisture regimes. The breeding habitat probabilities were developed for this report based on Doherty et al. 2016. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

significantly when conifer canopy exceeds 4 percent in the immediate vicinity (within 3,280 ft; 1000 m) of the lek (Baruch-Mordo et al. 2013), and most active leks average less than 1 percent conifer cover at landscape scales (3.1 mi; 5 km; Knick et al. 2013).

7. Prioritize areas for management. The maps and data derived from the prior steps and the sage-grouse habitat matrix (table 4) are used to determine priority areas for management within the assessment area. The actual prioritization is based on consideration of several factors:

   a. The area provides suitable habitat and supports species populations. For GRSG and GUSG, this is the breeding habitat probability and breeding bird density (table 4 cells 1B, 2B, 3B, 1C, 2C, 3C).

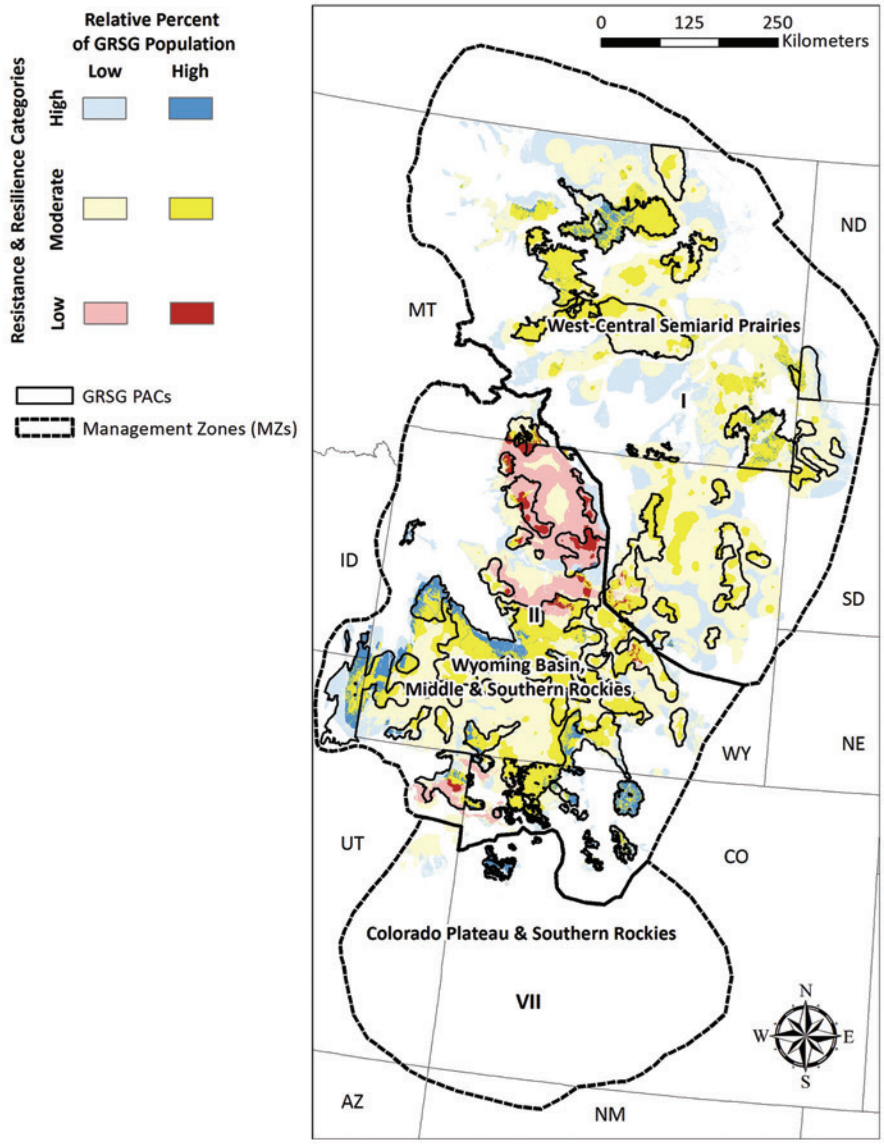


Figure 32—Relative percent of Greater sage-grouse population based on breeding abundance during 2010 to 2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes in Management Zones I, II, and VII (Stiver et al. 2006) and associated ecoregions (EPA 2016). The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3. A value of 80 percent is used to identify areas with high breeding abundance.

b. The area is at risk due to low resilience and resistance but has high conservation value for sage-grouse (table 4 cells 3B, 3C).
c. The area has reduced habitat suitability but could be improved by active management. These areas may be at higher risk of becoming unsuitable with additional disturbances that degrade habitat (table 4 cells 1B, 2B, 3B).

8. Determine the most appropriate management strategies. The maps and data derived from the prior steps and the sage-grouse habitat matrix (table 4) are also used to determine management strategies (table 5). At the scale of the ecoregion, or Priority Areas for Conservation within Management Zones for GRSG and range plus linkages for GUSG, management strategies

are developed that require interagency coordination, 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 (USDI BLM 2014); (2) coordinating efforts to use early detection and rapid response to prevent expansion of invasive annual grasses and other weeds; and (3) assessing habitat connectivity among Priority Areas for Conservation 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. 2016).

Differences in Resilience and Resistance, Breeding Habitat Probabilities, and Relative Percentage of the Population for the GRSG Management Zones

Here, a general overview of the similarities and differences in breeding habitat probabilities, relative percentage of population, and resilience and resistance is provided for Management Zones in the eastern portion of the range. Selecting priority areas for management will require more detailed analyses.

The area in GRSG Priority Areas for Conservation in Management Zones I and II is largest for moderate breeding habitat probabilities (46 percent and 43 percent), intermediate for high breeding habitat probabilities (33 percent and 31 percent), and smallest for low breeding habitat probabilities (19 percent and 21 percent), respectively (fig. 23; table 6). In Management Zone VII, the area in GRSG Priority Areas for Conservation is greatest for high breeding habitat probabilities (42 percent) followed by moderate (29 percent) and then low (24 percent). The area outside of Priority Areas for Conservation with high breeding habitat probability ranges from 8 percent in Management Zone VII, to 11 percent in Management Zone II, to17 percent in Management Zone I. This indicates significant acreages can be considered

Table 6—The area and percentage of breeding habitat probability classes for Greater sage-grouse for Management Zones (MZ) I, II, and VII (A) and for priority area for conservation (PACs) within each Management Zone (B).

A

Breeding habitat	MZ I			MZ II			MZ VII		
probabilities	acres	km^2	%	acres	km^2	%	acres	km^2	%
High	5,488,682	22,212	12	6,586,037	26,653	18	114,492	463	10
Moderate	13,919,754	56,331	30	13,311,428	53,870	36	386,027	1,562	33
Low	15,693,021	63,507	34	11,330,253	45,852	31	532,736	2,156	45
Unsuitable	10,924,858	44,211	24	5,647,767	22,856	15	147,250	596	12
Total	46,026,314	186,262	100	36,875,485	149,230	100	1,180,506	4,777	100

B

Breeding habitat	MZ I PACs			MZ II PACs			MZ VII PACs		
probabilities	acres	km^2	%	acres	km^2	%	acres	km^2	%
High	3,914,390	15,841	33	5,285,823	21,391	31	96,865	392	42
Moderate	5,328,819	21,565	46	7,406,972	29,975	43	68,201	276	29
Low	2,170,323	8,783	19	3,564,243	14,424	21	55,599	225	24
Unsuitable	291,090	1,178	2	882,906	3,573	5	11,614	47	5
Total	11,704,623	47,367	100	17,139,944	69,363	100	232,279	940	100

for conservation and restoration actions both within the high habitat probability class in the Priority Areas for Conservation and in adjacent areas of high and especially moderate habitat probability.

The majority of the area within the GRSG Priority Areas for Conservation in each Management Zone is characterized by moderate resilience and resistance for Management Zone I and II (91 percent and 62 percent, respectively; fig. 28; table 7), and by high resilience and resistance for Management Zone VII (90 percent). A smaller percentage of habitat within Priority Areas for Conservation is in the low (1 percent) than high (8 percent) category in Management Zone I; similar percentages of habitat within Priority Areas for Conservation are in high (21 percent) and low (17 percent) in Management Zone II; and a small percentage of habitat within Priority Areas for Conservation is in either moderate (9 percent) or low (1 percent) in Management Zone VII. The large area within the high and moderate categories indicates that much of the eastern portion of the range within Priority Areas for Conservation has the capacity to recover from disturbances given appropriate management. However, areas in and adjacent to Priority Areas for Conservation, especially in Management Zone II, are characterized by low resilience and resistance. These areas are more susceptible to invasive annual grasses and require longer periods for recovery from either disturbances or management treatments (Chambers et al. 2014a; Mealor et al. 2012).

Coupling breeding habitat probabilities with resilience and resistance indicates that Priority Areas for Conservation generally have more area with high and moderate habitat probabilities and with moderate to high resilience and resistance than the Management Zones as a whole (fig. 30; tables 8, 9). In Management Zone I and II, most of the area within GRSG Priority Areas for Conservation is comprised of moderate to high breeding habitat probabilities with moderate resilience and resistance (fig. 30; table 9). In Management Zone VII, most of the area within the GRSG Priority Areas for Conservation is comprised of moderate to high breeding habitat probabilities with high resilience and resistance. Relatively small areas within the Priority Areas for Conservation have habitat probabilities that are unsuitable or low regardless of resilience and resistance class.

Table 7—The area and percentage of resilience and resistance classes for Management Zones (MZ) I, II, and VII (A) and for priority areas for conservation (PACs) within each Management Zone (B).

A

Resilience and probabilities	MZ I			MZ II			MZ VII		
	acres	km^2	%	acres	km^2	%	acres	km^2	%
High	21,993,546	89,005	28	25,270,281	102,265	43	17,614,769	71,285	47
Moderate	55,414,038	224,253	71	23,466,452	94,966	40	3,830,409	15,501	10
Low	145,724	590	1	9,913,884	40,120	17	16,297,510	65,954	43
Total	77,553,308	313,848	100	58,650,618	237,351	100	37,742,688	152,739	100

B

Resilience and probabilities	MZ I PACs			MZ II PACs			MZ VII PACs		
	acres	km^2	%	acres	km^2	%	acres	km^2	%
High	901,296	3,647	8	3,450,456	13,964	21	210,705	853	90
Moderate	10,549,022	42,690	91	10,384,371	42,024	62	20,400	83	9
Low	97,818	396	1	2,871,828	11,622	17	2,121	9	1
Total	11,548,135	46,734	100	16,706,656	67,610	100	233,226	944	100

Table 8—The area and percentage of breeding habitat probability class by resilience and resistance class for Greater sage-grouse for each Management Zone (MZ). Percentages within a Management Zone add to 100.

Breeding habitat probability	Resilience and resistance								
	Low			Moderate			High		
	acres	km^2	%	acres	km^2	%	acres	km^2	%
MZ I									
High	18,503	75	0	4,991,493	20,200	11	443,768	1,796	0
Moderate	69,366	281	0	12,986,234	52,554	29	720,665	2,916	2
Low	34,089	138	0	13,974,961	56,555	31	1,477,070	5,977	3
Unsuitable	12,319	50	0	7,503,099	30,364	17	3,241,274	13,117	7
Total	134,276	543	0	39,455,788	159,672		5,882,776	23,807	
MZ II									
High	796,172	3,222	2	4,586,273	18,560	13	1,121,366	4,538	3
Moderate	2,144,299	8,678	6	8,979,738	36,340	25	1,975,062	7,993	5
Low	2,313,881	9,364	6	6,325,700	25,599	18	2,411,600	9,759	7
Unsuitable	2,328,125	9,422	6	1,574,251	6,371	4	1,571,550	6,360	4
Total	7,582,478	30,685		21,465,962	86,870		7,079,578	28,650	
MZ VII									
High	1,530	6	0	4,277	17	0	108,532	326	9
Moderate	236,219	956	20	23,873	97	2	125,936	510	11
Low	173,717	703	15	102,109	413	9	256,693	1,039	22
Unsuitable	18,368	74	2	48,244	195	4	80,532	326	7
Total	429,833	1,739		178,503	722		571,693	2,200	

Table 9—The area and percentage of breeding habitat probability class by resilience and resistance class for Greater sage-grouse for priority areas for conservation (PACs) within each Management Zone (MZ). Percentages within a Management Zone add to 100.

Breeding habitat probability	Resilience and resistance								
	Low			Moderate			High		
	acres	km^2	%	acres	km^2	%	acres	km^2	%
MZ I PACs									
High	17,400	70	0	3,507,329	14194	30	359,745	1456	3
Moderate	59,363	240	1	4,882,662	19759	42	301,332	1219	3
Low	20,147	82	0	1,919,033	7766	17	192,156	778	2
Unsuitable	911	4	0	238,578	965	2	47,959	194	0
Total	97,822	396		10,547,602	42,685		901,192	3,647	
MZ II PACs									
High	673,119	2,724	4	3,547,203	14,355	21	993,466	4,020	6
Moderate	1,268,264	5,132	8	4,858,003	19,660	29	1,140,357	4,615	7
Low	799,051	3,234	5	1,734,161	7,018	10	881,707	3,568	5
Unsuitable	131,216	531	1	244,175	988	1	431,869	1,748	3
Total	2,871,650	11,621		10,383,542	42,021			13,951	
MZ VII PACs									
High	206	1	0	2,320	9	1	94,452	382	41
Moderate	1,591	6	1	3,512	14	2	63,245	256	27
Low	267	1	0	10,799	44	5	44,166	179	19
Unsuitable	25	0	0	3,384	14	1	8,156	33	4
Total	2,089	8		20,016	81		210,019	850	

Intersecting the resilience and resistance categories with the breeding bird densities provides information similar to the breeding habitat probabilities for GRSG Priority Areas for Conservation, but allows greater focus on areas known to support large populations of birds (fig. 32; tables 10, 11). A high percentage of the breeding bird density within both the Management Zones and Priority Areas for Conservation is within areas characterized by moderate resilience and resistance in Management Zones I and II, and by high resilience and resistance in Management Zone VII (tables 10, 11).

Examination of other data layers shows that different persistent ecosystem and land use and development threats exist across the eastern portion of the range and allows managers to focus on the primary threats to sage-grouse habitat within targeted areas. Cropland conversion is clearly one of the primary threats in the northern portion of Management Zone I (fig. 19). Oil and gas development is a threat across much of the eastern range, particularly the southern portion of Management Zone I, large areas of Management Zone II, and the northern and eastern portion of Management Zone VII (fig. 17).

Differences in Resilience and Resistance and Breeding Habitat Probabilities for the Gunnison Sage-grouse Range plus Linkages

Examining the breeding habitat probabilities and resilience and resistance for the GUSG the range plus linkages shows a high degree of diversity in habitat characteristics. Breeding habitat probabilities are classified as unsuitable (54 percent) or low (20 percent) for a relatively high percentage of the GUSG range plus linkages, while lesser amounts are classified as moderate (12 percent) or high (14 percent) (fig. 24; table 12). Areas with low resilience and resistance (34 percent) are generally found in the western portion of the range plus linkages, and areas with moderate (14 percent) to high (52 percent) resilience and resistance occur largely in the east and center portion of the range plus linkages (fig. 29; table 13). Intersecting the breeding habitat probabilities with resilience and resistance shows that areas with moderate to high breeding habitat probabilities are generally characterized by moderate resilience and resistance (fig. 31; table 14). This indicates that these areas likely have the potential to recover after disturbance and respond favorably to management actions.

Table 10—Relative percentage of the Greater sage-grouse population by resilience and resistance class for Management Zones (MZ) I, II, and VII (A) and for priority areas for conservation (PACs) within each Management Zone (B).

A

Resilience and resistance	MZ I	MZ II	MZ VII
		Percent	
High	10	20	92
Moderate	90	70	6
Low	0	10	2

B

Resilience and resistance	MZ I PACs	MZ II PACs	MZ VII PACs
		Percent	
High	14	16	81
Moderate	55	54	2
Low	0	7	0

Table 11—Relative percentage of the Greater sage-grouse population with high and low breeding bird densities by resilience and resistance class for Management Zones (MZ) I, II, and VII (A) and for priority areas for conservation (PACs) within each Management Zone (B). High breeding bird density (High BBD) was defined as the smallest area that contained 80 percent of the breeding population of Greater sage-grouse within 26% to 34% of occupied breeding habitat within a Management Zone (see figure 11 in Doherty et al. 2016). Low breeding bird density (Low BBD) was defined as the area that contained all remaining breeding sage-grouse.

A

Breeding bird density in MZs	Resilience and resistance		
	Low	Moderate	High
	- - - - Percent - - - -		
MZ I			
High BBD	0	72	8
Low BBD	0	18	1
MZ II			
High BBD	6	57	17
Low BBD	4	13	3
MZ VII			
High BBD	2	3	76
Low BBD	1	2	16

B

Breeding bird density in MZs	Resilience and resistance		
	Low	Moderate	High
	- - - - Percent - - - -		
MZ I PACs			
High BBD	0	49	7
Low BBD	0	6	7
MZ II PACs			
High BBD	0	48	15
Low BBD	0	6	1
MZ VII PACs			
High BBD	0	1	68
Low BBD	0	1	13

Table 12—The area and percentage of Gunnison sage-grouse breeding habitat probability classes in the Gunnison sage-grouse rnage plus linkages.

Class	Acres	Area (km^2)	Percent
High	261,317	1,058	12
Moderate	303,683	1,229	13
Low	400,177	1,619	18
Unsuitable	1,273,925	5,155	57
Total	2,239,102	9,061	100

Table 13—The area and percentage of resilience and resistance classes in the Gunnison sage-grouse range plus linkages.

Class	Acres	Area (km^2)	Percent
High	1,268,414	5,133	52
Moderate	339,267	1,373	14
Low	831,168	3,364	34
Total	2,438,849	9,870	100

Table 14—The area and percentage of breeding habitat probability class by resilience and resistance class for the Gunnison sage-grouse range plus linkages. Percentages add to 100.

	Resilience and resistance								
Breeding habitat	Low			Moderate			High		
probability	Acres	Area (km^2)	%	Acres	Area (km^2)	%	Acres	Area (km^2)	%
High	5,067	21	1	69,622	282	3	175,097	708	8
Moderate	64,865	262	3	60,723	246	3	163,007	659	7
Low	118,930	481	5	43,721	177	2	232,846	942	11
Unsuitable	547,486	2,216	25	161,010	652	7	561,051	2,270	25
Total	736,348	2,980		335,076	1,357		1,132,001	4,579	

8. 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 determine the most appropriate management strategies and identify project areas. The sage-grouse habitat matrix and the general criteria for prioritizing areas for management in Step 7 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 5).

8.1 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 practices over time. A general approach using questions to identify the information required in each step is shown in table 15. These questions can be modified to include the specific information needed for each project area and for treating different ecological sites.

Table 15—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/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 posttreatment 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.

Ecological Site Descriptions

Ecological site descriptions (ESDs) 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). Soil survey data from the Natural Resource Conservation Service (http://soils.usda.gov/survey/), including soil temperature/moisture regimes and other soil characteristics, are integral to the development of ecological site descriptions. The Natural Resource Conservation service and their partners have developed ecological site descriptions to assist land management agencies and private landowners with making resource decisions and are often available for the sage-grouse Management Zones. For a detailed description of ESDs and access to available ESDs 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 both plant community resilience to disturbance as well as the resistance of a plant community to nonnative invasive species (tables 3, 4). Within a particular ecological site description, there is a similar level of resilience to disturbance and resistance to nonnative invasive species. This information can be used to determine the most appropriate management actions.

A tool has recently been developed through the Web Soil Survey that produces a Resilience and Resistance Score Sheet Soils Report for the Great Basin based on the approach developed in Miller et al. (2014, 2015) (http://websoilsurvey.nrcs.usda.gov/app/). This tool provides managers with necessary information to assess the soils characteristics of a project area and determine its relative resilience to disturbance and management treatments and resistance to nonnative invasive annual grasses. It can be adapted to the eastern range.

State-and-Transition Models

These models are a central component of ecological site descriptions and 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; Stringham et al. 2003; USDA NRCS 2015a). State-and-transition models have been developed for 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 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 natural disturbance regimes 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 required for 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 3 are provided in Appendix 6. These state-and-transition models are generally applicable to Management Zone I (West-Central Semiarid Prairies) and Management Zones II and VII (Wyoming Basin and Central Middle Rockies, and Colorado Plateau and Southern Rockies).

8.2 Examples of How to Apply the Concepts and Tools

Examples of the approach discussed in this report are provided below for two areas that support GRSG populations and one area that supports GUSG populations. These areas differ in relative resilience and resistance as indicated by soil temperature and moisture regimes and the dominant habitat threat.

Example #1: East-central Montana

This area is characterized primarily by cool and summer moist bordering on dry soil temperature and moisture regimes (fig. 33) with moderate resilience and resistance (table 4 cells 2A, 2B, 2C). Most of the area is privately owned (fig. 34),

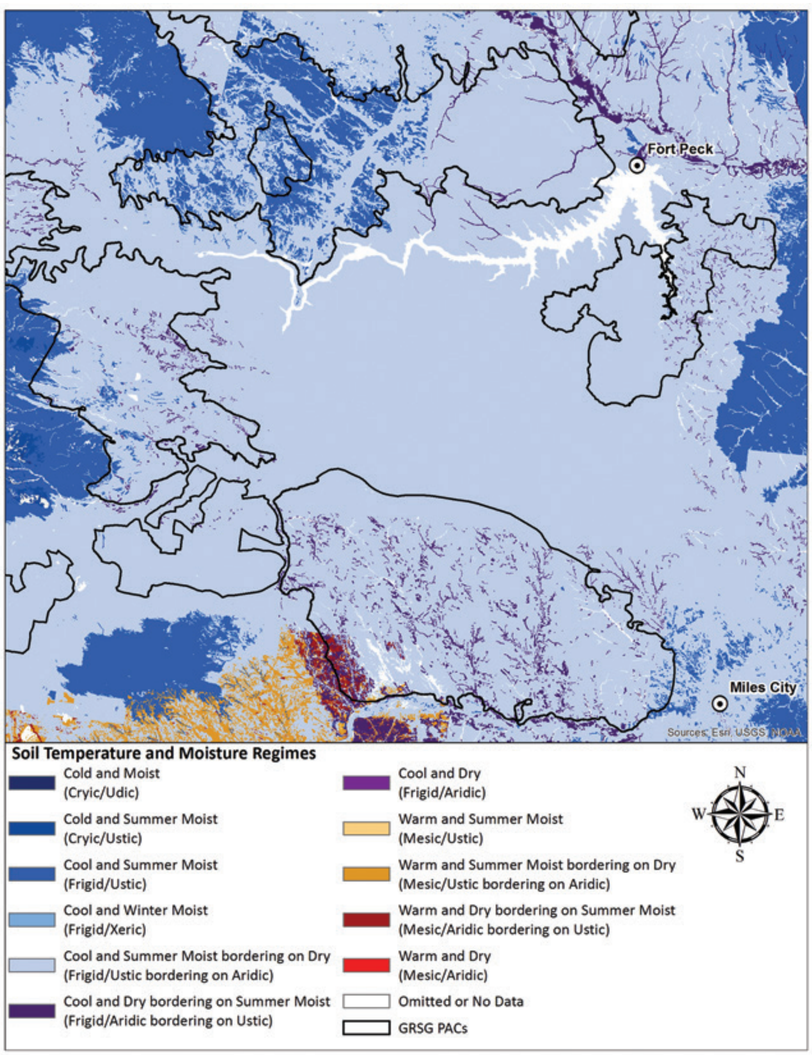


Figure 33—Soil temperature and moisture regimes by soil moisture subclass for an area in eastern Montana. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

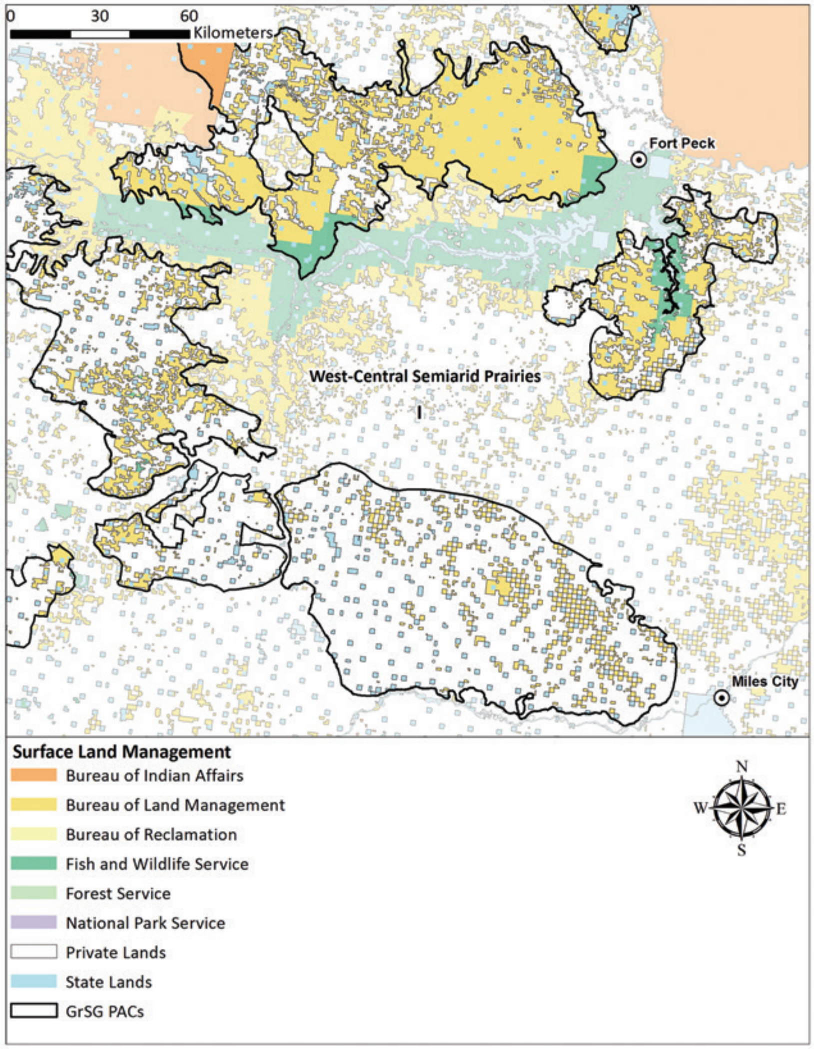


Figure 34—Surface land management for an area with agricultural conversion in eastern Montana (BLM 2015).

and large cropland areas exist adjacent to Priority Areas for Conservation with moderate to high GRSG populations (fig. 35a, 36). Areas on private lands that support high breeding habitat probabilities and that have or are adjacent to high population concentration centers could be targeted for conservation easements, term easements, or other conservation options to keep native rangelands intact. Also, USDA and state-based initiatives may provide incentives for transitioning expiring Conservation Reserve Program (CRP) or other cultivated lands to rangelands that support perennial plant communities. The Sage-Grouse Initiative (SGI) 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. 35b; Smith et al. 2016).

A generalized state-and-transition model for the dominant ecological type in this area identifies the alternative states and transitions for this type (fig. A6.3). Following prolonged drought, improper grazing, and frequent sagebrush control treatments, the site can transition to an alternative state that is dominated by low

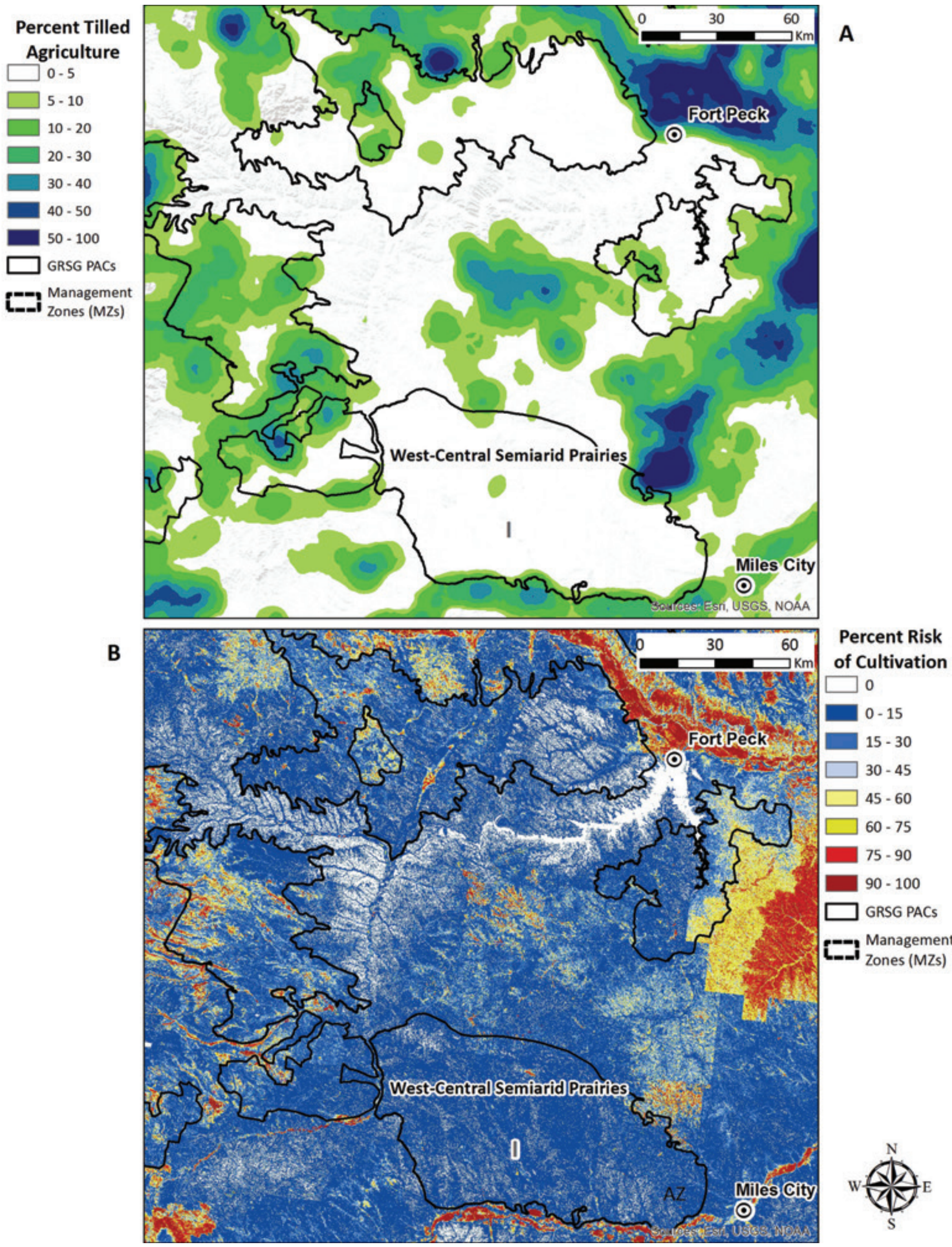


Figure 35—(A) Percent annually tilled agricultural land (NASS 2014) within 5.0 km of each pixel for an area in eastern Montana. (B) Percent risk of cultivation for the same area derived from the Sage-Grouse Initiative cultivation risk mapping tool (http://map.sagegrouseinitiative.com/), which is based on climate, soils, and topography.

statured cool season and sod-forming grasses (fig. A6.3). 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 non-native invasive plants such as Russian Knapweed (*Cenaurea repens*), field brome, and cheatgrass (see http://invader.dbs.umt.edu/queryarea.asp for a complete county list), and early detection and rapid response 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 5). Livestock management that maintains

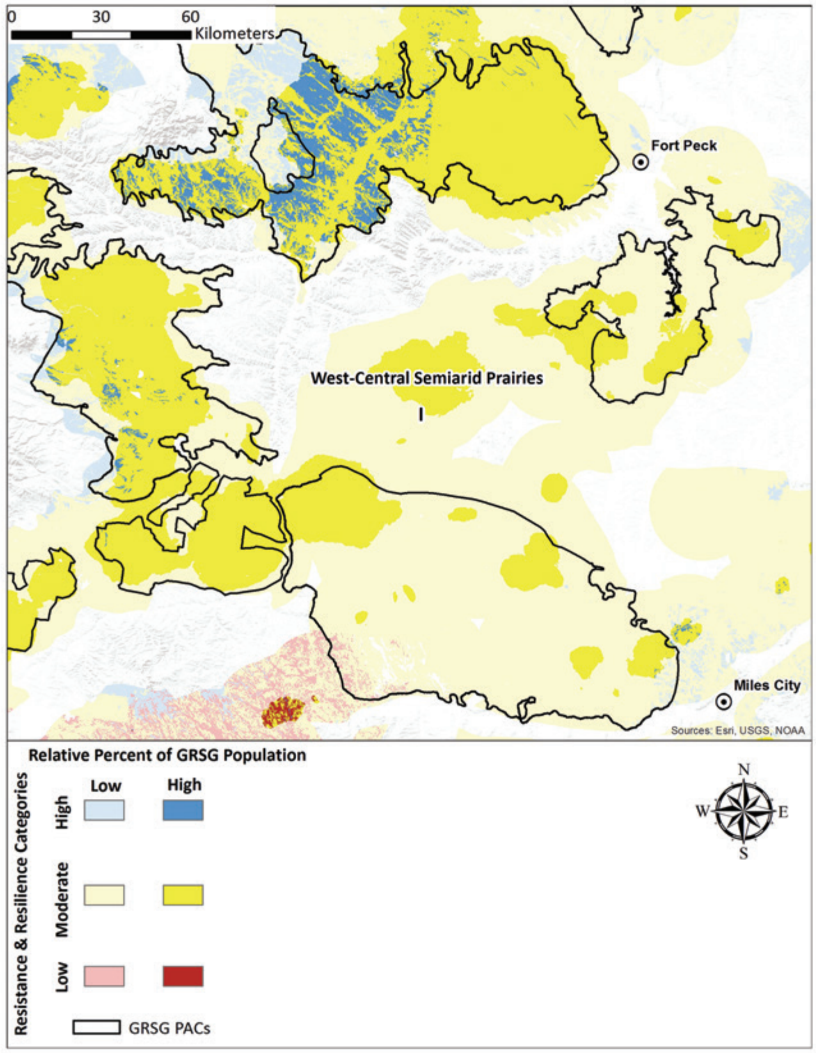


Figure 36—Relative percent of Greater sage-grouse population based on breeding abundance during 2010 to 2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes for an area in eastern Montana. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3. A threshold value of 80 percent is used to identify high breeding concentration centers.

a balance of native perennial grasses (cool and warm season species) and forbs will allow natural regeneration of sagebrush and increase competitive ability with nonnative invasive plants. Also, an altered/seeded state exists where introduced perennial grasses such as crested wheatgrass were seeded onto former croplands. These introduced perennial grasses can prevent establishment of sagebrush and other native species and spread into and dominate sagebrush ecosystems (Lessica and Deluca 1996). Thus further seeding of these species following disturbances is not recommended.

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 have high to low resilience and resistance (fig. 37). Surface land management is primarily USFS, BLM, and private (fig. 38). The area has wide-spread oil and gas development along with high GRSG concentration areas (figs. 39, 40).

In areas with high habitat probabilities and breeding concentration centers avoiding development and fragmentation where feasible and consistent with existing State and Federal conservation plans is recommended regardless of resilience and resistance category (table 4 cells 1C, 2C, 3C). Reducing energy and other transport corridors as well as vehicle access where consistent with the above mentioned plans can also minimize fragmentation. Exurban residential development is also fragmenting habitats and conservation easements can be an important tool for ameliorating this threat (fig. 41).

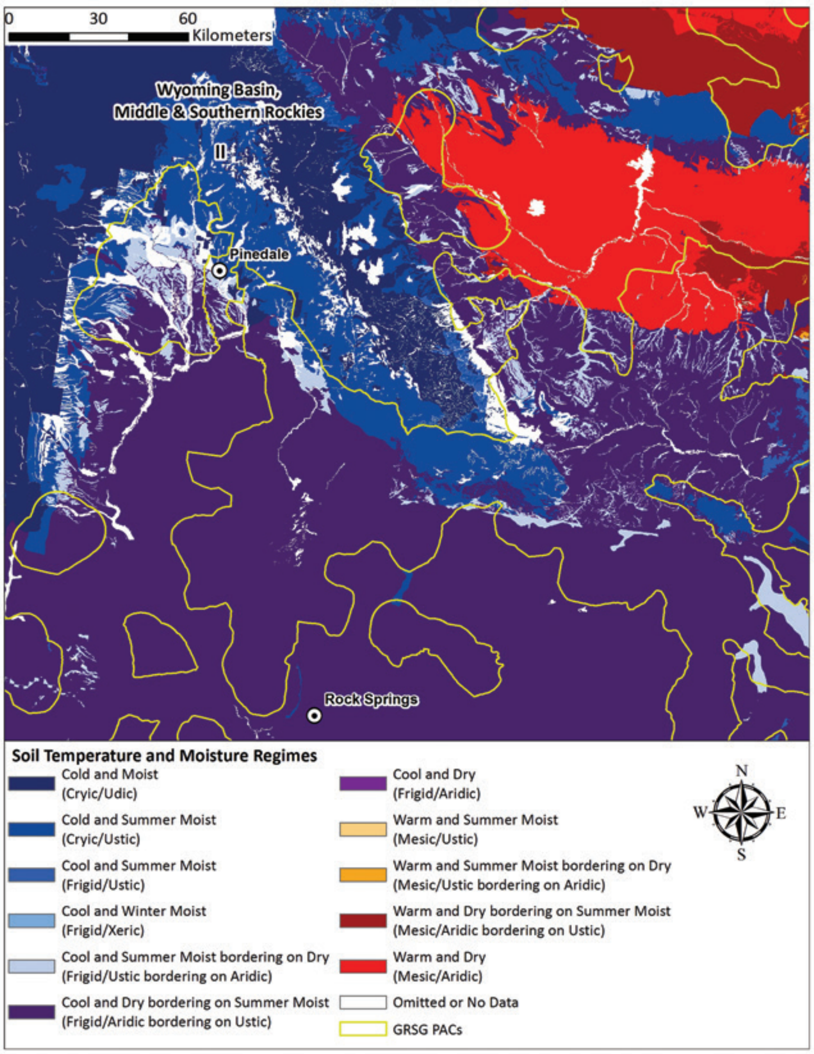


Figure 37—Soil temperature and moisture regimes by soil moisture subclass for an area in southwest Wyoming with oil and gas development. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

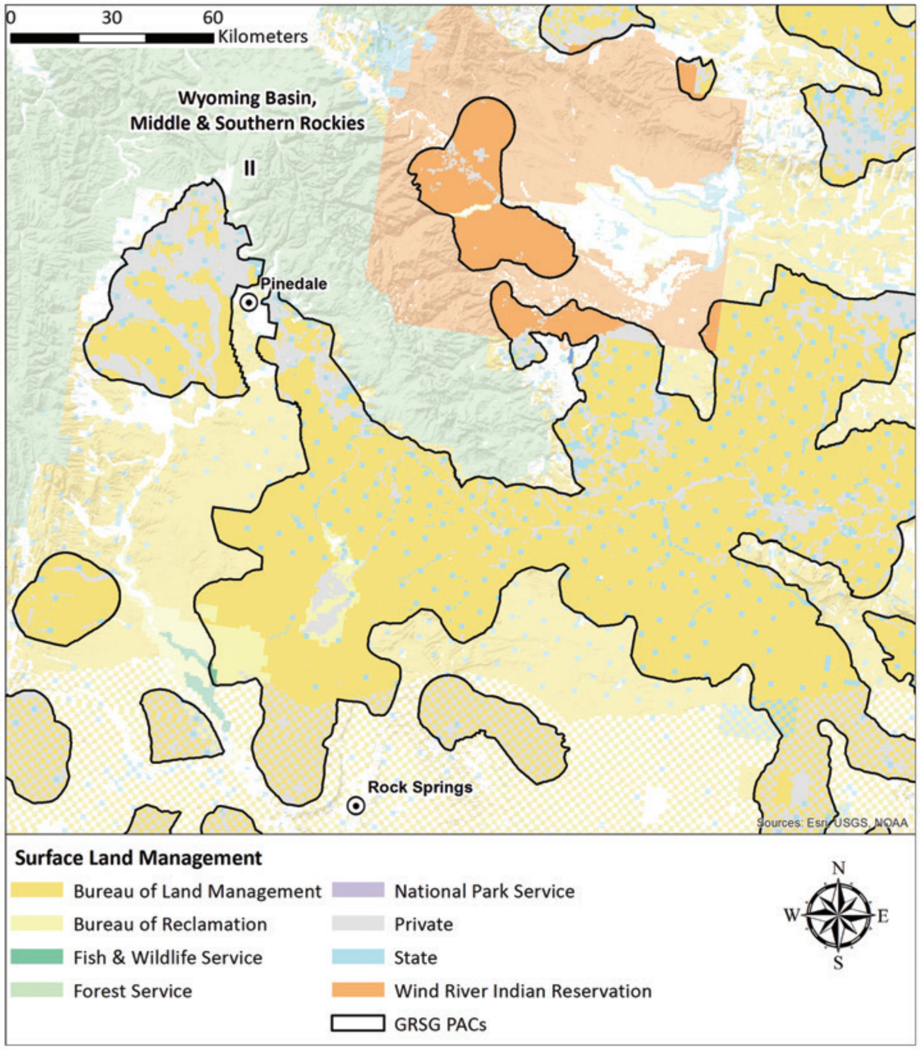


Figure 38—Surface land management for an area with oil and gas development in southwest Wyoming (BLM 2015).

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 A (figs. A.6.5, A.6.6, A.6.7, A.6.9, A.6.10). In general, continuous, heavy grazing of cool season grasses during the critical growth period can result in an alternative state dominated by grazing tolerant species. Further grazing can result in an eroded state that 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 rest 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 understory grasses and forbs has the potential to increase resilience and resistance to both drought and fire.

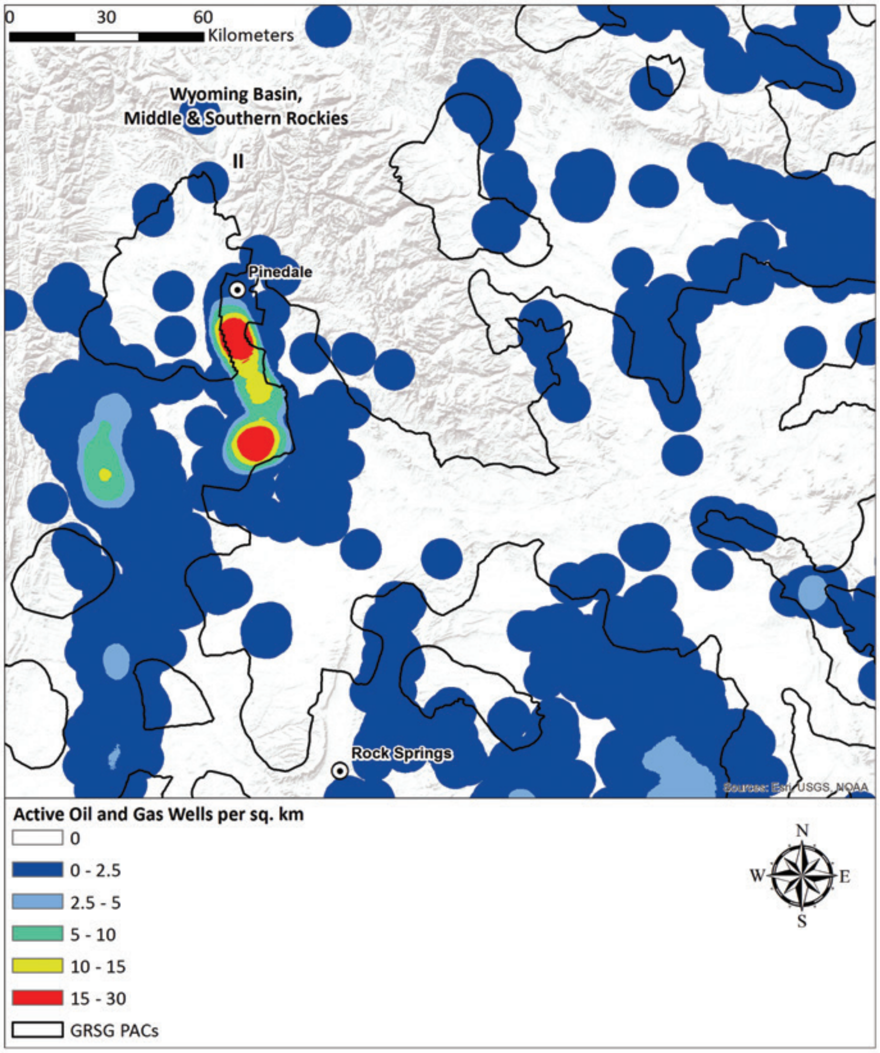


Figure 39—Number of active oil and gas wells per square kilometer (IHS; BLM [AFMSS]) for an area in southwest Wyoming.

The area is susceptible to numerous nonnative invasive plants and proactive weed management is recommended in all areas with high habitat suitability and breeding concentration centers (see table 5). Nonnative invasives include several *Bromus* species such as cheatgrass and field brome, *Poa* species such as bulbous bluegrass (*P. bulbosa*) and Kentucky bluegrass (*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 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

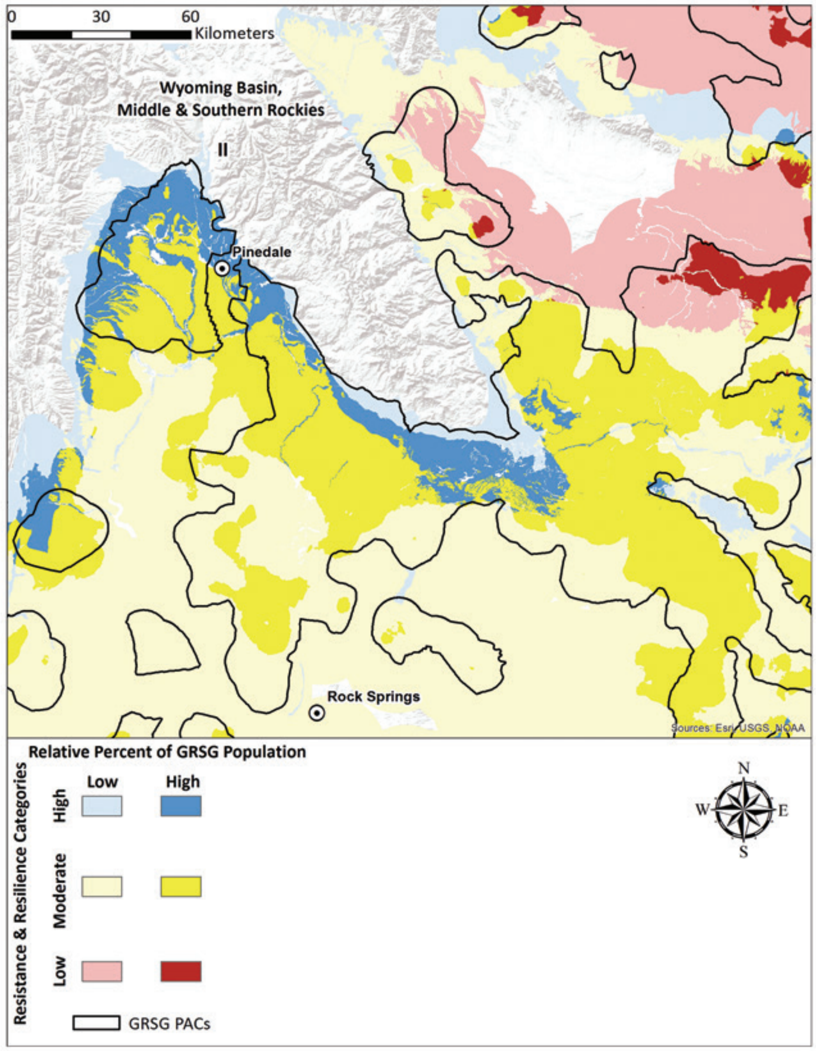


Figure 40—Relative percent of Greater sage-grouse population based on breeding abundance during 2010 to 2014 (Doherty et al. 2016) intersected with resilience and resistance categories developed from soil temperature and moisture regimes for an area in southwest Wyoming. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3. A threshold value of 80 percent is used to identify high breeding concentration centers.

technologies, and monitoring. In low resilience and resistance areas, multiple interventions may be required to restore sagebrush habitat. 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 or restoration of sagebrush habitat can be avoided, especially in cooler and moister areas where native species establish well.

Figure 41—A conservation easement near Pinedale, Wyoming (photo by Jeremy Roberts, Conservation Media; used with permission).

Example #3: Piñon Mesa Population of Gunnison Sage-Grouse in Central Colorado

This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and moist to warm and dry bordering on summer moist (fig. 42). Surface land management is primarily Bureau of Land Management, U.S. Forest Service, and private (fig. 43). This area has high GUSG breeding habitat probabilities with relatively large breeding concentration centers and is threatened by conifer expansion, primarily two-needle piñon and Utah juniper (figs. 44, 45).

A state-and-transition model for a dominant ecological type on the *Piñon Mesa* identifies the alternative states and transitions for the type (fig. A6.8). In general, improper livestock use, such as heavy grazing during the critical growth period, can decrease perennial grasses and forbs, increase woody biomass (fuel loads), and elevate susceptibility to invasive annual grasses. Research on the Uncompahgre Plateau indicates that old growth piñon and juniper stands are common and range from relatively open and juniper dominated at low elevations to closed canopied and piñon dominated at higher elevations (Shinneman and Baker 2009). Improper livestock grazing after Euro-American settlement in the late 1800s likely reduced understory grasses and forbs (Shinneman and Baker 2009). This, in turn, decreased competition with tree seedlings and facilitated tree establishment, primarily two-needle piñon, during favorable climatic periods (Shinneman and Baker 2009). Tree infilling is occurring locally and fires in piñon and juniper stands at or near full tree stocking are typically of high severity (Baker and Shinneman 2004).

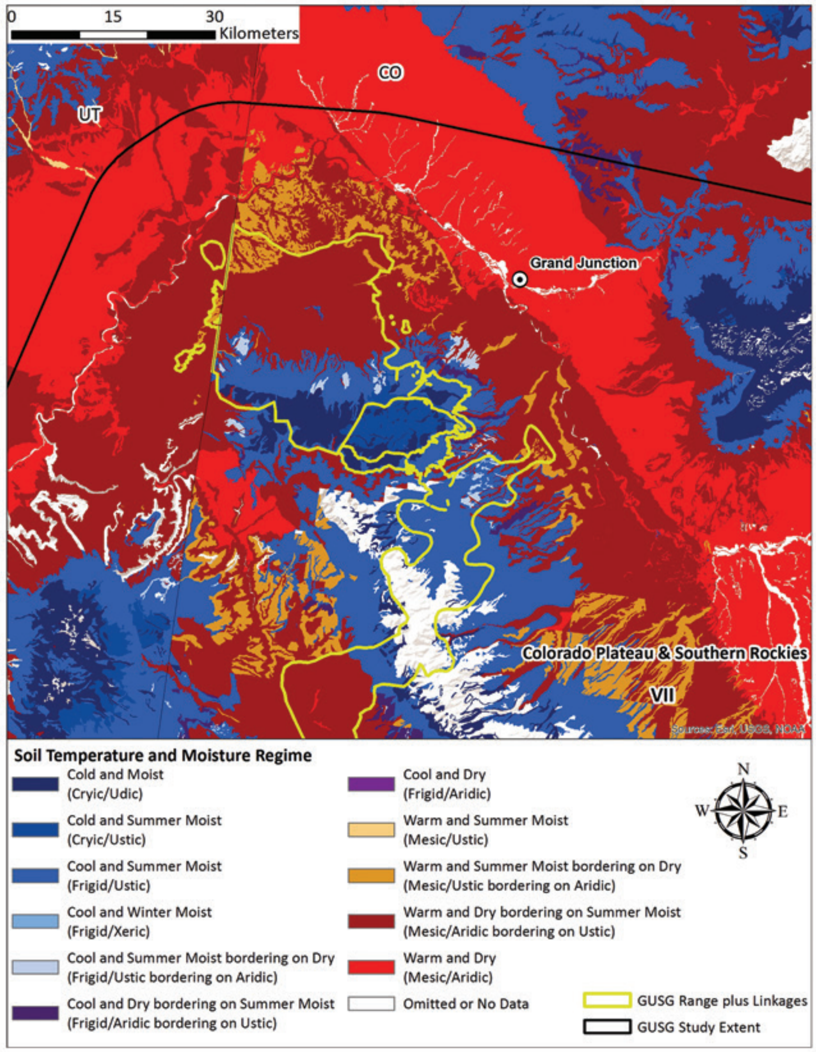


Figure 42—The soil temperature and moisture regimes by soil moisture subclass for an area in the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) with piñon and juniper expansion (Mesa County, Colorado). The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

Infilling of trees and/or improper livestock grazing can result in reductions in understory sagebrush and cool season grasses and increase susceptibility to invasion by cheatgrass. In southwestern Colorado in Mesa Verde National Park, piñon and juniper stands that had sparse understories prior to burning are now dominated largely by cheatgrass and other annual invaders (Floyd et al. 2006). Increases in invasive annual grasses may cause more frequent and continuous fires and result in conversion to alternative states dominated by annuals (Floyd et al. 2006). Proper management of livestock grazing can promote native perennial grass and forb growth and reproduction and maintain or enhance resilience to wildfires and resistance to invasive annual grasses.

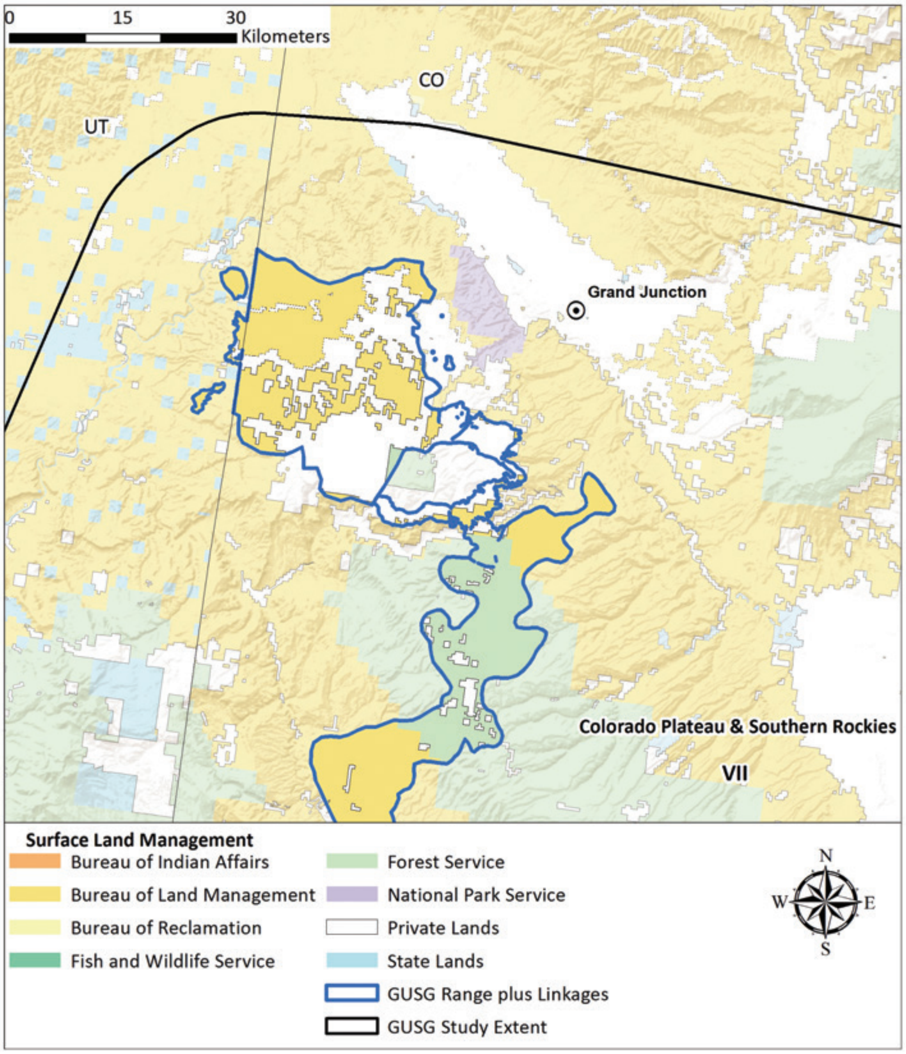


Figure 43—Surface land management for an area in the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) with piñon and juniper expansion (Mesa County, Colorado) (BLM 2015).

In areas with high habitat probabilities that occur adjacent to breeding concentration centers or that could increase connectivity, management activities may include (1) targeted tree removal in early to mid-phase (Phase I and II) post-settlement piñon and juniper expansion areas to maintain or increase shrub/perennial herbaceous cover and decrease fuel loads, and (2) targeted tree removal or thinning in later phase (Phase III) post-settlement piñon and juniper to decrease possibility of high severity fire. Following tree removal or thinning, relatively cool and moist areas with moderate to high resilience and resistance and residual understories of perennial grasses and shrubs are often capable of unassisted recovery after either treatment or disturbance. However, relatively warm and dry areas with low resilience and resistance may not recover in a reasonable amount of time and may be susceptible to invasion by nonnative annual grasses and other weeds. If post treatment areas lack sufficient perennial native vegetation to promote recovery, they can be seeded with perennial grasses and forbs with capacity to persist and stabilize ecosystem processes under altered disturbance regimes and in a warming environment.

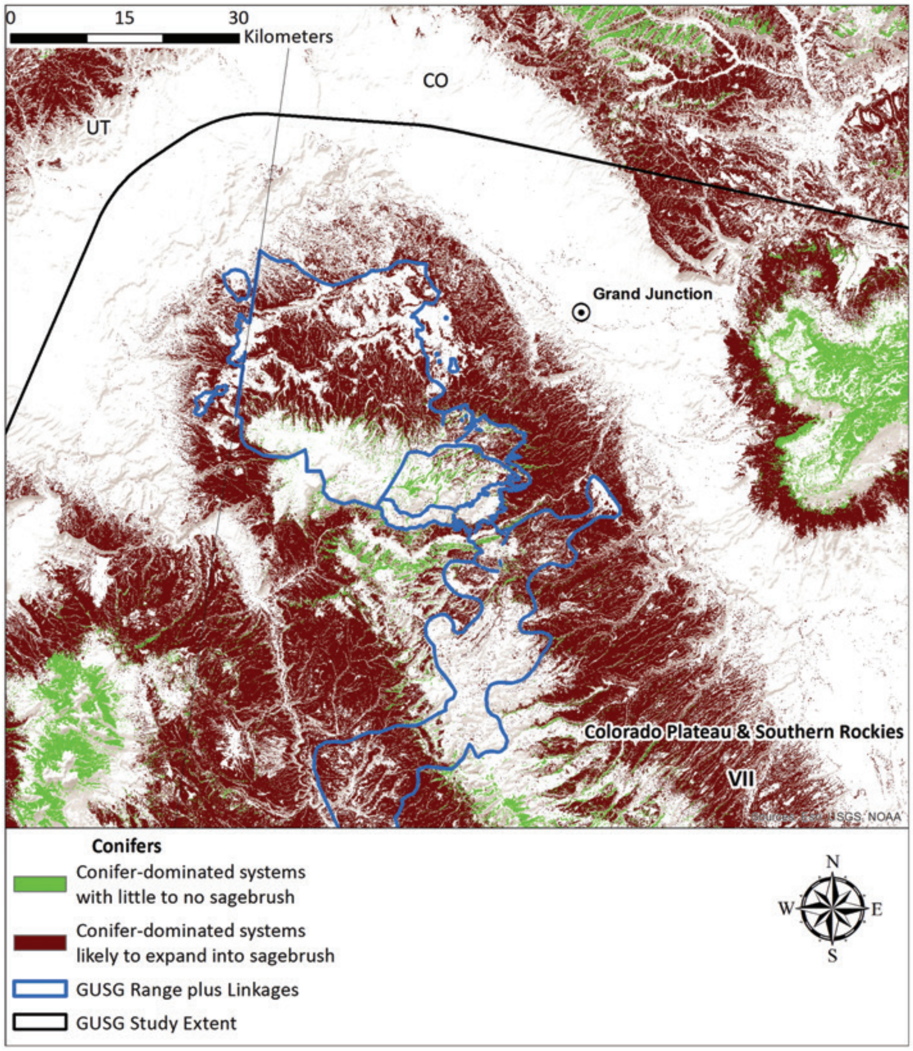


Figure 44—Conifer-dominated ecological systems (USGS 2014) for an area in the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) with piñon and juniper expansion (Mesa County, Colorado). The dark brown colors represent conifer-dominated systems with the potential to expand into sage-brush-dominated systems (USDI BLM 2014).

Posttreatment seeding or postfire rehabilitation in low resilience and resistance areas may require more than one intervention for restoration success. This situation occurs in sage-grouse habitat along the Utah-Colorado border in the area known as Fish Park, where two fires recently occurred. In 1999, 3,580 ac (14.5 km^2) burned and in 2006, a second fire burned an additional 1,400 ac (5.7 km^2), of which 543 ac (2.2 km^2) overlapped the first fire. Even with postfire rehabilitation treatments, invasion of nonnative annual grasses occurred and additional intervention is now necessary. Establishing sagebrush is often challenging in these warm and dry areas with low resilience and resistance and the Bureau of Land Management is currently conducting trials to ascertain the best procedure to reestablish sagebrush (Heidi Plank, Colorado BLM, Grand Junction Field Office, personal communication). Seeding of introduced species, in this case western wheatgrass, can retard recovery of native perennial grasses and forbs that are important to sage-grouse and should be avoided in these types of areas (e.g., Lesica et al. 1996).

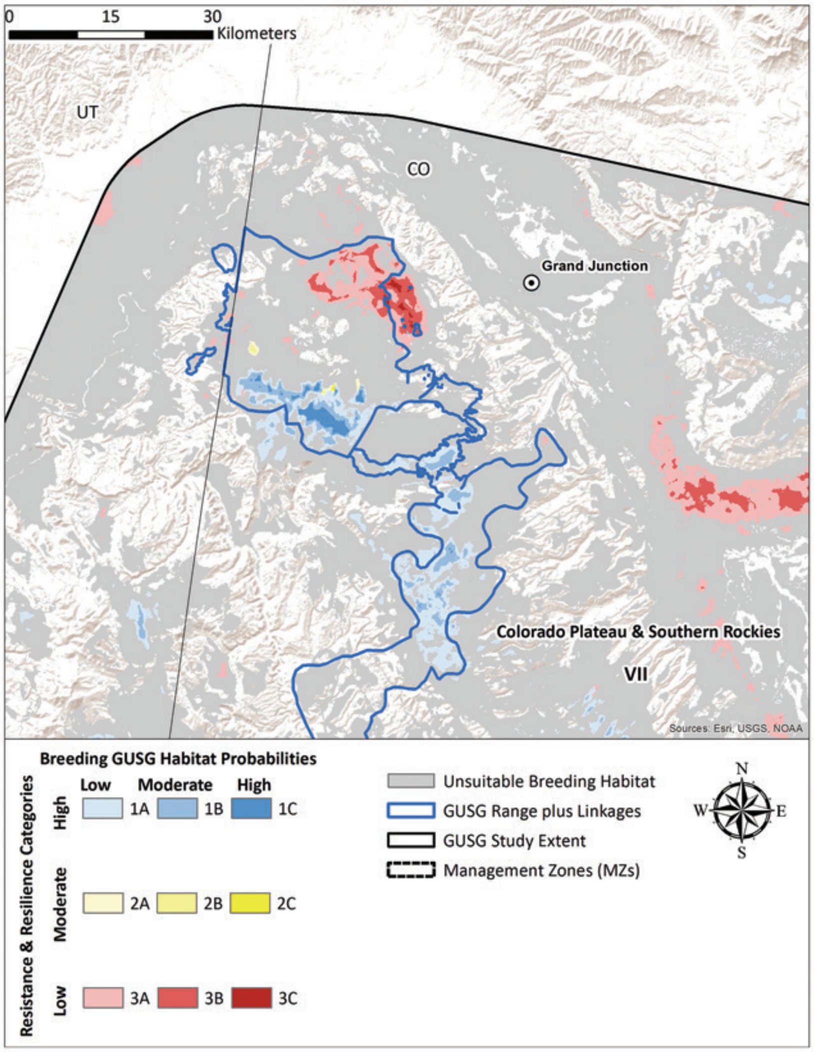


Figure 45—Gunnison sage-grouse breeding habitat probabilities for the Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a) and surrounding area based on lek data from 1995 to 2015 intersected with resilience and resistance categories developed from the soil temperature and moisture regimes. The area is in Mesa County, Colorado and is exhibiting piñon and juniper expansion. The breeding habitat probabilities were developed for this report based on Doherty et al. 2016. The soil temperature and moisture regime data used in this report and the soil temperature and moisture regime categories are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 3.

On the Piñon Mesa, areas with lower resilience and resistance and high to moderate breeding habitat probabilities, large, contiguous areas of sagebrush with intact understories are a high priority for conservation. In these areas, emphasis is on maintaining or increasing habitat conditions by minimizing stressors and disturbance. Appropriately managing livestock and recreational use in targeted areas is especially important to promote native perennial grass and forb growth and reproduction and to maintain or enhance resilience and resistance.

Historically, drought likely had a greater influence on tree dynamics than fire in this area (Shinneman and Baker 2009). However, in some areas of the northern Colorado plateau, a decline in piñon-juniper woodlands over the past century may have occurred due to an excess of fire since Euro-American settlement (Arendt and Baker 2013). Management aimed at restoring understory grasses and forbs has the potential to increase resilience and resistance to both drought and fire given climate warming. Monitoring can provide the necessary information to track change and adapt management.

8.3 Monitoring and Adaptive Management

Monitoring programs designed to track ecosystem changes in response to both stressors and management actions can be used to increase understanding of ecosystem resilience and resistance, realign management approaches and treatments, and implement adaptive management (Herrick et al. 2012; Reever-Morghan et al. 2006). Information is increasing on likely changes in sagebrush ecosystems undergoing additional stress and climate warming, but a large degree of uncertainty still exists. Currently, two consistent national monitoring efforts inventory vegetation and soil attributes and describe land health at the landscape scale: the Natural Resource Conservation Service, National Resource Inventory of non-Federal lands and the Bureau of Land Management, Landscape Monitoring Framework of public lands managed by the Bureau (part of the Bureau's Assessment Inventory and Monitoring strategy).

Strategic placement of monitoring sites and repeated measurements of ecosystem status and trends (e.g., ground cover, vegetation height, phase of tree expansion, soil and site stability) can be used to decrease uncertainty and increase effectiveness of management decisions (Rowland and Vojta 2013). Ideally, monitoring sites span environmental/productivity gradients and sagebrush ecological types that characterize sage-grouse habitat. Of particular importance are (1) ecotones between ecological types where changes in response to climate are expected to be largest (Loehle 2000; Stohlgren et al. 2000), (2) ecological types with climatic conditions and soils that are exhibiting nonnative species invasion and increased fire risk, and (3) ecological types with climatic conditions and soils that are exhibiting tree expansion and increased fire risk. Monitoring the response of sagebrush ecosystems to management treatments, including both pre and posttreatment data, is a first order priority because it provides information on treatment effectiveness that can be used to adjust methodologies.

Monitoring activities are most beneficial when standard approaches are used among and within agencies to collect, analyze, and report monitoring data (Rowland et al. 2013). Currently, effectiveness monitoring databases that are used by multiple agencies do not exist. However, several databases have been developed for tracking invasive species management and restoration/rehabilitation activities.

The National Fire Plan Operations and Reporting System is an interdepartmental and interagency database that accounts for hazardous fuel reduction, burned area rehabilitation, and community assistance activities. To our knowledge, this system is not capable of storing and retrieving the type of effectiveness monitoring information that is needed for adaptive management.

The FEAT FIREMON Integrated (https://www.frames.gov/partner-sites/ffi/ffi-home/) is a monitoring software tool designed to assist managers with collection, storage, and analysis of ecological information. It was constructed through a complementary integration of the Fire Ecology Assessment Tool (FEAT) and Fire Effects Inventory and Monitoring Protocol (FIREMON). This tool allows the user to select among multiple techniques for effectiveness monitoring. If agencies agreed on effectiveness monitoring techniques, FEAT FIREMON databases with standard structures could be used in interagency effectiveness monitoring.

The Database for Inventory, Monitoring and Assessment (http://jornada.nmsu.edu/monit-assess/dima) is similar to FEAT FIREMON. This is a computer tablet-based data entry tool for field data entry directly into a database for later management and interpretation. This Microsoft Access database uses standardized plant nomenclature based on the current U.S. Department of Agriculture Plants Database. The data can be easily stored in the Land Treatment Digital Library (see below) to keep all treatment planning and implementation information together with the monitoring data. Also, the National Invasive Species Information Management System is designed to reduce redundant data entry regarding invasive species inventory, management, and effectiveness monitoring with the goal of providing information that can be used to determine effective treatments for invasive species. However, this tool is currently available only within the Bureau of Land Management.

Common databases can be used by agency partners to record and share monitoring data. The Land Treatment Digital Library (USGS 2015) provides a method of archiving and collecting common information for land treatments and might be used as a framework for data storage and retrieval. At present, interagency use is limited because of barriers affecting database access and data security. The Land Treatment Digital Library has demonstrated how this can work by accessing a variety of databases to populate useful information relating to land treatments.

To effectively evaluate treatments for adaptive management, the agencies involved will need to agree on monitoring methods and a common data storage and retrieval system. Once data can be retrieved, similar treatment projects can be evaluated to determine how well they achieve objectives for sage-grouse habitat, such as the criteria outlined in documents like the Habitat Assessment Framework (Stiver et al. 2006) or those in the GRSG example in Goldstein et al. (2013). Results of monitoring activities on treatment effectiveness are most useful when shared across jurisdictional boundaries, and several mechanisms are currently in place to improve information sharing (e.g., the Landscape Conservation Cooperatives, https://lccnetwork.org/; and Fire Science Exchange Projects, https://www.firescience.gov/JFSP_exchanges.cfm).

8.4 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 non-native invasive species, including information on individual species, planning and prioritizing threats, 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 and handbooks have recently been developed that explicitly incorporate resilience and resistance concepts. These resources can be adapted to Management Zones 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) post-fire rehabilitation (Miller et al. 2015), and (3) rehabilitation/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).

Resources also exist to assist in addressing land use and development threats. 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 at the national Grazing Lands Coalition website (http://www.grazinglands.org/) and Grass: The Stockman's Crop (http://agrilifecdn.tamu.edu/coastalbend/files/2015/02/Grass-The-Stockmans-Crop.pdf). Finally, the Federal land management agencies each have guidelines for livestock grazing.

A variety of programs exist to help support ranchers and enhance their ability to maintain rangelands as working lands. 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/). Also, 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 offered by the National Resource Conservation Service (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/).

9. Conclusions

This report provides a strategic, multiscale approach for prioritizing areas for management and determining effective management strategies in the eastern portion of sagebrush biome. The focus is on addressing persistent ecosystem and land use and development threats to sagebrush ecosystems, GRSG, and GUSG. A highly similar approach was developed for the western portion of the range (Chambers et al. 2014a). That approach was subsequently incorporated into the "Greater Sage-Grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment" (USDI BLM 2014), and served as the basis for a multi-year program of work by the BLM in the Great Basin.

The approaches developed for the western portion of the range (Chambers et al. 2014a) and for this report were used to develop an initial Science Framework (Chambers et al. 2016b) for the Conservation and Restoration Strategy of DOI Secretarial Order 3336 on Rangeland Fire Prevention, Management and Restoration (USDI 2015a,b). The Science Framework will ultimately include sections that relate specific management issues/activities (climate change, wildfire, nonnative invasive plant species, grazing practices, seed strategy considerations, monitoring, mitigation) to the approach developed for prioritizing areas for management and determining effective management strategies. Sections on wildfire and fuels management and climate change were developed for this report and are included in Appendices 7 and 8 because they are central to the issues facing sagebrush ecosystems and sage-grouse.

The approach described in this report and in the Science Framework is intended to be adaptive. As new science and information are developed for sagebrush ecosystems and on sagebrush obligate species, they will be used to improve our ability to prioritize areas for management and determine effective management strategies.

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Appendix A1. 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, geological, 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) — The 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 biotic and abiotic 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 (Caudle et al. 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.

Resilience — Ability of a species and/or its habitat to recover from stresses and disturbances. Resilient ecosystems reorganize and regain their fundamental structure, processes, and functioning when altered by stresses like increased CO_2 , nitrogen deposition, and drought and to disturbances like land development and fire (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 — Restoration pathways describe 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 between vegetation, soil, animals, hydrology, disturbances (fire, lack of fire, grazing and browsing, 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, burning, 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).

Appendix A2. Explanation of Soil Temperature and Moisture Regime Data

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. Complete descriptions can be found in the 12th edition of the *Keys to Soil Taxonomy* (http://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1252094&ext=pdf).

Exhibit A2.1. Definitions of the dominant soil temperature and moisture regimes in the Eastern Range

Soil Temperature Regimes

Cryic (cold): Soils that have a mean annual soil temperature between 0 and 8 °C 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 °C and the difference between mean summer and mean winter soil temperatures is >6 °C 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 °C and the difference between mean summer and mean winter soil temperatures is >6 °C 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 eastern range of sage-grouse (Maestas et al. 2016). 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. 7). 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. 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 join issues along political boundaries, 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 for the eastern range that has three categories: high, moderate, and low. We used the relationship among the predominant ecological types in the eastern range, soil temperature and moisture regimes, and relative resilience and resistance (table 3) to inform these categories. 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, 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 and as low in the Cold Deserts in MZ II and VII. Soils with high water tables, wetlands, or frequent ponding or uncommon regimes that would not typically support sagebrush were excluded.

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

Exhibit A2.2. Resilience and resistance (R&R) rating for the soil temperature and moisture regimes.

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

Appendix A3. Methods for Determining the Predominant Ecological Types

The steps used to determine the ecological types that dominate the eastern range of Greater sage-grouse and the range of Gunnison sage-grouse are outlined below.

1. National Soil Information System (NASIS) data were exported for each Environmental Protection Agency Level II Ecoregion, including Cold Deserts (10.1), Western Cordillera (6.2), and West Central Semiarid Prairies (9.3), within the eastern range of Greater sage-grouse, (Management Zones I, II, and VII), and the range of Gunnison sage-grouse. The information exported included acreages of the dominant Ecological Site (ES) within the Greater sage-grouse Priority Areas of Conservation (PACs) and Gunnison sage-grouse critical habitat as well as soil temperature regime, moisture regime, and moisture subclass assigned at the soil map unit component level. The analyses were conducted by Steve Campbell, NRCS, Portland, Oregon.
2. Ecological Site Descriptions (ESDs) were first sorted by Major Land Resource Area (MLRA) and State and then by soil temperature regime, moisture regime, and moisture subclass to evaluate the ecological sites most often correlated with the PACs. A map was produced intersecting Level III Ecoregions with MLRAs and PACs (fig. A3.1). Each Level II Ecoregion spreadsheet was filtered by central MLRA concepts for the Ecoregion as follows:
    a. Cold Deserts MLRAs:

        32—Northern Desertic Basins: Bighorn and Wind River Basins in Wyoming (96%), small amount in Montana (4%); average precipitation 5–12” (Aridic-Typic, Aridic bordering on Ustic, Ustic bordering on Aridic); and average annual temperature 4–9 °C (Frigid, Mesic)

        34A—Cool Central Desertic Basins and Plateaus: Wyoming Basin in Wyoming (85%), small amounts in Colorado (13%) and Utah (2%); average precipitation 7–12” (Aridic bordering on Ustic, Ustic bordering on Aridic); and average annual temperature 5–7 °C (Frigid)

        34B—Warm Central Desertic Basins and Plateaus: Uinta Basin and Colorado Plateau, mostly Utah (70%) with some in Colorado (30%); average precipitation 6–6” (Aridic-Typic, Aridic bordering on Ustic, Ustic bordering on Aridic); and average annual temperature 7–12 °C (Mesic)

        36—Southwestern Plateaus, Mesas, and Foothills: Canyonlands and Colorado Plateau, mostly New Mexico (58%), Colorado (32%), and Utah (10%), but applicable areas for this analysis reside in Colorado/Utah in identified Gunnison sage-grouse areas; average precipitation 12–20” (Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic); and average annual temperature 7–14 °C (Mesic)

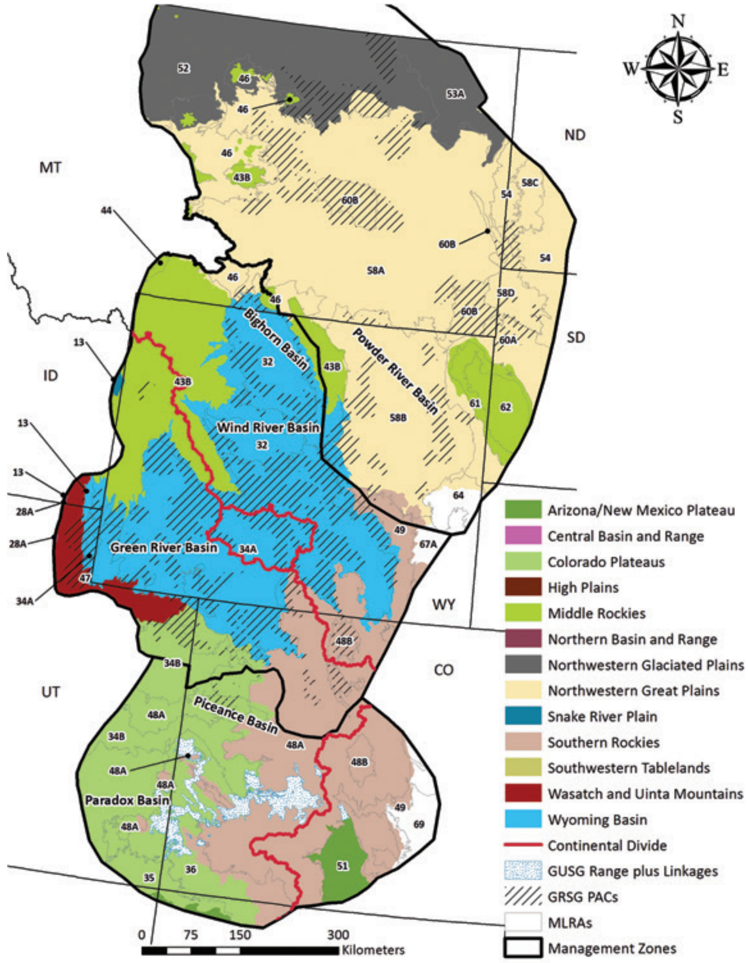


Figure A.3.1—Map of the Major Land Resource Areas (MLRAs) intersected with the Level III ecoregions, management zones, Greater sage-grouse Priority Areas for Conservation, and Gunnison sage-grouse range plus linkages (GSGRSC 2005; UDWR 2012; USFWS 2014a).

b. Western Cordillera MLRAs:

43B—Central Rocky Mountains: very large, covers Montana (38%), Idaho (32%), and Wyoming (30%), but applicable areas for this area mostly reside in Wyoming; average precipitation 25–60” (Udic); and average annual temperature <3 °C (Cryic)

46—Northern Rocky Mountain Foothills: conceptually occurs only in Montana, but concept has been proposed and accepted for use in Wyoming for foothills which are current grouped into 32, 34A, or 43B but do not fit MLRA concept; average precipitation 1–20” (Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic); and average annual temperature 1–9 °C (Cryic, Frigid, Mesic)

47—Wasatch and Uinta Mountains: mostly in Utah (86%) with small amounts in Wyoming (8%) and Colorado (4%); average precipitation 16-30+” (Xeric-Typic, Xeric bordering on Ustic, Ustic bordering on Xeric, Ustic-Typic, Udic bordering on Ustic, Udic-Typic); and average annual temperature 1–7 °C (Cryic, Frigid)

48A—Southern Rocky Mountains: mostly in Colorado (76%) with small amounts in New Mexico (11%), Utah (8%), and Wyoming (5%), but applicable areas for this analysis reside in Colorado and Wyoming and includes areas of importance to Gunnison sage-grouse as well as Greater sage-grouse; average precipitation 16–32 (50)” (Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic, Udic-Typic); and average annual temperature 3–9 °C (Cryic, Frigid, warm Frigid)

48B—South Rocky Mountain Parks: mostly in Colorado (96%) with small amount in Wyoming (4%), includes Middle and South Parks; average precipitation 10–16” (Ustic bordering on Aridic, Ustic-Typic); and average annual temperature 1–6 °C (Cryic, Frigid)

c. West-Central Semiarid Prairies MLRAs:

52—Brown Glaciated Plain: northern Montana above Hwy 2; average precipitation 10–17” (Ustic bordering on Aridic, Ustic-Typic); and average annual temperature 4–7 °C (Frigid)

54—Rolling Soft Shale Plain: mostly in North Dakota (64%), but some in South Dakota (33%) and Montana (3%); average precipitation 14–18” (Ustic bordering on Aridic, Ustic-Typic); and average annual temperature 3–8 °C (Frigid)

58A—Northern Rolling High Plains, Northern Part: mostly in Montana (99%) with small amount in Wyoming (1%); average precipitation 8–22” (Aridic bordering on Ustic, Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic); and average annual temperature 5–10 °C (Frigid, Mesic)

58B—Northern Rolling High Plains, Southern Part: mostly eastern Wyoming (95%) with some in Montana (5%); average precipitation 9–27” (Aridic bordering on Ustic, Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic, Udic-Typic); and average annual temperature 5–9 °C (Frigid, Mesic)

58C—Northern Rolling High Plains, Northeastern Part: mostly North Dakota (96%), but small amount in Montana (4%); average precipitation 14–17” (Ustic bordering on Aridic, Ustic-Typic); and average annual temperature 5–7 °C (Frigid)

58D—Northern Rolling High Plains, Eastern Part: mostly South Dakota (65%), but with some in Montana (21%) and North Dakota (14%); average precipitation 14–17” (Ustic bordering on Aridic, Ustic-Typic); and average annual temperature 6–7 °C (Frigid)

60A—Pierre Shale Plains: mostly South Dakota (70%) but with some in Wyoming (20%), NE (8%), and Montana (2%), but applicable areas for this analysis reside mostly in South Dakota; average precipitation 13–22” (Ustic bordering on Aridic, Ustic-Typic, Udic bordering on Ustic, Udic-Typic); and average annual temperature 6–9 °C (Frigid, Mesic)

60B—Pierre Shale Plains, Northern Part: mostly in Montana (94%) with small amount in Wyoming (6%) and North Dakota; average precipitation 1–15” (Ustic bordering on Aridic); and average annual temperature 6–8 °C (Frigid)

3. The Ecological Site Information System (ESIS) was used to query dominant ESDs supporting big sagebrush plant communities based on NASIS export, MLRA concept, and consultation with NRCS State Rangeland Management Specialists or equivalent. In some cases, ES concepts exist with no STM and/or there are variable STM concepts depending on age of ESDs. The most contemporary STMs were prioritized for consideration, but older products were used when they were the best available product to represent a regime concept. Individuals consulted were:
    a. Kirt Walstead, Jon Siddoway, Tammy Decock, Montana
    b. Rachel Murph and Suzanne Mayne, Colorado
    c. Shane Green, Dean Stacy, Utah
    d. Jeff Prince, Jody Forman, North Dakota
    e. Stan Boltz, South Dakota
    f. Karen Clause, Ray Gullion, Jim Haverkamp, George Gamblin, Ryan Murray, Marji Patz, and Bryan Christensen, Wyoming
    g. Brendan Brazee, Idaho
4. Potentially representative ESs were downloaded to folders and organized by soil temperature/moisture regime concepts. Often the various resources used were not in agreement, and each area was reviewed to determine the best source of data. Resources used to determine the regime include:
    a. ESD climate section
    b. LRU concept or state ecological zones, when available
    c. MLRA Description climate section—edits to MLRA descriptions are anticipated by local staff providing input on these descriptions, and have been incorporated as appropriate
    d. NASIS assigned temperature and moisture regime by mapunit component and accompanying map—many areas in this region are populated with older mapping concepts or are not populated in NASIS
    e. PRISM maps
5. Regime concepts with representative MLRAs and ESDs listed here for reference:
    a. Cold Deserts
        i. Frigid bordering on Cryic/Ustic bordering on Aridic (Cool bordering on Cold, Summer Moist bordering on Dry)

        Representative Area: Wyoming Basin—MLRA 34A in Wyoming west of continental divide into Rich County, Utah; Note: More applicable to Dillon Area than the Great Basin as described in Chambers et al. (2014a).

Status of ESDs: Wyoming has draft Land Resource Unit concepts developed and a couple of contemporary STMs in Wyoming plus older vintage examples

1. R034AC122WY_LoamyPP_Provisional2014cold
2. R034AC150WY_SandyPP_Provisional2014cold
3. R034AY222WY_Loamy10-14W_Provisional2005
4. R034AY250WY_Sandy10-14W_Provisional2005

ii. Frigid/Ustic bordering on Aridic (Cool, Summer Moist bordering on Dry)

Representative Area: Wyoming Basin—MLRA 34A in Wyoming's lower Green River Basin (west of continental divide) and Great Divide Basin

Status of ESDs: In Wyoming, 1 contemporary draft STM and older vintage sites; in Utah a contemporary draft STM

1. R034AF122WY_LoamyBR_DRAFT2015
2. R034AI122WY_LoamyPV_DRAFT2015warm
3. R034AY322WY_Loamy10-14SE_Provisional2005
4. R034AY350WY_Sandy10-14SE_Provisional2005
5. R046XA122WY_Loamy10-14E-Frigid_DRAFT-ALL

iii. Frigid/Aridic bordering on Ustic (Cool, Dry bordering on Summer Moist)

Representative Area: Wyoming Basin—MLRA 34A in Green River Basin (west of continental divide) and Great Divide Basin

Status of ESDs: In Wyoming, 1 contemporary draft STM and older vintage sites plus into Utah a contemporary draft STM

1. R034AB122WY_LoamyGR_DRAFT2015
2. R034AY122WY_LoamyGR_Provisional2005
3. R034AY150WY_SandyGR_Provisional2005
4. R034AY220UT_Semi-desertLoam_DRAFT

iv. Mesic/Ustic bordering on Aridic (Warm, Summer Moist bordering on Dry)

Representative Area: Wyoming Basin—MLRA 32 foothills in Wyoming, MLRA 34B and 36 in Colorado and Utah; potential Gunnison sage-grouse; Potential for juniper or pinyon-juniper invasion. This is 10-14" ppt in Wyoming, but 12 to 16" ppt in Colorado, Utah, and New Mexico

Status of ESDs: Contemporary vintage STMs in Colorado and Wyoming

1. R032XD122WY_Loamy10-14BH_Provisional2014
2. R034AY289CO_ClayeyFoothhills_DRAFT- – is really a 36 site –miss labeled in NASIS
3. R036XY284CO – Loamy Foothills
4. R036XY306UT_UplandLoam_2008Prov

v. Mesic/Aridic-Typic (Warm, Dry)

Representative Area: Wyoming Basin—LRA 32 in Wyoming (Bighorn and Wind River Basins) ONLY

Status of ESDs: 1 contemporary STM and older examples of STMs included; Utah and Colorado sites in this zone are salt desert shrub sites and outside scope of analysis (no big sage)

1. R032XA122WY_Loamy5-9BH_Provisional2014
2. R032XY150WY_Sandy5-9BH_Provisional2005
3. R032XY222WY_Loamy5-9WR_Provisional2005
4. R032XY250WY_Sandy5-9WR_Provisional2005

vi. Mesic/Aridic bordering on Ustic (Warm, Dry bordering on Summer Moist)

Representative Area: Wyoming Basin and Colorado Plateau—MLRAs 32 foothills in Wyoming and MLRA 34B and 36 in Colorado and Utah; Gunnison sage-grouse potential in Colorado

Status of ESDs: Wyoming has a couple contemporary STMs and MLRA 34B in Utah and Colorado have some contemporary draft STMs

1. R032XY124WY_LoamyCalc10-14E_Provisional2014
2. R034A-BY327CO_SemidesertLoam_RangeSiteOnly
3. R034BY212UT_SemidesertLoam_DRAFT

vii. Frigid bordering on Mesic/Ustic-Typic (Cool bordering on Warm, Summer Moist)

Representative Area: Colorado Plateau—MLRA 48A/34A Piceance Basin-Book Cliffs in Colorado/Utah (This zone is treated as 48A, but some 34A shows on map); Gunnsion sage-grouse potential

Status of ESDs: Colorado has a draft contemporary STM

1. R034AY285CO_FoothillSwale_DRAFT2014

b. Western Cordillera

i. Cryic/Ustic-Typic (Cold, Summer Moist)

Representative Area: Middle and Southern Rockies – MLRAs 46/43B Foothills in Wyoming & Montana; MLRA 48A in Wyoming and Northern Colorado (north of Colorado River/I-70); MLRA 49 in Wyoming (not in Colorado); potential Gunnison sage-grouse in Colorado

Status of ESDs: MLRA 43B has contemporary draft STM from Idaho and older vintage from Wyoming; MLRA 49 has older vintage STM from Wyoming; MLRA 48 DRAFT site in Wyoming

1. R043BY009ID_Loamy 16-20_DRAFT
2. R043BY222WY_Loamy15-19W_Provisional2007
3. R043BY322WY_Loamy15-19E_Provisional2007
4. R048AY122WY_Loamy15-19SE_DRAFT
5. R049XA122WY_Loamy15-19SE_Provisional2008

ii. Cryic/Udic (Cold, Wet)

Representative Area: Middle and Southern Rockies—MLRA 43B in Wyoming and Montana; areas of 48A in Colorado; MLRA 47 (Wasatch north and south) high mountain valleys; potential Gunnison sage-grouse in Colorado

Status of ESDs: MLRA 43B has contemporary draft STM from Idaho and older vintage from Wyoming; MLRA 47 has contemporary STM from Utah and DRAFT site in 48A in Colorado

1. R043BY003ID_Loamy 22+_DRAFT
2. R043BY122WY_Loamy20M_Provisional2007
3. R047XA516UT_HighMtnLoam_Provisional2012
4. R048AY250CO_SubalpineLoam_2015DRAFT

iii. Frigid/Ustic-Typic (Cool, Summer Moist)

Representative Area: Middle Rockies—Uinta Mountains (MLRA 47 LRU C) in Utah and Wyoming; Southern Rockies in Colorado and Utah – MLRA 48A south of Colorado River and I-70; potential Gunnison sage-grouse in Colorado

Status of ESDs: MLRA 47 has site concept with no STM from Utah, closest thing with an STM is a site that is more xeric; MLRA 48A has a draft contemporary STM from Colorado and another site concept from Utah with no STM

1. R047XA430UT_MtnLoam-Provisional2012Xeric
2. R047XC430UT_MtnLoam-Provisional-noSTM
3. R048A228CO_MountainLoam_2015DRAFT
4. R048A247CO_DeepClayLoam_2015DRAFT
5. R048AY405UT_MtnLoam_Provisional-noSTM

iv. Frigid/Xeric (Cool, Winer Moist) – MLRA 47 Wasatch Mountains – this regime was covered in Chambers et al. (2014a) so no analysis was conducted

c. West-Central Semiarid Prairies

i. Frigid bordering on Cryic/Ustic bordering on Aridic (Cool bordering on Cold, Summer Moist bordering on Dry)

Representative Area: Northwestern Glaciated Plains—MLRA 52 in northern Montana

Status of ESDs: MLRAs 52 has several draft contemporary STMS representing the cooler phase of Frigid with more summer precipitation

1. R052XC205MT_Clayey_10_to_14_inch_pz_2005DraftCool
2. R052XC206MT_Dense_Clay_10_to_14_inch_pz_2005DraftCool
3. R052XC217MT_Silty_10_to_14_inch_pz_2005DraftCool

ii. Frigid/Ustic bordering on Aridic (Cool, Summer Moist bordering on Dry)

Representative Area: Northwestern Great Plains—LRA 58A in Montana and 58D in South Dakota, 58C in North Dakota

Status of ESDs: MLRA 58A, LRU C and LRU E represents most of eastern Montana with older vintage STMs; MLRA 58D has STMs from South Dakota to represent this regime (vintage?)

1. R058AC041MT_Clayey11-14ppz_Provisional
2. R058AC052MT_DenseClay11-14ppz_Provisional
3. R058AC054MT_Claypan11-14ppz_Provisional
4. R058AE002MT_Clayey10-14ppz_Provisional
5. R058DY011SD_Clayey_Provisional2009
6. R058DY013SD_Claypan_Provisional2010
7. R058DY015SD_ThinClaypan_Provisional2010

iii. Frigid/Ustic-Typic (Cool, Summer Moist)

Representative Area: Northwestern Great Plains—MLRA 60A in South Dakota

Status of ESDs: MLRA 54 has contemporary STM from North Dakota that may be applicable; MLRA 60A has several STMs from South Dakota (age uncertain)

1. R054XY021ND_Claypan_Provisional2011
2. R060AY011SD_Clayey-13-16ppz_Provisional2012
3. R060AY015SD_ThinClaypan_Provisional2012
4. R060AY018SD_DenseClay_Provisional2012
5. R060AY025SD_ShallowDenseClay_Provisional2012

iv. Mesic/Ustic bordering on Aridic (Warm, Summer Moist bordering on Dry)

Representative Area: Northwestern Great Plains—drier portions of MLRA 58B in Wyoming, but could also apply to warmer portions of MLRA 58A, LRU C in Montana

Status of ESDs: MLRA 58B has older vintage STMs from Wyoming

1. R058BY104WY_Clayey10-14NP_Provisional2005
2. R058BY122WY_Loamy10-14NP_Provisional2005
3. R058BY158WY_ShallowClayey10-14NP_Provisional2005
4. R058BY162WY_ShallowLoamy10-14NP_Provisional2005

v. Mesic/Ustic-Typic (Warm, Summer Moist)

Representative Area: Northwestern Great Plains—wetter portions of MLRA 58B in Wyoming near Black Hills

Status of ESDs: MLRA 58B has older vintage STMs from Wyoming

R058BY222WY_Loamy15-17NP_Provisional2005

Appendix A4. Data Sources 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 16 Sept 2015].

Ecoregions

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

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 16 Sept 2015].

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 1 Feb 2016].

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 15 Sept 2015].

Greater sage-grouse breeding habitat model

Source: Doherty, K.E.; Evans, J.S.; Coates, P.S.; [et al.]. 2015. Importance of regional variation in conservation planning and defining thresholds for a declining species: A range-wide example of the greater sage-grouse. https://www.sciencebase.gov/catalog/folder/560ea672e4b0ba4884c5ebb7 [Accessed 6 Oct 2015].

Greater sage-grouse population index model

Source: Doherty, K.E.; Evans, J.S.; Coates, P.S.; [et al.]. 2015. Importance of regional variation in conservation planning and defining thresholds for a declining species: A range-wide example of the greater sage-grouse. https://www.sciencebase.gov/catalog/folder/560ea65de4b0ba4884c5ebb5 [Accessed 6 Oct 2015].

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.

Gunnison sage-grouse lek data

Source: Colorado Parks and Wildlife; Utah Division of Wildlife Resources

Contacts: Kathy Griffin, Colorado Parks and Wildlife, 711 Independent Ave., Grand Junction, CO 81505; kathy.griffin@state.co.us; Avery Cook, Utah Division of Wildlife Resources, 1594 West North Temple, Salt Lake City, UT 84116; averycook@utah.gov.

Gunnison sage-grouse range plus linkages shapefile

Source: Utah Division of Wildlife Resources [UDWR] 2012. Gunnison sage-grouse habitat GIS shapefiles for occupied and vacant-unknown habitat. Last updated March 2012. http://dwrcdc.nr.utah.gov/ucdc/downloadgis/disclaim.htm [Accessed 7 June 2016].

Source: Colorado Parks and Wildlife (CPW) 2015. Gunnison sage-grouse habitat and linkage zones. Last updated November 2015. http://www.fws.gov/coloradoes/GUSG/ [Accessed December 2015].

Human disturbance

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

Land cover—conifer (GRSG)

Source: U.S. Geological Survey (USGS). 2012. LANDFIRE 1.3.0 Existing Vegetation Type layer. Updated 12/17/2014. Washington, DC: U.S. Department of the Interior, Geological Survey. http://landfire.cr.usgs.gov/viewer/ [Accessed 26 Aug 2015].

Land cover—conifer (GUSG)

Source: Falkowski, M.J.; Evans, J.S.; Naugle, D.E.; [et al.]. [In press]. Mapping tree canopy cover in support of proactive prairie grouse conservation in western North America. Rangeland Ecology and Management. http://dx.doi.org/10.1016/j.rama.2016.08.002 [Accessed 1 11511 5151].

Land cover—sagebrush

Source: U.S. Geological Survey (USGS). 2012. LANDFIRE 1.3.0 Existing Vegetation Type layer. Updated 12/17/2014. Washington, DC: U.S. Department of the Interior, Geological Survey. http://landfire.cr.usgs.gov/viewer/ [Accessed 26 Aug 2015].

Land ownership

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

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 11 May 2016].

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. Online: http://www.esri.com/data/streetmap [Accessed 11 May 2016].

Soil data (SSURGO)

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

Soil data (STATSGO)

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

Soil temperature and moisture regime

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 10 May 2016].

Appendix A5. 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).

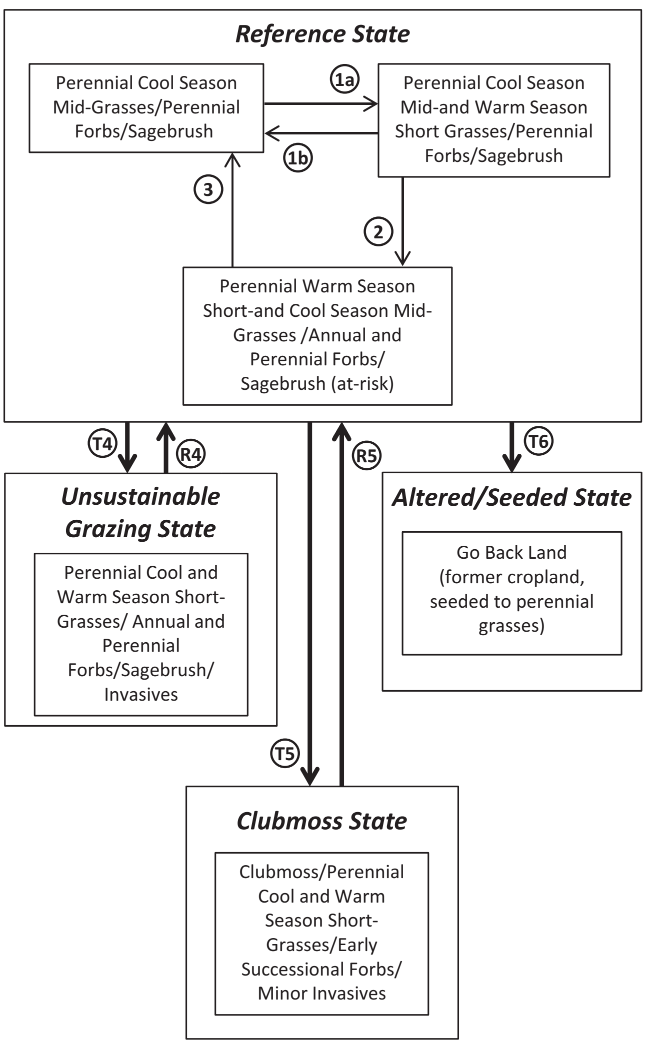
Remotely sensed data of land cover is typically used to represent landscapes. These data may combine several sources of data and may include ancillary data, such as elevation, to improve the interpretation of data. These data are organized into pixels that contain a size or grain of land area. For example, Landsat Thematic Mapper spectral data used in determining vegetation cover generally have pixels that represent ground areas of 900 m^2 (30 m 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 m 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.

Appendix A6. State-and-Transition Models for the Predominant Sagebrush Ecological Types in the West-Central Semiarid Prairies, Western Cordillera, and Cold Desert

The characteristics and relative resilience and resistance of the ecological types in the state-and-transition models are in table 3. 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 West Central Semiarid Prairies
Frigid bordering on Cryic/Ustic bordering on Aridic
Grass Dominated w/ SilverSagebrush (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.

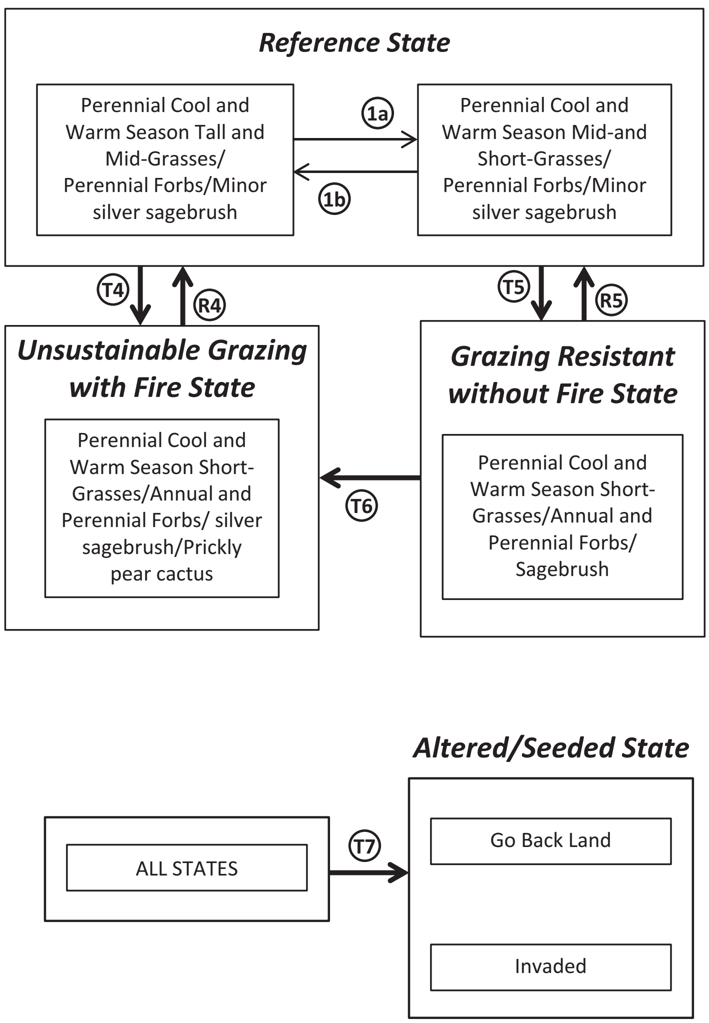
T5 Extended drought (>7 years) may result in dense stands of clubmoss. However, no grazing, light grazing, and rotational grazing combined with drought can result in more rapid increase in clubmoss than drought alone. Lack of fire may contribute to this transition as well. Potential for invasives such 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.6.2 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.

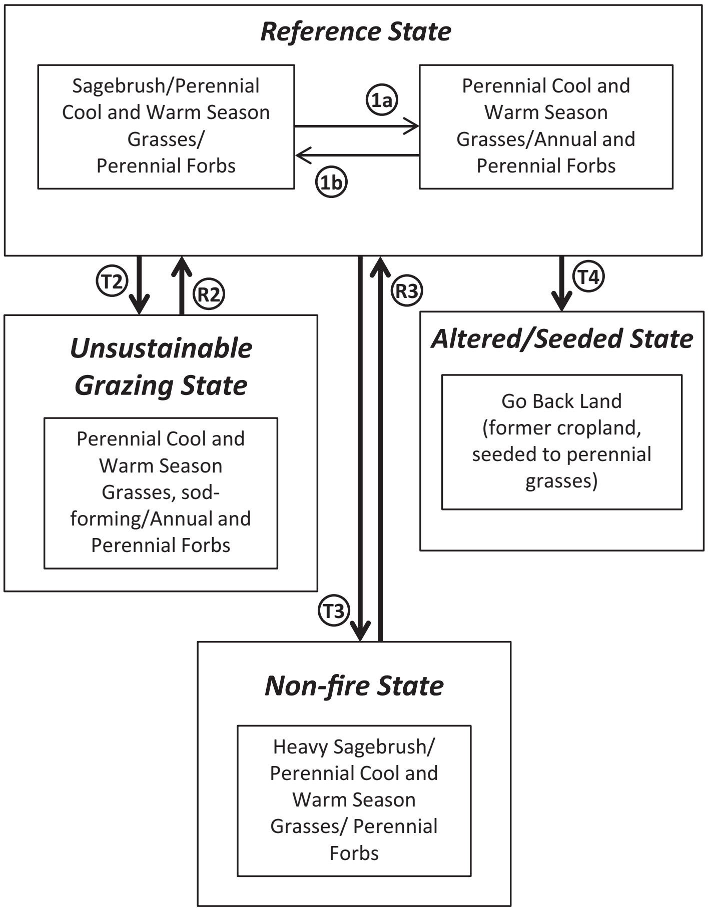
R5 Extended periods of normal precipitation, possibly seeding (if an adequate seedbank does not exist), mechanical renovation, and reduced grazing pressure that varies season of use can return the site to one resembling the reference state.

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.6.3 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.

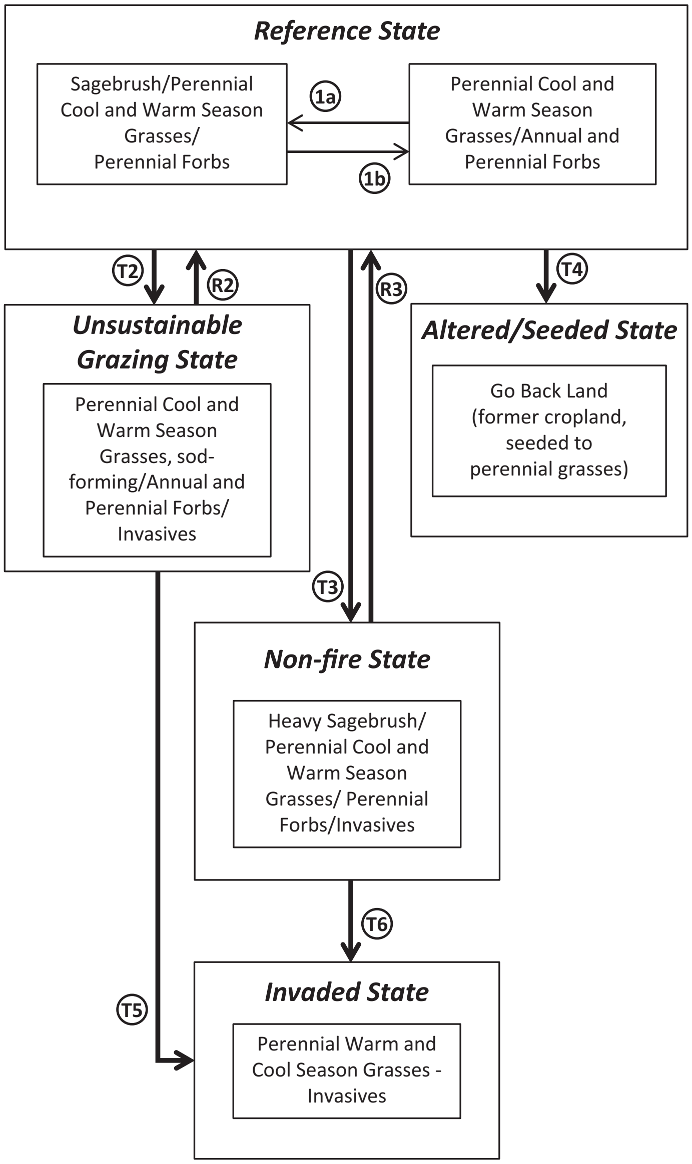
R2 Normal precipitation patterns, reducing the frequency and severity of disturbances that kill sagebrush, and proper timing and intensity grazing regime that varies season of use can return the site to the reference state.

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.6.4 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.

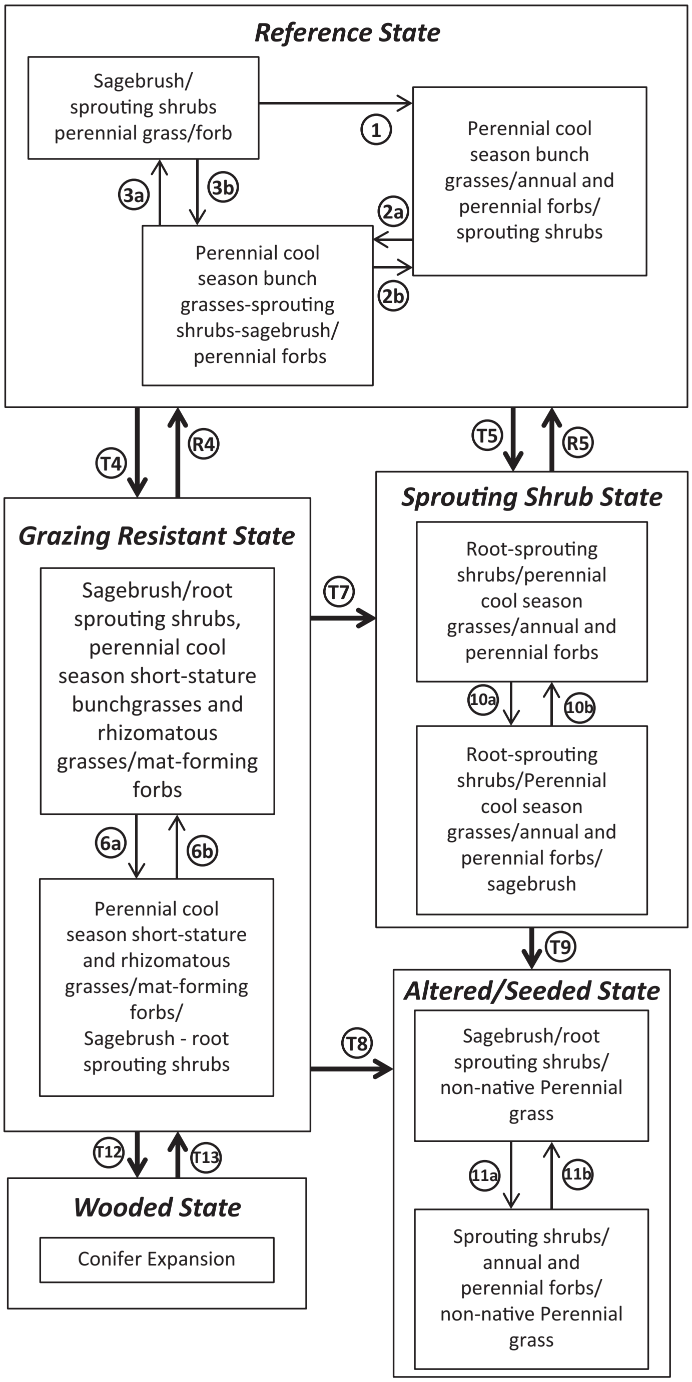
R3 Extended periods of normal precipitation, treatment with fire surrogates, seeding (if adequate seedbank does not exist), and reduced grazing pressure that varies season of use can return the site to the reference state.

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.6.5 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 forbs 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 grazingtolerant 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.

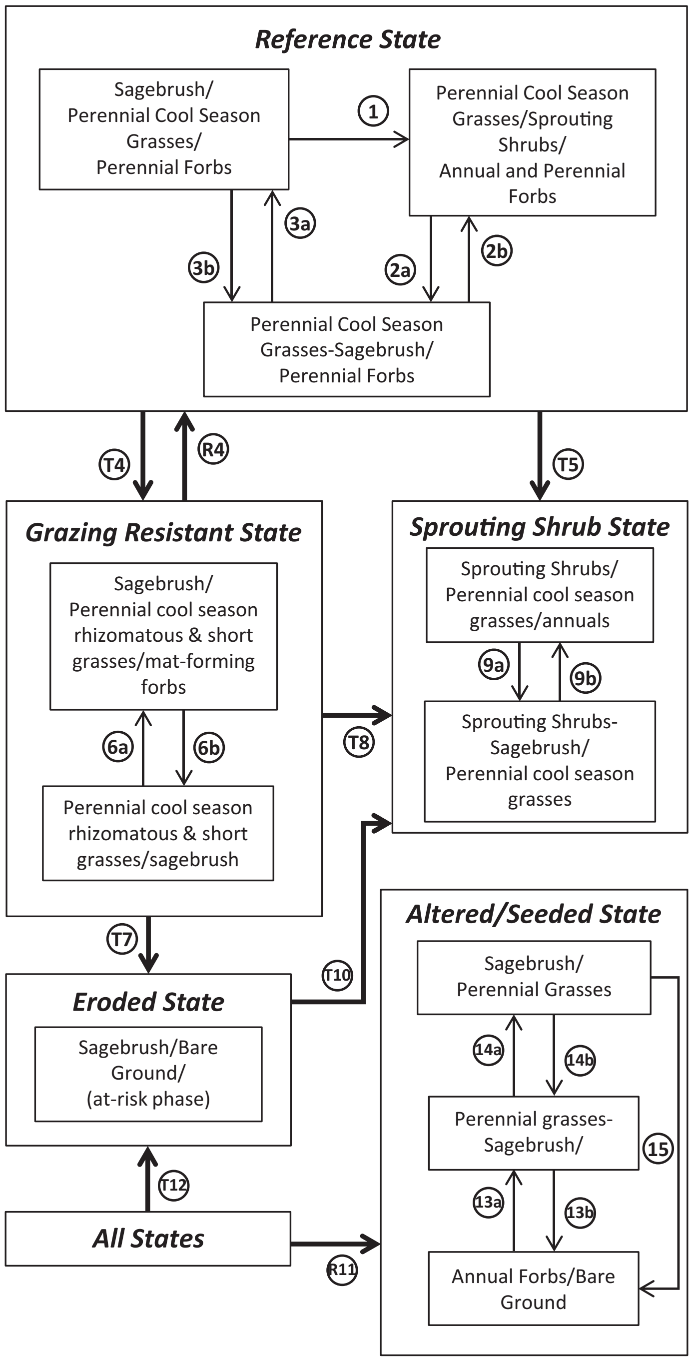
11b Sagebrush and other shrubs increase.

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.

T13 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.6.6 Cold Deserts – Frigid bordering on Cryic/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 bare ground 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.

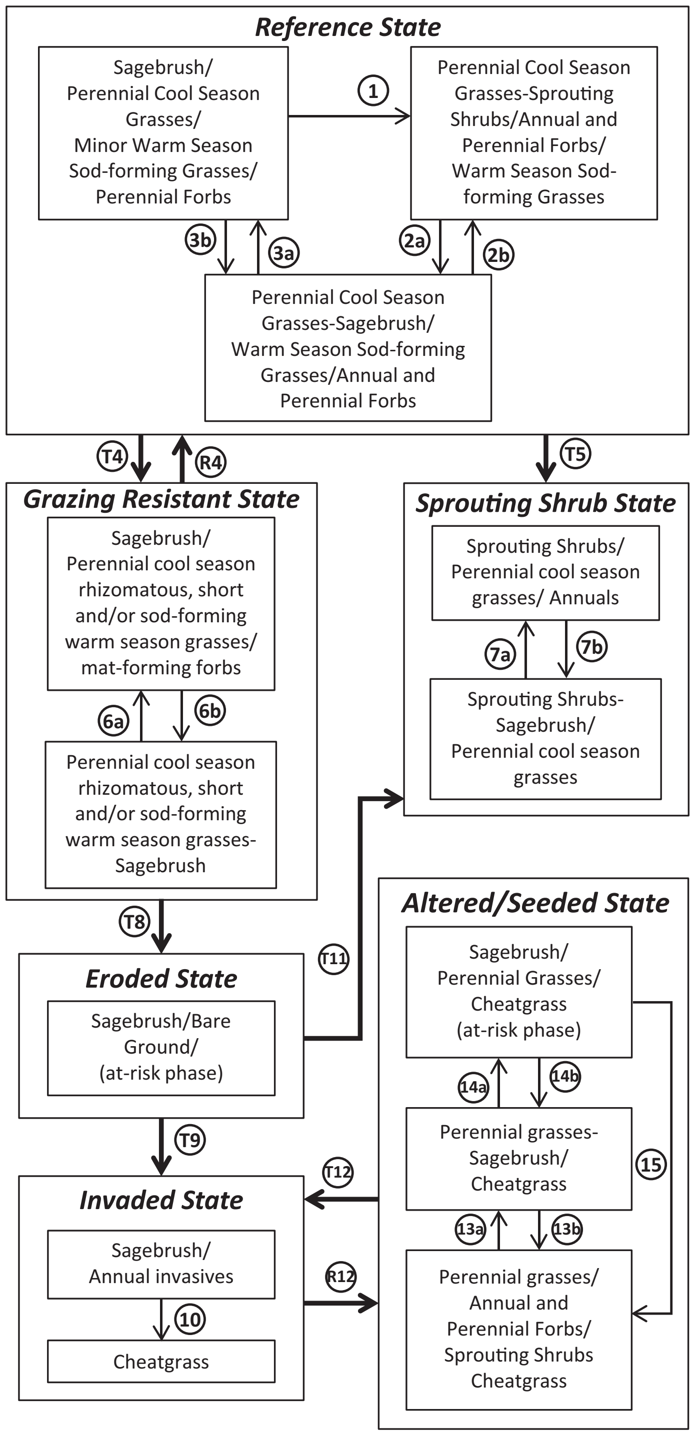
14a Sagebrush increases with no disturbances over time.

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.6.7 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.

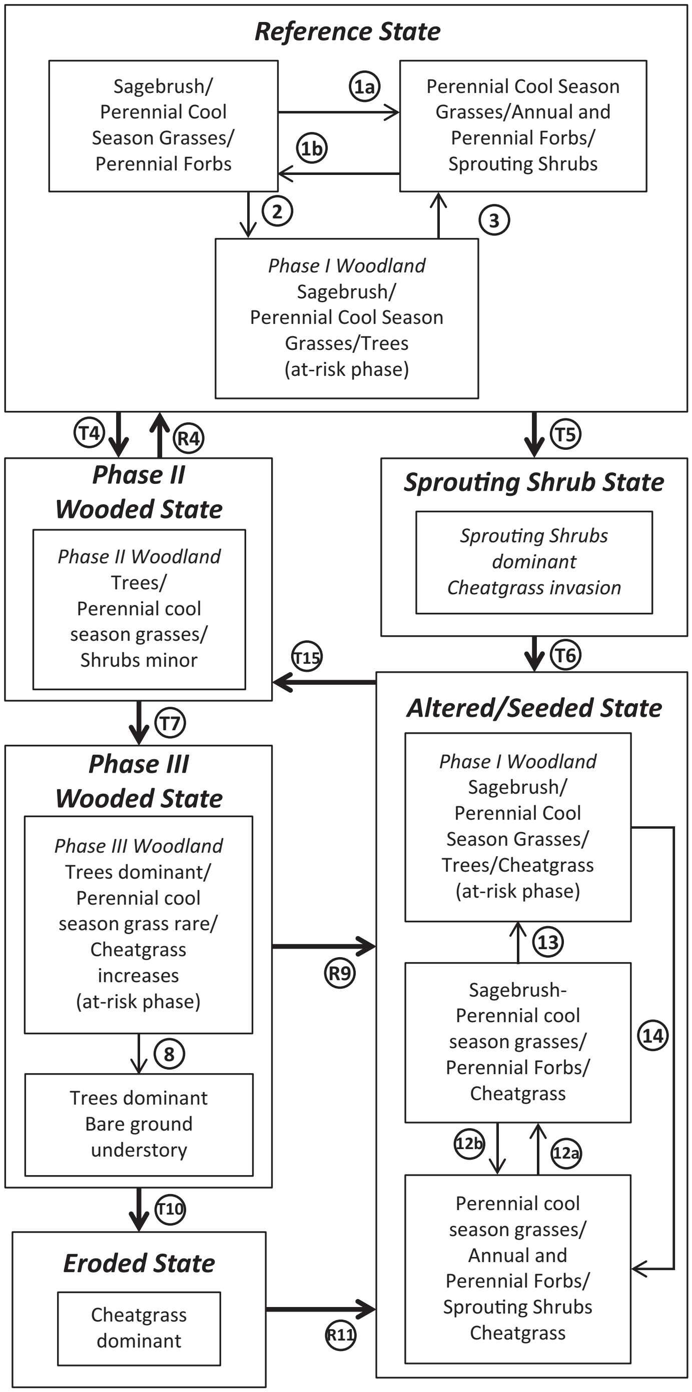
14b Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush.

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

A.6.8 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 Woodland invasion 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 decrease until 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 is soil water and nutrient availability result in increased cheatgrass.

(12b) Sagebrush increases until co-dominant with the herbaceous species. Cheatgrass decreases, but is present.

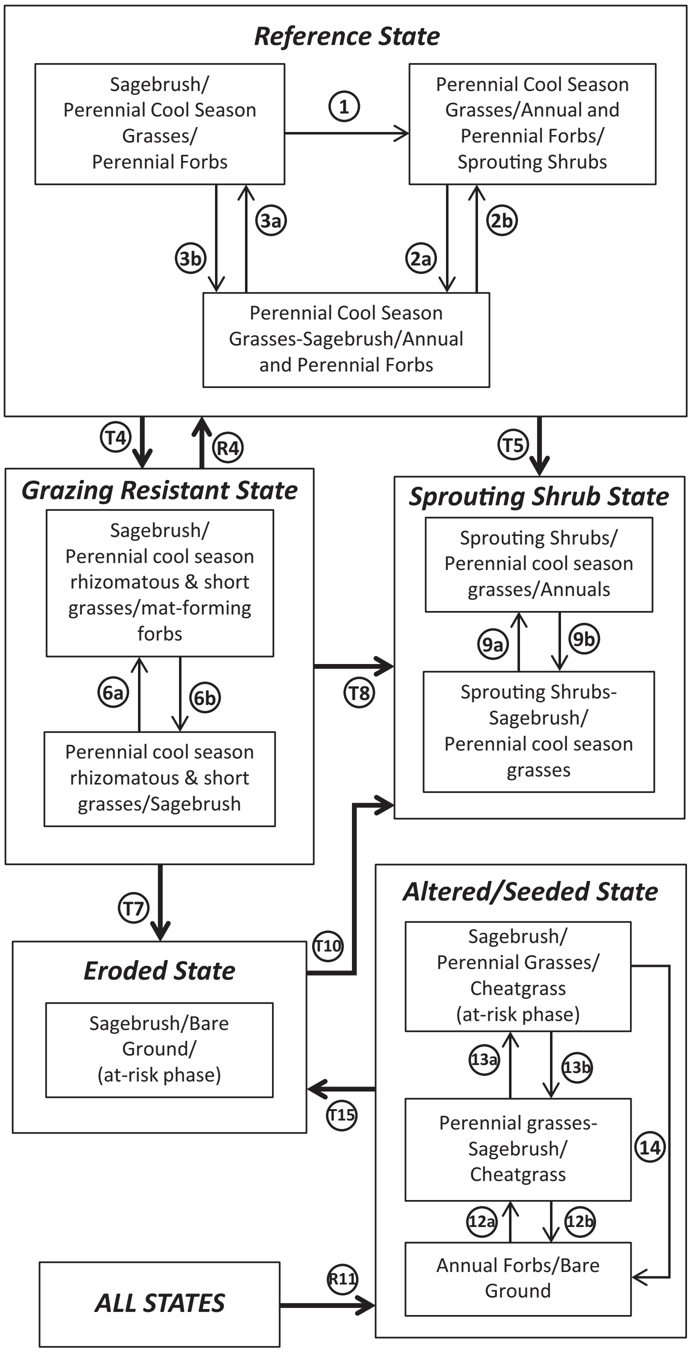
(13) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland and an at-risk phase.

(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.6.9 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 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 chemicalor 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.

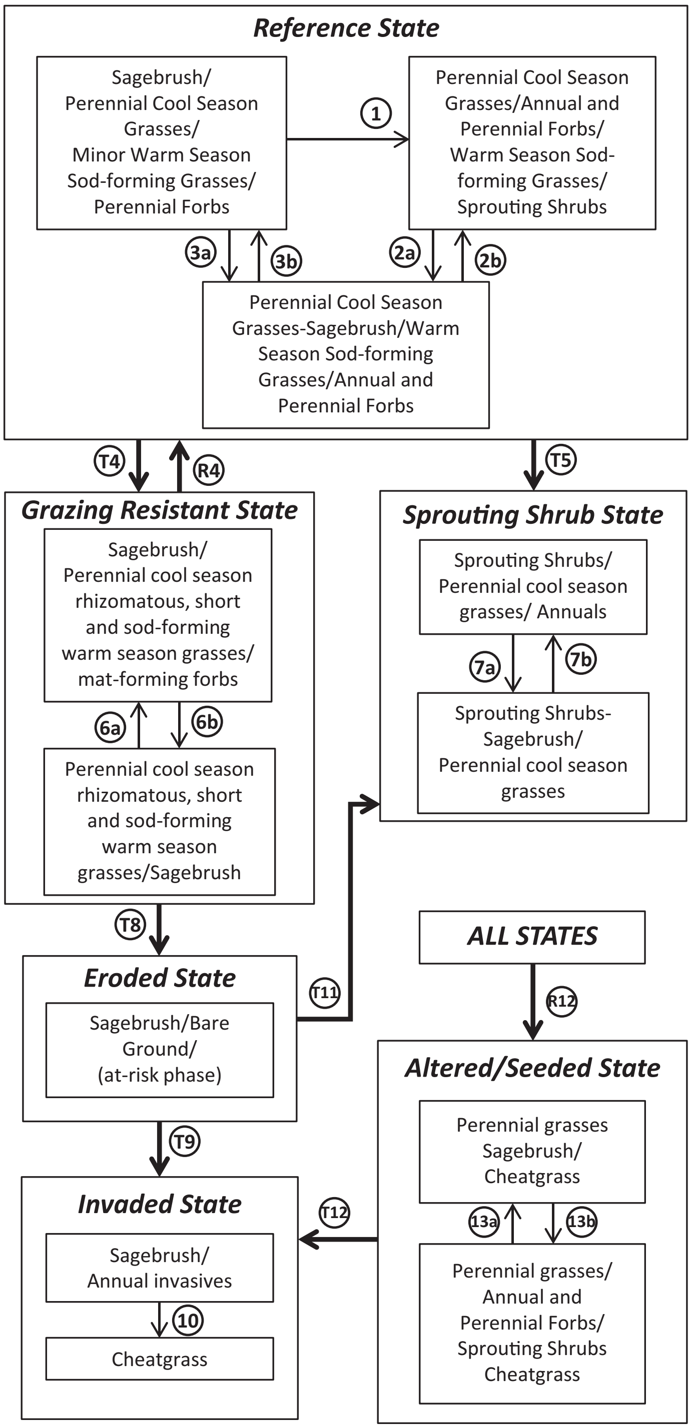
13b Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush. There may be a temporary flush of annuals.

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.6.10 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.

(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 removalof 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.

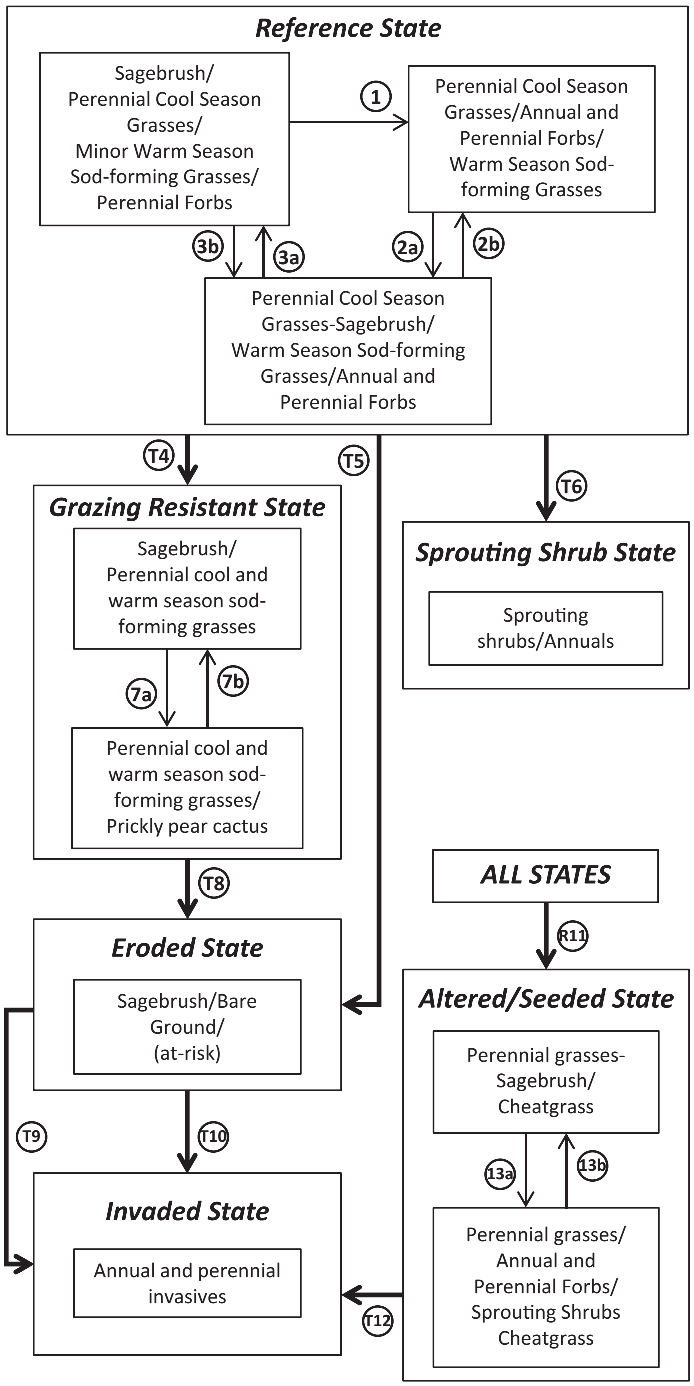
(R12) A restoration treatment after severe ground disturbing activities, including mechanical treatment, seeding with non-native perennials can restore a perennial grass community and eventually support an altered sagebrush community with some invaders present. Sagebrush will be slow to reestablish.

(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.6.11 Cold Deserts – Mesic/aridic Wyoming big sagebrush (5 to 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 becomedominant 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 A7. Informing Wildfire and Fuels Management Strategies to Conserve Sagebrush Ecosystems and Sage-Grouse

Vegetation and fuels management projects are important for the conservation, maintenance, and restoration of sagebrush landscapes. Resilience and resistance concepts provide a science-based background that can inform strategic placement of fuels treatments, augment effective fire operations, and inform allocation of scarce assets during periods of heightened fire activity across the Interior West. Collectively, fuels management includes vegetation projects that mitigate wildfire risk, improve resilience to disturbance, and restore habitat, as well as habitat protection projects intended to protect intact sage-grouse habitat (fig. A7.1, A7.2). Mechanical treatments are typically applied to reduce fuel loading or to change species composition consistent with land management objectives. Prescribed burning is used to improve habitat conditions or create fuel conditions that reduce negative impacts from wildfire. Also, chemical and seeding treatments are conducted to reduce invasive plant species and to shift species composition to native or more fire resistant species.

In fire operations, firefighter and public safety is the overriding objective in all decisions; land managers, however, also consider numerous other values at risk, including the wildland-urban interface, species habitats, and infrastructure when allocating assets and prioritizing efforts. In each case, managers are designing management activities that reflect the unique ecosystem responses that occur across environmental gradients. Resilience and resistance concepts are especially relevant for evaluating tradeoffs related to current ecological conditions, rates of recovery, and possible ecological consequences of different fire management activities. For example, prioritizing initial attack efforts based on ecological types and their resilience and resistance at fire locations is one application of resilience and resistance concepts. Also, fire prevention efforts can be focused on intact, high quality habitats with inherently low resilience and resistance where human ignitions have commonly occurred.

Fuels management projects are often applied on a landscape scale to (1) constrain or minimize fire spread; (2) alter species composition; (3) modify fire intensity, severity, or effects; (4) create fuel breaks or anchor points that augment fire management efforts; (5) improve wildlife habitat; (6) create resilient landscapes; and (7) restore habitats or vegetation conditions (see table 5). These activities are selectively used based on the projected ecosystem response, anticipated fire patterns, and probability of success. For example, in areas that are difficult to restore due to low to moderate resilience, fuel treatments can be placed to minimize fire spread and conserve sagebrush habitat. In cooler and moister areas with moderate to high resilience and resistance, mechanical or prescribed fire treatments may be appropriate to prevent conifer expansion and dominance.

Given projected climate change and longer fire seasons across the western United States, fuels management represents a proactive approach for modifying large fire trends and maintaining desired vegetation patterns. Fire operations and fuels management programs contribute to a strategic, landscape approach when coupled with data that illustrate the likelihood of fire occurrence, potential fire behavior, and risk assessments (Finney et al. 2010; Oregon Department of Forestry 2013). In tandem with resilience and resistance concepts, these data can further inform fire operations and fuels management decisions.

Figure A7.1—Common fuels management practices to improve sage-grouse habitat. Photos A and B show conifer mastication using a bobcat and bullhog. Photo C shows hand removal of conifers using a chainsaw. Photo D shows targeted prescribed burning in a mountain big sagebrush area exhibiting conifer expansion. Adjacent, intact sagebrush communities are intentionally avoided. Photos E and F show targeted prescribed burning of masticated and standing juniper fuels while intentionally avoiding sagebrush communities (Bureau of Land Management file photos).

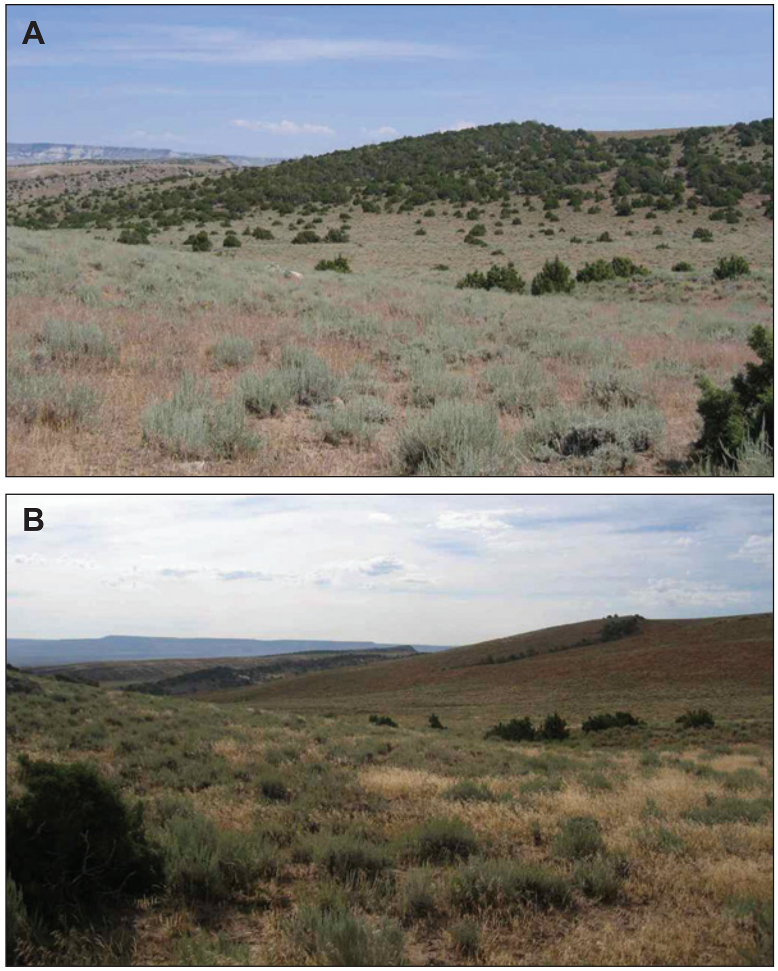


Figure A7.2—Before (A) and after (B) photos of mechanical conifer removal within Greater sage-grouse habitat southeast of Lander, Wyoming. This project had the objectives of moderating fire behavior characteristics and improving Greater sage-grouse and mule deer habitat. Fuels managers have been successful in restoring Greater sage-grouse habitats through mechanical treatments that reduce conifer dominance (Bureau of Land Management file photos).

Fire managers and researchers are closely analyzing wildfire trends in the eastern range of GRSG and the entire range of GUSG. Recent fire history, climate trends, wildfire probability, and vegetation changes are key sources of data that are being used to develop proactive measures being implemented by the fire operations and fuels management programs. Concerns of fire and fuels managers in the eastern range include large fires in or adjacent to sage-grouse habitats, increases in woody plant expansion, and increases in the extent of nonnative annual grass populations. Currently there is little evidence of the same type of feedback cycle between wildfires, annual grasses, and larger fire size as exists in the western portion of the range (Taylor et al. 2014). Managers are aware of this potential, however, and are monitoring trends in fire size, postfire community composition, and rehabilitation success to detect the development of this type of cycle and adapt management to ensure positive future trends. Several large, severe fires have burned in sagebrush and grass ecosystems or sagebrush ecosystems exhibiting piñon and juniper expansion since 2000, including: Alkali, Colorado, (2014; 22,000 ac [8,903 ha]); Wolf Den, Utah (2012; 19,865 ac [8,039 ha]); Cato, Wyoming (2012; 27,680 ac [11,202 ha]); Sheep Mountain, Wyoming (2000; 34,346 ac [13,899 ha]); and Wildhorse Basin, Wyoming (2000; 36,762 ac [14,877 ha]).

Proactive fuels management practices in the eastern range of GRSG differ from those in the western range. For example, roadside linear fuel breaks are seldom used in the eastern range, but are more commonly used in the western range. Conifer expansion in the western range is largely pinñon and juniper species; expanding conifers in the eastern range include limber pine (*Pinus flexilus*), Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*). In addition, successional advancement of mountain shrubs in Management Zone VII (e.g., gambel oak [*Quercus gambelii*], serviceberry [*Amelanchier* spp.], curlleaf mountain mahogany [*Cercocarpus ledifolius*], snowberry [*Symphoricarpos* spp.], and cliff fendlerbush [*Fendlera rupicola*]) into sagebrush communities are treated as a vegetation management issue.

Mechanical treatments of expanding conifers, which include mastication and chainsaw treatments, are increasingly used in the eastern range to retain sagebrush cover. Prescribed burning, a fuels management tool, is selectively applied in eastern range GRSG habitats, typically to: (1) reduce downed woody fuels resulting from mechanical treatments; (2) treat expanding conifers; (3) convert conifer woodlands to shrub-steppe; (4) reduce the dominance of mountain shrub communities to favor sagebrush; (5) create age class and structural diversity within sagebrush communities; and (6) restore riparian systems through multi-phased treatments. Managers are cognizant of the tradeoffs related to sagebrush removal through burning and apply this tool in consultation with wildlife managers and in consideration of site conditions. Additional fuels management practices in the eastern range include monitoring and treating areas with invasive annual grass populations with herbicides and seedings where insufficient perennial grasses and forbs exist for recovery, and installing fuels breaks, which can complement fire suppression effectiveness.

In the eastern range, cooperators such as rural, city, and State agencies contribute to GRSG conservation through their roles in both fire suppression and fuels management. Unlike areas in the western range where there are unprotected lands, in the eastern range, States and counties have jurisdictional responsibilities for wildfires on State and private lands. There are isolated, underprotected lands in the eastern range where opportunities exist to develop additional, non-Federal capacity, particularly by providing training and equipment, should Federal funding be made available.

The tools and data presented in this section can be used by fire and fuels managers, in cooperation with resource managers, to inform strategies for fire operations and fuels management related to suppression responses, treatment planning, and postfire management. Postfire rehabilitation in the eastern range is a cross-cutting effort involving disciplines such as range, wildlife, fire, and fuels management. Managers apply knowledge of seed zones, resilience and resistance, and ecological sites to inform rehabilitation strategies. The postfire emergency stabilization and rehabilitation handbook and manual (USDI BLM 2012) provide technical guidance on considerations in rehabilitation practices. The importance of GRSG and GUSG habitats is recognized in dispatch procedures and allocation of resources for wildfire incident management. These efforts align with the recommendations/guidance in the Final Report for the DOI Secretarial Order 3336 (USDI 2015).

Appendix A8. Informing Management Strategies in the Face of Climate Change

Assessing the projected magnitude of climate change for a given area provides a basis for informed management into the future. The degree to which climate change and other stressors interact influences the approaches that can be taken to minimize losses. In those areas where climate change interactions are expected to be relatively small, and knowledge and capacity high, a logical approach might be to continue to use best management practices. In areas where the effects of climate change and its interactions with stressors are expected to be severe, our current suite of management actions may be ineffective.

Where climate change-stressor interactions are expected to be small, the logical approach is to use best management practices to build resilience to climate change into sagebrush ecosystems. Maintaining and restoring habitat, conservation actions to facilitate species of interest, and an increased emphasis on managing other stressors, such as nonnative invasive plants, improper grazing, and fire, are key components of building resilience.

As climate change progresses and temperatures increase, the frequency and magnitude of drought is expected to increase. Implementing measures to reduce the interacting negative effects of habitat loss and climate change and facilitate recovery from drought will become increasingly important. Drought adaptation measures may include changes in land uses such as a reduction in livestock stocking rates because plants that have been overgrazed or cropped too frequently are less able to recover after drought (Hart and Carpenter 2005). An increased emphasis on early detection and rapid response to address nonnative invasive plants may be needed as climate suitability for species like cheatgrass is likely to increase in many areas (Bradley et al. 2016). Also, habitat modifications such as creating and protecting migration corridors in fragmented landscapes may be necessary to facilitate persistence of sage-grouse and other species that use sagebrush habitats such as mule deer (Anderson and Jenkins 2006).

Drought adaptation may require modifying or delaying restoration practices during droughts. For example, it may be best to focus restoration efforts on removal of undesirable plants as opposed to planting treatments. In the West-Central Semiarid Prairies, efforts to restore native grassland may be more effective when crested wheatgrass control measures are implemented in drier years and native species are seeded in wetter years (Bakker et al. 2003). In the Cold Desert, juniper removal by mastication (shredding) can both decrease competition for water and enhance soil moisture beneath shredded debris benefitting herbaceous species (Young et al. 2013), potentially offsetting the effects of drought. If planting is deemed necessary during a drought year, a variety of strategies and techniques can be employed to increase the probability of successful plant establishment in the short term and species persistence in the long term (see review in Finch et al. 2016). For example, snow fences were constructed and arranged to maximize snow capture and increase sagebrush establishment on abandoned natural gas pads in the Wyoming Basin (David 2013). Stubble from winter-sown annual crops has been shown to capture snow and may benefit seedling establishment in the West-Central Semiarid Prairies (Greb 1980). Also, pitters and imprinters can be used to create micro-catchments in the soil that capture and concentrate water (Bainbridge 2007).

Regardless of the seeding or planting technique used, plant materials should be carefully selected to ensure that the species and ecotypes are adapted to both site conditions and drought and that they are resilient if drought is episodic or long-term climate change is projected. Transplanting has been found to be effective for establishing shrubs and forbs in water-limited environments, especially if transplants are hardened prior to planting and provided with supplementary water afterwards (Bainbridge 2007).

Current management strategies may be ineffective where the effects of climate change and its interactions with stressors are expected to be severe. In this case more proactive strategies for habitat management may be necessary to facilitate transition to a new site potential. Assisted migration, the purposeful movement of individuals or propagules of a species to facilitate or mimic natural range expansion or long distance gene flow within the current range, may become integral to conservation strategies as the rate of climate change increases (Havens et al. 2015). Assisted migration can encompass a broad range of goals, from minimizing loss of biodiversity to preventing extinction, and it can operate at a range of spatial scales, from local to continental (Williams and Dumroese 2013). Seed transfer guidelines can be used to determine transfer distances that avoid maladaptation (Johnson et al. 2004). These guidelines can be reprojected using models of expected future environmental conditions (Thomson et al. 2010) and will play an integral role in the planning of assisted migration efforts under climate change.

Management and research studies coupled with landscape monitoring can provide the basis for developing cost-effective and feasible management strategies for adapting to climate change. Carefully designed studies can increase our understanding of viable approaches for adaption measures such as appropriate grazing regimes for drought conditions, conservation actions to facilitate species persistence during climate warming, seeding and transplanting techniques during drought, and species and ecotypes for assisted migration. Monitoring to detect the rates and magnitudes of change occurring across the landscape can preemptively identify both populations and habitats that may suffer decline (Carwardine et al. 2011; Field et al. 2004). Monitoring can also identify potential new or novel combinations of species that constitute a functioning ecosystem under climate change. Increased understanding of both the changes occurring and viable strategies for addressing that change can reduce uncertainty and provide direction for proactive management strategies (Hobbs et al. 2009).

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