Science Framework for the Conservation and Restoration Strategy of the Department of the Interior Secretarial Order 3336

Using Resilience and Resistance Concepts to Assess Threats to Sagebrush Ecosystems and Greater Sage-Grouse, Prioritize Conservation and Restoration Actions, and Inform Management Strategies

Version I, August 5, 2016

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This document is Version I of the Science Framework for the Conservation and Restoration Strategy of the Department of the Interior Secretarial Order 3336. This version will undergo further development and review. The final version of the document will be published as a USDA Forest Service, Rocky Mountain Research Station, General Technical Report in early 2017. Comments that will improve use of the document and the approach described herein can be sent to Jeanne Chambers (jchambers@fs.fed.us) by September 30, 2016.

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Abstract

The Science Framework for the Conservation and Restoration Strategy of the Department of the Interior, Secretarial Order 3336 (SO 3336), Rangeland Fire Prevention, Management and Restoration, provides a strategic, multiscale approach for prioritizing areas for management and determining effective management strategies across the sagebrush biome. The emphasis of this version is on sagebrush ecosystems and greater sage-grouse. The Science Framework uses a six step process in which sagebrush ecosystem resilience to disturbance and resistance to nonnative, invasive annual grasses is linked to species habitat information based on the distribution and abundance of focal species. The predominant ecosystem and anthropogenic threats are assessed, and a habitat matrix is developed that helps decision makers evaluate risks and determine appropriate management strategies at regional and local scales. Areas are prioritized for management action using a geospatial approach that overlays resilience and resistance, species habitat information, and predominant threats. Decision tools are discussed for determining the suitability of priority areas for management and the most appropriate management actions at regional to local scales. The Science Framework and geospatial crosscut are intended to complement the mitigation strategies associated with the Greater Sage-Grouse Land Use Plan amendments for the Department of the Interior Bureaus, such as the Bureau of Land Management, and the U.S. Forest Service.

Keywords: sagebrush habitat, Greater Sage-Grouse, persistent ecosystem threats, anthropogenic threats, climate change, management prioritization, resilience, resistance, conservation, prevention, restoration

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Contents

1.1 Purpose and Use this Document

In January 2015, a Department of the Interior, Secretarial Order (SO 3336) was issued to enhance policies and strategies for preventing and suppressing rangeland fire and restoring rangeland landscapes affected by fire in the Western United States (USDI 2015a). Priority was placed on protecting, conserving, and restoring Great Basin sagebrush (*Artemisia* spp.) ecosystems and, in particular, greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) habitat with the intent of allocating agency resources and assets to reflect that Departmental priority. The implementation plan for SO 3336, "An Integrated Rangeland Fire Management Strategy: Final Report to the Secretary of the Interior," (USDI 2015b) describes an approach for meeting the objectives of SO 3336 that includes numerous actions and activities. An action integral to plan implementation is using emerging scientific knowledge on ecological resilience and resistance in the design and implementation of future land management actions for habitat and fuels management and restoration projects (Section 7b iv; USDI 2015b). This action calls for a multi-scale Conservation and Restoration Strategy (C&R Strategy) that considers ecological resilience and that can be used to (1) guide the development of scientific information and decision-support tools that facilitate prioritization of conservation and restoration actions, (2) inform options for management activities across scales and ownerships, (3) provide clear linkages to existing assessments and plans, and (4) inform budget prioritization and adaptive management. The Science Framework provides a science-based approach for the C&R Strategy that can be used to prioritize conservation and restoration actions, and determine effective management strategies in sagebrush ecosystems. The Science Framework is linked to the other action items and activities identified in the Integrated Rangeland Fire Management Strategy for SO 3336, specifically fire and fuels management and suppression (7b i, ii, iii), invasive plant species (7b vii), the seed strategy (7b ix), the monitoring crosscut (#3), and the data and geospatial crosscut (#2). The Science Framework and geospatial crosscut compliment the mitigation strategies associated with the Greater Sage-Grouse Land Use Plan amendments for the Department of the Interior Bureaus, such as the Bureau of Land Management (BLM), and the U.S. Forest Service (USFS).

The Science Framework is intended 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. Ultimately, the 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, GRSG, and other focal species and resources. The approach couples information on ecosystem resilience to disturbance and resistance to invasive plant species with data on species habitat and population abundance to prioritize areas for management and determine the most appropriate management strategies at multiple scales. Prioritization of areas for management at the scale of ecoregions or management zones (MZ; Stiver et al. 2006) is a key step in the planning process. Once these priority areas for management are determined, they are used to inform budget prioritization across the sagebrush biome and to ensure consistent allocation of funds. To step down ecoregion/MZ priorities to a mid to local scale, managers and stakeholders are engaged to refine priorities based on higher resolution geospatial products and additional species information and to identify opportunities to leverage partner resources. The Science Framework 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. The Science Framework is intended to be adaptive and will incorporate new science and information and data on resource values and focal species as they become available.

This document is divided into parts that can be used by the reader to gain an understanding of (1) the background and structure of the Science Framework, (2) the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems and GRSG, (3) the key concepts and approach used in the Science Framework to prioritize areas for management and develop effective management strategies, and (4) the necessary information for determining appropriate management treatments. Users of the document will find the background for the Science Framework as well as the approach, scope, and scales in 1.2. Individuals who are unfamiliar with the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems and GRSG can access that information in 1.3 and 1.4, 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 1.5. The key elements of the approach used in the Science Framework are in 1.6 and 1.7 and will be of interest to all users. Section 1.6 combines information on resilience and resistance with species habitat requirements to develop a spatially explicit sage-grouse habitat matrix that can be linked directly to management strategies for maintaining or increasing sagebrush habitat. Section 1.7 provides the data sources and geospatial process for delineating priority areas for management at the biome, ecoregional/MZ, and local scale. Section 1.8 is the final section and provides information and examples for determining appropriate management treatments at the local scale and will be of general interest. In addition to this technical document, geospatial tools and training are being developed to assist managers in implementing the resilience-based approach described here. Also, handbooks and guides for implementing this approach are available for the western portion of the sagebrush biome that can be adapted to the eastern portion of the sagebrush biome (Miller et al. 2014; 2015; Pyke et al. 2015a,b).

1.2 Overview of the Science Framework

Background

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

Two types of threats impact sagebrush ecosystems and sagebrush obligate species. Persistent ecosystem threats include invasion of nonnative invasive plant species, altered fire regimes, conifer expansion, and climate change (Miller et al. 2011, Knick et al. 2011). These types of threats are difficult to regulate and are managed using ecologically-based approaches (Evans et al. 2013; Boyd et al. 2014a). (See Appendix 1 for definitions used in this report.) In contrast, threats due to land uses and development include improper livestock grazing, cropland conversion, energy development, mining, roads and other infrastructure, urban and exurban development, and recreation (USFWS 2013). These types of threats can be regulated but because of human population growth and increasing resource demands will likely continue to affect sagebrush ecosystems. The two types of threats often interact with each other. For example, oil and gas development can increase the spread of invasive annual grasses and potential for wildfire, and invasive annual grasses can increase the difficulty of restoring sites impacted by oil and gas development (Mealor et al. 2013). Many of the threats due to land uses and development have been the subject of detailed assessments or reviews in recent years (see Wisdom et al. 2005; Knick and Connelly 2011; Knick et al. 2011; Hanser et al. 2011; Manier et al. 2011). The Science Framework focuses on persistent ecosystem threats and the secondary effects of land use and development threats on ecosystems such as reduced ecosystem functioning and landscape connectivity. Importantly, the same types of ecologically-based approaches used to manage the detrimental effects of persistent ecosystem threats can be used to promote avoidance, minimize impacts, guide mitigation, and increase restoration effectiveness of habitats affected by land use and development.

Spatially-explicit knowledge of how ecosystem resilience and resistance vary across large landscapes can provide the basis for threat management (Wisdom and Chambers 2009; Chambers et al. 2014a,c; Chambers et al. *in press*). Resilient ecosystems have the capacity to ***reorganize and regain*** their fundamental structure, processes, and functioning when altered by stressors such as invasive plant species and disturbances such as improper livestock grazing and altered fire regimes (Holling 1973). Resistant ecosystems have the capacity to ***retain*** their fundamental structure, processes, and functioning when exposed to stressors, 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 nonnative invasive plant species, it is possible to assess and predict how native ecosystems and species will respond to management actions designed to mitigate persistent threats.

Approach

The Science Framework uses a multi-step approach (table 1). The first step is to obtain information on the distribution and abundance of the focal species and assess the species habitat requirements. Next, an understanding of ecosystem resilience to disturbance and resistance to invasive annual grasses is developed across land ownerships for the planning area. Then, a decision matrix for habitat resilience and resistance combines information on resilience and resistance with species habitat requirements to allow spatial assessments of (1) potential species habitat and (2) ecosystem response to disturbance and management actions. The information in the matrix and an assessment of the predominant threats are used to (1) prioritize habitats/areas for targeted management intervention and (2) determine appropriate management strategies and treatments.

This approach builds on those developed by two Western Association of Fish and Wildlife Agencies (WAFWA) working groups – the Fire and Invasives Team and the Sagebrush Resilience and Resistance Team. The approach developed by these teams was published in two U.S. Department of Agriculture (USDA), Forest Service, Rocky Mountain Research Station, General Technical Reports (GTRs) (Chambers et al. 2014b, Chambers et al. *in press*). The first GTR focused on persistent ecosystem threats, specifically invasive annual grasses, uncharacteristic wildfire, and conifer expansion, in the western range of sagebrush and GRSG (MZs III, IV and V; Chambers et al. 2014b). The second addressed both persistent ecosystem and anthropogenic threats to sagebrush ecosystems, Gunnison sage-grouse (*C. minimus*; GUSG), and GRSG in the eastern portion of its range (MZs I, II, and VII; Chambers et al. *in press*). The approach developed for the western portion of the range was subsequently incorporated into the "Greater Sage-grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment" (USDI BLM 2014), and served as the basis for a multi-year program of work by the BLM in the Great Basin. To support future assessments related to the Science Framework, geospatial data, maps, and models are provided through the U.S. Geological Survey (USGS) ScienceBase (https://www.sciencebase.gov/catalog/item/576bf69ce4b07657d1a26ea2) and BLM Landscape Approach Data Portal (http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/dataportal.html). The Landscape Approach Data Portal is being updated and enhanced as part of SO 3336 the data and geospatial crosscut action item (#2).

Scope and Scales

This version of the Science Framework focuses on sagebrush ecosystems and GRSG. Subsequent versions of the Science Framework will be updated to include additional resources and species as biome-wide and other data become more available. For example, a new Sagebrush Science Initiative developed by USFWS and WAFWA is identifying focal species for the sagebrush biome as a whole and as information and data are compiled for these species they will be added to the Science Framework.

The Science Framework provides a cross-walk between Environmental Protection Agency (EPA) ecoregions (EPA 2016) and MZs (Stiver et al. 2006) (fig. 1). Distinct differences in the type and extent of sagebrush habitat, persistent threats, resilience to disturbance, and resistance to invasive annual grasses exist across the sagebrush biome that are reflected in the different ecoregions. The sagebrush biome encompasses four Level II and thirteen Level III ecoregions (fig. 1; EPA 2016). The seven MZs are based largely on ecoregional differences, and provide a common basis for GRSG management within the sagebrush biome (fig. 1).

The Science Framework uses a strategic, multi-scale approach with scales represented by a nested set of management relevant boundaries including the sagebrush biome, ecoregions and MZs, and local land planning areas (table 2). This approach aligns with the Sage-grouse Habitat Assessment Framework (Stiver et al. 2015) and Johnson's (1980) orders of habitat selection. The sagebrush biome approximates GRSG species range (1st order), ecoregions/MZs provide population relevant information (2nd order), and local planning areas inform decisions regarding seasonal habitats (3rd and 4th order). Data, models, and tools from a variety of partners (USFS, Natural Resources Conservation Service [NRCS], WAFWA, non-governmental organizations [NGOs], States, and USDI bureaus including USGS, BLM, and USFWS) are available at each scale. The data, models, and tools are specific to the different scales, but are additive from the sagebrush biome scale to the local land planning area scale. For example, habitat data available at the biome scale, such as landscape cover of sagebrush, is also relevant at the ecoregion/MZ scale, but higher resolution or more detailed data may further inform ecoregional assessments.

Similarly, data from ecoregional scales are relevant at local planning area scales, but higher resolution or more detailed data may be available from planning area assessments or monitoring.

The three scales inform different aspects of the planning process (table 2). Prioritizations of areas for management actions are typically conducted at the mid-scale (individual or multiple ecoregions/MZs) because of similarities in environmental characteristics, ecosystem threats, and management strategies. At the sagebrush biome scale, such ecoregional/MZ assessments are used to prioritize budgets within USDI and help ensure range-wide consistency in allocating funds. At the local scale, local data and expertise are used to select project sites and determine appropriate management strategies and treatments within areas prioritized for management. In this document, management strategies are coordinated management activities conducted at mid- to local scale to achieve vegetation and habitat objectives (e.g., strategically locating firefighting resources to protect habitat, coordinating Early Detection and Rapid Response (EDRR) activities for invasive plant species, or positioning treatments to increase habitat connectivity). Treatments are local scale management actions that directly manipulate vegetation to achieve a vegetation or habitat objective (e.g., conifer removals, invasive annual grass controls, fuel treatments, or seeding plants).

1.3 Climatic Regimes and Vegetation Types in the Sagebrush Biome

The ecoregions within the sagebrush biome vary with respect to climatic regimes, dominant landforms and elevation ranges, and soil temperature and moisture regimes (table 3; Griffith 2010). Consequently, they also differ with respect to vegetation types, resource availability and use, and persistent ecosystem and anthropogenic threats. These differences affect resilience to disturbance and resistance to invasive annual grasses and influence management strategies both within and among ecoregions. Here, Level II and Level III EPA Ecoregions are used as the basis for describing these differences (fig. 1; table 3).

Ecoregions are characterized by distinct temperature and precipitation regimes (fig. 2) and differ in the amount of precipitation received in winter versus summer (fig. 3). Differences in overlap between seasonality of precipitation and temperature, and onset of the dry season, are of particular importance in determining ecoregional differences. In the western portion of the sagebrush biome most precipitation arrives as winter snow and rain. In contrast, in the eastern portion of the biome as much as 30% to 50% of the annual precipitation arrives during the summer months of July, August, and September (fig. 3). These differences, especially when coupled with total amount of precipitation, influence both plant functional type dominance (Sala et al. 1997, Lauenroth et al. 2014) and competitive interactions with invasive species such as cheatgrass (*Bromus tectorum*) and field brome (*B. arvensis*, formerly *B. japonicus*) (Bradford and Lauenroth 2006). The amount of precipitation that is received during the period when temperature, and thus potential evapotranspiration, is low influences the amount of water stored in deep soil layers and therefore the balance between woody and herbaceous species (Sala et al. 1997, Lauenroth et al. 2014). 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 (fig. 4 a, b). In contrast, areas that receive predominantly summer precipitation are typically dominated by grasses. Also, seasonality of precipitation during the period when temperatures are favorable for plant growth is an important control on the balance between C3 and C4 (cool and warm season with different photosynthetic pathways) 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 landscape cover of sagebrush. Most of the western portion of the sagebrush biome is characterized by sagebrush dominated systems, while the West-central Semiarid Prairies are characterized by grass-dominated systems with sagebrush components (fig. 5).

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

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 2013) and thus can be used in large-scale analyses (Maestas et al. 2016a). (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 2015). The soil temperature and moisture regimes that characterize sagebrush ecosystems vary due to the large latitudinal differences and elevation gradients that the area encompasses as well as the variation in seasonality of precipitation (fig. 6). As with most large-scale mapping products, there are limitations in using Soil Survey information including incongruities in soil regime classifications, especially along mapping boundaries, and variation in the level of survey detail available. However, areas with incongruities represent a relatively minor component of the data set and have been taken into account in this report. Until improved products emerge, the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) provides access to the most complete data set across the biome for understanding ecosystem response to both disturbances and management treatments. Project level planning based on resilience and resistance concepts can be further informed by local climate and soils data.

West-Central Semiarid Prairies Ecoregions

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 (fig. 1; 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 (Griffith 2010; table 3). In the Northwestern Glaciated Plains soil temperature and moisture regimes are predominantly cool (frigid) and summer-moist (ustic), respectively, but in the Northwestern Great Plains both cool (frigid) and warm (mesic) soil temperature regimes and summer-moist bordering on dry (ustic bordering on aridic) soil moisture regimes are typical (fig. 6). 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 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. t.* ssp. *tridentata*) (Miller et al. 2011; USGS 2013). Dominant grasses include wheatgrasses (*Pascopyrum smithii* and *Elymus* spp.), grama grasses, 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).

Cold Deserts Ecoregions in the Eastern Part of the Sagebrush Biome

The Cold Deserts in the eastern part of the sagebrush biome and GRSG range include the Wyoming Basin in the western and central portions of Wyoming, and the Colorado Plateau in eastern and southern Utah and western Colorado (fig. 1). The Wyoming Basin is a broad, intermontane basin that ranges in elevation from about 4000 ft to 9450 ft (1220 m to 2850 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 2950 ft to over 9840 ft (900 m to over 3000 m) (Griffith 2010; table 3). The Cold Deserts ecoregion in general has a continental climate with warm to hot and dry summers and cool to cold and wet winters. The large topographic gradients in the Wyoming Basin and Colorado Plateau result in considerable variation in mean annual temperature and precipitation but the Colorado Plateau is generally warmer (table 3). Cool and warm (frigid and mesic) soil temperature regimes and dry and summer moist (aridic and ustic) soil moisture regimes occur in the Cold Deserts ecoregion (table 3; fig. 6). Vegetation is characterized largely by arid to semiarid shrublands which 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). Sagebrush types vary along soil temperature and moisture gradients and lower elevation sagebrush types are dominated by Wyoming big sagebrush. Black sagebrush (*A. nova*) occurs on windswept ridges and in areas with shallow soils while early sagebrush (*A. arbuscula* ssp. *longiloba*) occurs on sites with higher precipitation and clay content. Basin big sagebrush is found in areas with deeper soils and higher available soil moisture across the region, as is silver sagebrush in eastern portions of the Wyoming Basin. In ecotones between Cold Deserts and Western Cordillera Ecoregions at mid elevations, Wyoming big sagebrush transitions into mountain big sagebrush (*A. t.* ssp. *vaseyana*), and at higher elevations mountain big sagebrush co-occurs with mountain shrubs (e.g., Saskatoon serviceberry [*Amelanchier alnifolia*], 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 (Winward 2004; Monsen 2005). 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.

Cold Deserts Ecoregions in the Western Part of the Sagebrush Biome

The western Cold Deserts include the Columbia Plateau in east central Washington and Oregon; Snake River Plain in central Idaho; Northern Basin and Range in southern Idaho, northern Nevada, and eastern Oregon; and Central basin and range largely in central Nevada and western Utah (fig. 1). These ecoregions are generally characterized by mid-latitude steppe and desert climates, marked by warm to hot summers and cold winters (table 3; Griffith 2010). Topography tends to be characterized by tablelands and hills in the Columbia Plateau, and by mountains, basins, and valleys in the other ecoregions. The variable topography results in large ranges in mean annual temperature and number of frost-free days and in mean annual precipitation (table 3; Griffith 2010). Soil temperature regimes range from cold (cryic) to warm (mesic) and soil moisture regimes from winter moist (xeric) to dry (aridic) (table 3; fig. 6). Vegetation in the Columbia Plateau is largely arid sagebrush steppe and grassland due to relatively high mean annual precipitation coupled with loess soils (Griffith 2010). Much of the vegetation in the Northern Basin and Range and Snake River Plain is typically classified as sagebrush steppe due to relatively cooler temperatures and more effective precipitation (West 1983a,b). In contrast, the Central Basin and Range is typically characterized by warmer and/or drier conditions and is classified as sagebrush desert (West et a. 1983a,b). The species of sagebrush are generally similar across these ecoregions, but differ along soil temperature and moisture gradients with mountain big sagebrush dominating on cool to cold sites, Wyoming big sagebrush on warm sites, and basin big sagebrush on warm to cool sites with deep soils (Appendix 2; Miller et al. 2011). Dwarf species of sagebrush that dominant on warm, gravelly soils are black sagebrush (*A. nova*) and on warm, shallow soils are low sagebrush (*A. a. spp. arbuscula*) (Appendix 2; Miller et al. 2011). Broadly distributed shrubs across the gradient are rabbit brushes (*Chrysothamnus* and *Ericameria* species) and bitterbrush. These ecoregions are dominated largely by bunchgrasses such as Idaho fescue (*F. idahoensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), needle grasses, and Sandberg bluegrass (*P. secunda*), but warm season, rhizomatous grasses such as James' galleta (*Pleuraphis jamesii*) and sand dropseed (*Sporobolus cryptandrus*) are also relatively common in the southern part of the Central Basin and Range. Western juniper (*J. occidentalis*) occurs largely in the Columbia Plateau, Snake River Plain, and Northern Basin and Range. Utah juniper occurs primarily in the eastern part of the Northern Basin and Range and in the Central Basin and Range where it co-occurs with single-leaf piñon (*P. monophylla*).

Western Cordillera Ecoregions in the Eastern Part of the Sagebrush Biome

The Western Cordillera is represented by the Middle Rockies that occur in southwestern Montana, eastern Idaho, western Wyoming, the Black Hills of western South Dakota and northeastern Wyoming, and the Southern Rockies which extend from southern Wyoming through Colorado (fig. 1; Griffith 2010). The Western Cordillera Ecoregion is characterized by high elevation mountains and foothills that range from 5085 ft to over 14400 ft (1550 m to over 4390 m), and by cool to warm short summers and cold winters. Mean annual temperature and precipitation vary greatly with elevation, but tend to be higher in the Middle Rockies than in the Southern Rockies (table 3). Soil temperature regimes range from cool to cold (frigid to cryic), and moisture regimes are summer moist and wet and humid (ustic, udic) (table 3, fig. 6). In the Middle and Southern Rockies, coniferous forests cover much of the region, with a pattern of elevational banding. The foothills are partly wooded or shrub- and grass-covered, and intermontane valleys are grass- and/or shrub-covered. In the Southern Rockies, the lowest elevations are generally grass or shrub covered, with sagebrush, mountain mahogany (*Cercocarpus* spp.), two-needle piñon, Utah juniper, or scattered Gambel oak (*Quercus gambelii*) woodlands (Griffith 2010). Dominant sagebrush species at higher elevations are mountain big sagebrush, low sagebrush, silver sagebrush, three-tip sage (*A. tripartita*) and spiked big sagebrush (*A. t.* ssp. *spiciformis*), and at lower elevations are Wyoming big sagebrush and black sagebrush (Miller 2011; 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 Deserts ecoregions (fig. 1) including wheatgrasses, needlegrasses, fescues, and bluegrasses.

Western Cordillera Ecoregions in the Western Part of the Sagebrush Biome

The Western Cordillera in the western sagebrush biome includes the Eastern Cascade Slopes and Foothills in northern California and eastern Oregon, Blue Mountains in Oregon and Idaho, Idaho Batholith largely in Idaho, and Wasatch and Uintah Mountains in Utah. These ecoregions are characterized by mountains and plateaus and mountains and foothills with mid-latitude, continental climates (Griffith 2010; table 3). Precipitation and temperature are relatively high in the Eastern Cascade Slopes and Foothills but are lower and similar among the other ecoregions (table 3). Soil temperatures are generally cold (cryic) to warm (mesic) or cold (cryic) to cool (frigid), while soil moisture regimes are udic (moist) or xeric (winter moist) (table 3, fig. 6). Coniferous forests cover much of these ecoregions, with lower foothills and valleys characterized by sagebrush and grasses. The sagebrush and grass species are largely the same as those that occur in cold to cool soil temperatures and moist soil moisture regimes in the adjacent Cold Deserts of the western part of the sagebrush biome.

1.4 Threats to Sagebrush Ecosystems and Greater Sage-Grouse

Assessing the persistent ecosystem and anthropogenic threats to sagebrush ecosystems and GRSG populations is a primary component of the strategic approach for the Science Framework to develop effective management objectives (table 4). This report addresses the threats identified in the Sage-Grouse Conservation Objectives Team Final Report (COT Report) which were based on known locations of threats, existing management strategies, and best professional judgment based on field experience. These threats are consistent with those included in the Greater Sage-Grouse Monitoring Framework developed by the Interagency Greater Sage-Grouse Disturbance and Monitoring Subteam (IGSDMS 2014). Here climate change is included and an overview of these threats is provided for sagebrush ecosystems and GRSG to inform a resilience and resistance approach. We focus on the effects of persistent ecosystem threats and secondary ecosystem threats of land use and development. Because the Cold Deserts transition into the Western Cordillera and have similar threats, we combine them for this discussion.

Persistent Ecosystem Threats

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

Herbivory, in conjunction with fire, strongly influenced plant community composition, structure, and productivity of the West-Central Semiarid Prairies (Samson and Knopf 1996). Prior to Euro-American settlement, large numbers of bison (*Bos bison*) moved nomadically through the area in response to changes in vegetation associated with drought, past herbivory, and fire (Bragg and Steuter 1996). The interval between grazing episodes may have ranged from one to eight years (Malainey and Sherriff 1996), but the impacts of these herds on the vegetation, soils, and riparian areas were probably extensive. Also, the mixed and short-grass prairies comprising the West-Central Semiarid Prairies may have supported the highest densities of black-tailed prairie dogs (*Cynomys ludovicianus*) in the prairie ecoregions (Knopf 1996). Rocky Mountain locusts (*Melanoplus spretus*), which became functionally extinct by 1900, often erupted in swarms numbering in the billions and their impact on vegetation was presumed to be extensive (Lockwood and DeBrey 1990). Drought also played an important role in structuring the composition of plant communities in this ecoregion, and resulted in temporal changes in the dominant graminoid species (e.g., shifts from western wheatgrass [*Agropyron* spp.] to blue grama [*Bouteloua gracilis*]; Bragg and Steuter 1996). Large fires often occurred, but fire regimes were probably highly variable depending on rainfall and subsequent grass growth (Umbanhowar 1996; Bukowski and Baker 2013). Because the burns removed much of the vegetation, continual shifts in the abundance and distribution of herbivores across large areas occurred with the direction and extent of vegetation response mediated by drought and grazing by bison and/or locusts (Umbanhowar 1996).

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

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

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

Euro-American arrival in the mid-1800s initiated a series of changes in vegetation composition and structure in the Cold Deserts that had cumulative effects on sagebrush habitats. Native American land-use practices were curtailed and new land-uses and management activities were introduced such as livestock grazing, sagebrush removal, mining and road-building, and fire suppression (Romme et al. 2009; Morris and Rowe 2014). First, improper grazing by livestock led to a decrease in native perennial grasses and forbs (Miller and Eddleman 2001; Miller et al. 2011). Decreased competition from perennial herbaceous species, in combination with accelerating climate change and favorable conditions for woody species establishment at the beginning of the twentieth century, resulted in a widespread increase in shrub abundance (primarily *Artemisia* species) as well as increases in juniper and piñon pine at mid elevations (Miller et al. 2008; Romme et al. 2009; Baker 2011; Miller et al. 2011, 2013).

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 anthropogenic development (Knapp 1996; Mealor et al. 2013; Knight et al. 2014; Pyke et al. 2016). Invasive annual grasses can increase the amount and continuity of fine fuels in lower elevation sagebrush habitats and initiate annual grass/fire cycles characterized by shortened fire return intervals and larger, more contiguous fires (fig. 8; D'Antonio and Vitousek 1992; Brooks et al. 2004). A reduction in fire-free intervals can effectively prevent establishment of many native sagebrush species, especially sagebrush (Miller et al. 2013). Annual grass/fire cycles are most problematic in the western part of the sagebrush biome (Brooks et al. 2015). Cheatgrass and other invasive annuals now dominate at least 6% (650,000 km^2) of the central Great Basin (Balch et al. 2013) and have potential to spread across many of the remaining low to mid elevation sagebrush ecosystems in the western part of the sagebrush biome. For example, Suring et al. (2005b) determined that approximately 58% of combined sagebrush cover types in the Great Basin were at moderate to high risk of displacement by cheatgrass. In the eastern part of the biome conversion to invasive annual grasses is a rapidly emerging problem (Baker 2011; Mealor et al. 2012; Brooks et al. 2015). These grasses increase with wildfire in both the Wyoming Basin (Knight et al. 2014) and Colorado Plateau, particularly in the eastern portion (Floyd et al. 2006; Shinneman and Baker 2009a). On sites with oil and gas drilling and mining disturbances, invasive annual grasses and a host of other annual invaders typically increase at the expense of native species diversity and cover (fig. 9; Allen and Knight 1984; Bergquist et al. 2007). Also, vegetation management treatments designed to reduce Wyoming big sagebrush density and increase understory grasses and forbs often result in an increase in invasive annuals grasses if they area already present (Beck et al. 2012; Chambers et al. 2014c) and lead to slow recovery of sagebrush canopy cover and height required by nesting and brooding GRSG (Hess and Beck 2012a).

Third, expansion of juniper and piñon pine trees into sagebrush types at mid to high elevations is reducing the grass, forb, and shrub species associated with these types (fig. 10, 11; Romme et al. 2009; Miller et al. 2008, 2011, 2013). Over the past 150 years, juniper and piñon communities have had a substantial natural range expansion and infill primarily due to favorable climate conditions (Romme et al. 2009; Miller et al. 2011; Miller et al. 2013). Other drivers also influenced expansion such as atmospheric CO_2 increases, fire suppression in montane sagebrush communities, livestock grazing, and natural recovery where Euro-American settlers heavily used juniper for mining, home structures, fuel, fencing, etc., (Romme et al. 2009; Miller et al. 2011, 2013; Morris and Rowe 2014). Ongoing infill of trees is increasing woody fuels, but reducing fine fuels (grasses and forbs) and resulting in less frequent fires in mid- to high- elevation sagebrush communities (fig. 4; Miller et al. 2013). Extreme burning conditions (high winds, high temperatures, and low relative humidity) in high density (Phase III) stands are resulting in large and severe fires that result in significant losses of above- and below-ground organic matter (sensu Keeley 2009) and may have detrimental ecosystem effects (fig. 12; Miller et al. 2013). Based on tree-ring analyses at sites in the Northern Basin and Range, Snake River Plain and Central Basin and Range, it is estimated that the extent of piñon and/or juniper woodland increased two to six fold since settlement. However, this increase is not uniform across the region (Miller et al. 2008; Romme et al. 2009). Areas with substantial increases may exhibit canopy closure within the next 50 years (Miller et al. 2008). In the eastern part of the biome, juniper and piñon expansion is a more localized issue. For example, infill of persistent woodlands and wooded shrublands and expansion of 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 2009b).

Warmer temperatures and prolonged droughts may be increasing the risk of invasive annual grasses and wildfire in both the western and eastern part of the biome (fig. 7; Littell et al.

2009; Brooks et al. 2015; Bradley et al. 2016). Shorter fire rotations caused by interactions with cheatgrass and other fire prone invasives in portions of the Colorado Plateau are leading to a net decline of PJ cover in some areas compared to their historical extent (Arendt and Baker 2013). For example, 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). Also, severe drought-induced dieback has resulted in up to 90% mortality of piñon in portions of the SW (e.g., Breshears et al. 2005), perhaps reversing expansion trends in some areas.

Threats to Greater Sage-grouse

The COT Report (USFWS 2013) provides a ranking of threats to sagebrush habitats and GRSG for each MZ by GRSG population that helps illustrate differences across the sagebrush biome in persistent ecosystem threats and identify management priorities and strategies. In general, persistent ecosystem threats are ranked more highly in the western than eastern part of the range, and fire and weeds/invasive annual grasses are ranked more highly than conifer expansion (figs. 7, 8, 10, 11). In the eastern part of the range (MZs I, II, VII), which includes15 GRSG populations, persistent and widespread threats are altered fire regimes in 9 populations, weeds/annual grasses in 10 populations, and conifers in 5 populations. In the western part of the range (MZs III, IV, V, VI), which includes 29 GRSG populations, persistent and widespread threats are fire in 23 populations, weeds/annual grasses in 26 populations, and conifers in 16 populations.

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

Reductions in sagebrush cover due to persistent ecosystem threats, uncharacteristic wildfires, invasive annual grasses, and conifer expansion, are affecting the ability of land managers to achieve the range-wide goal of stable-to-increasing population trends. Sage-grouse are true sagebrush obligates that require large and intact sagebrush landscapes and that respond negatively when wildfires occur at the extremes of the natural range of variability and remove sagebrush over large areas (Knick and Connelly 2011; Coates et al. 2015). Reduction of sagebrush cover is most critical in low- to mid-elevations with moderate to low resilience and resistance where natural recovery of sagebrush can be very limited within timeframes important to GRSG population dynamics (Davies et al. 2011; Chambers et al. 2014a).

Nonnative annual grasses and forbs have invaded vast portions of the sagebrush biome, reducing both habitat quantity and quality (Rowland et al. 2006; Miller et al. 2011; Balch et al. 2013). Due to repeated fires in the western part of the range, some low- to mid-elevation native sagebrush communities are shifting to novel annual grassland states resulting in habitat loss that may be irreversible with current management practices (Davies et al. 2011; Miller et al. 2011; Chambers et al. 2014a). At the broadest scales, the presence of non-native annual grasslands on the landscape may be influencing both GRSG distribution and abundance. In an analysis of active leks, Knick et al. (2013) found that most leks had very little annual grassland cover (2.2%) within a 3.1-mi (5-km) radius of the leks; leks that were no longer used had almost five times as much nonnative annual grassland cover as active leks. Johnson et al. (2011) found that lek use became progressively less as the cover of invasive annual species increased at both the 3.1-mi (5-km) and 11.2 mi (18 km) scales. Also, few leks had >8% invasive annual vegetation cover within both buffer distances.

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

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

Piñon and juniper expansion at mid to upper elevations into sagebrush ecosystems also has altered fire regimes and reduced GRSG habitat availability and suitability over large areas with population-level consequences (Miller et al. 2011; Baruch-Mordo et al. 2013; Knick et al. 2013). Conifer expansion results in non-linear declines in sagebrush cover and reductions in perennial native grasses and forbs as conifer canopy cover increases (Miller et al. 2000) and this has direct effects on the amount of available habitat for sagebrush-obligate species. Sites in the late stage of piñon and juniper expansion and infill (Phase III from Miller et al. 2005) have reduced fire frequency (due to decreased fine fuels), but are prone to higher severity fires (due to increased woody fuels) which significantly reduces the likelihood of sagebrush habitat recovery (fig. 11, 12; Bates et al. 2013). Even before direct habitat loss occurs, GRSG avoid or are negatively associated with conifer cover during all life stages in both the western and eastern portions of the range (i.e., nesting, brood-rearing, and wintering; Doherty et al. 2008, 2010; Atamian et al. 2010; Casazza et al. 2011; Dinkins et al. 2014b; 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). Also, GRSG incur population-level impacts at a very low level of conifer encroachment. The ability to maintain active leks is severely compromised when conifer canopy exceeds 4% in the immediate vicinity (within 1000 m) of the lek (Baruch-Mordo et al. 2013), and most active leks average less than 1% conifer cover at landscape scales (5 km; Knick et al. 2013).

Climate Change

Climate change projections and the likely effects of global warming differ among ecoregions in the sagebrush biome (U.S. National Climate Assessment, Kunkel et al. 2013a,b,c). Future temperature projections are based on Global Circulation Models (GCMs) and depend on the model(s), CO_2 emissions scenario, and time frames used in the models. Downscaled models are rare for the sagebrush biome, but temperature values are generally similar for ensemble GCMs (CMIP3) with a reference period of 1980 to 2000 for the Great Plains, Southwest, and Northwest U.S. (Kunkel et al. 2013a,b,c). In the Western Great Plains as a whole, average temperatures have increased 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. In the Great Plains, temperatures are expected to increase 2.5°F to 3.0°F by 2035, 3.5°F to 5.0°F by 2055, and 5.0°F to 8.0°F by 2085 relative to the 1971-1999 historical period (for low (B1) and high emissions (A2) scenarios, respectively) (Kunkel et al. 2013a). Notably, recent increases in temperature follow projected trend lines from the GCM models. Temperature increases in all seasons, however summer is expected to see the largest increases (3.4°F by 2035 for A2 scenario) and spring the smallest (2.5°F by 2035 for A2 scenario). Precipitation in general is more difficult to forecast (and therefore has higher uncertainty), but for the Western Great Plains is projected to change by about 0 to -6% in the west and increase by 3 to 9% in the east by 2070 (Kunkel et al. 2013a).

In the Southwest part of the sagebrush biome, annual temperature has generally increased over the past 115 years, and the recent 10-year averages surpass any previous decadal value in the southern portion of the area (Kunkel et al. 2013b). Nighttime temperatures show the greatest increase and the recent period of elevated temperatures is most prominent in the spring and summer. Recent precipitation was highly variable and showed no long-term trend. The frost-free season length has increased by about two weeks relative to the 1960s and 1970s and by a month relative to the early 1900s. Temperatures are expected to increase 2.5°F to 2.9°F by 2035, 4.4°F to 4.7°F by 2055, and 4.6°F to 8.0°F by 2085 relative to the 1971-1999 historical period for low (B1) and high emissions (A2), respectively, (Kunkel et al. 2013b). While temperature increases in all seasons, summer is expected to see the largest increases (3.5°F by 2035 for A2 scenario) and winter the smallest increase (2.5°F by2035 for the A2 scenario). There is a north-south gradient in predicted precipitation changes with the northern areas showing slight increases and southern areas losses. Most models were in agreement that the average maximum number of consecutive days with little or no precipitation will increase over most of this region by 15 days above the historical mean. Parts of Nevada, Arizona, and California that currently receive little precipitation are expected to see an increase of up to 25 days per year (Kunkel et al. 2013b).

In the Pacific Northwest part of the biome, all but two years since 1986 had above average temperatures (relative to 1901-1960), and the frost-free days increased by 11 days in 1991 to 2010 (relative to 1961 to 1990) (Kunkel et al. 2013c). Precipitation variability since 1976 has increased with most recent years below the 1901 to 1960 annual mean. Temperatures are expected to increase from 2.2°F to 2.5°F by 2035, 3.9°F to 4.1°F by 2055, and 4.2°F to 7.1°F by 2085 relative to the 1971-1999 historical period for low (B1) and high emissions (A2), respectively (Kunkel et al. 2013c). Temperature increases are projected to be largest in summer and the least in the spring. A slight increase in precipitation is projected for both scenarios and all time periods, with an increase of 0-3% in the south and 6 to 9% in the north by 2085. The average annual maximum number of consecutive days with little or no precipitation is likely to increase of 12 days for most of this region, with an increase of 15 days in western Oregon.

The changes in precipitation and temperature regimes described above are projected to have large consequences for species distributions, and because individual species differ in their climatic requirements, for community composition. Warmer temperatures are leading to species distribution shifts to the north and upward in elevation – a trend that has been observed for thousands of species globally (e.g., Parmesan and Yohe 2003; Root et al. 2003; Chen et al. 2011). Bioclimate envelope models for big sagebrush 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; Schlaepfer et al. 2012; Homer et al. 2015; Still and Richardson 2015). For Wyoming big sagebrush, which occupies the warmest and driest portions of the species range, a 39% 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 Deserts and the entirety of the Northern Great Plains. For juniper and piñon woodlands, habitat with suitable climate is projected to move north and upslope with principal gains in Colorado and southwest Wyoming and losses in the Southwest (Rehfeldt et al. 2006, 2012).

Climate change is also projected to have significant effects on invasive annual grasses. Cheatgrass will likely spread upwards in elevation and red brome (*B. rubens*) might expand northward and/or increase its abundance in the Cold Deserts 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%, particularly in mountain big sagebrush steppe in Montana and higher elevation areas of the Colorado Plateau (Bradley et al. 2016). Warming temperatures may facilitate the expansion of cheatgrass in the northern mixed-grass prairie, allowing it to more successfully colonize what is currently considered a largely invasion-resistant grassland (Blumenthal et al. 2016),

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

Climate-driven changes are likely to combine with both persistent ecosystem and anthropogenic 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 sage-grouse (Schrag et al. 2010; USFWS 2014).

Land Use and Development Threats

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

Cropland Conversion

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

The West-Central Semiarid Prairies (MZ I) have the highest percentage of private lands and highest amount of tilled cropland, followed by the Snake River Plain, and Columbia Basin (table 12.1 in Knick et al. 2011; Doherty et al. *in press*). 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) and the amount and configuration of sagebrush habitat in the surrounding landscape influence habitat use (Schroeder and Vander Haegen 2011). Several studies indicate that GRSG populations cannot persist in areas with < 25% landscape cover of sagebrush (Aldridge et al. 2008; Wisdom et al. 2011; Knick et al. 2013). Sage-grouse extirpations have occurred in areas where cultivated crops exceeded 25% landscape cover (Aldridge et al. 2008), and recent studies show that 96% of active leks are surrounded by less than 15% cropland in MZ I (SGI 2015; Smith et al. 2016).

Energy Development and Mining

Loss of landscape cover of sagebrush associated with energy development has been well documented in recent analyses, especially for oil and gas. Oil and gas development affects 8% of sagebrush habitats with the highest intensities occurring in the eastern part of the range; >20% of the sagebrush land cover is indirectly influenced in the North-West Semiarid Prairies, Wyoming Basins and Colorado Plateau (fig. 15, 16; table 12.16 in Knick et al. 2011). The "Wyoming Basin Ecoregional Assessment" (Hanser et al. 2011) which included south-central Montana, western and central Wyoming, northeastern Utah, and northern Colorado indicated that oil and gas development has removed approximately 658 mi^2 (1703 km^2) of sagebrush and other native habitats in this area since 1900 due to construction of well pads and supporting infrastructure, such as roads, power lines, and pipelines (Finn and Knick 2011).

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

Summary data for the effects of mining across the sagebrush biome and range of GRSG are not readily available. However, mining is considered a persistent and widespread threat to 8 of 15 populations in the eastern range and 9 of 29 populations in the western range in the COT Report (USFWS 2013).

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; Walker et al. 2007; Duncan 2010; Harju et al. 2010; Gregory and Beck 2014).

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; Lyon and Anderson 2003; Doherty et al. 2008; Holloran 2005; Dinkins et al. 2014a; Dinkins et al. 2014b; LeBeau et al. 2014; Smith et al. 2014; Kirol et al. 2015). Sage-grouse females with successful nests located their nests farther from roads in oil and gas fields than unsuccessful hens (Lyon and Anderson 2003). In addition, noise from natural-gas development activities has been found to lead to immediate and sustained declines in lek attendance (Blickley et al. 2012). Transmission towers may provide perches and nesting structures for raptors and ravens, and may also contribute to collision mortalities (Borell 1939; Beck et al. 2006; Coates et al. 2014a,b; 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).

Urban and Exurban Development

Loss of sagebrush land cover due to urban and exurban (residential) development since Anglo-American settlement is estimated at 48.4% for the Columbia Basin (MZ VI), 29.2% for the Colorado Plateau and adjacent Rockies (MZ VII), and from 12.5% to 18.5% for the remaining ecoregions/MZs (fig. 17, 18; table 12.2, Knick et al. 2011). In the COT Report, urban and exurban development was considered a present and widespread threat to 7 of 15 populations in the eastern range and 4 of 29 populations in the west (USFWS 2013). The rank order of the variables in Doherty et al.'s (*in press*) analysis showed that human disturbance was a major factor in predicting GRSG breeding habitat in MZ VII (#3) and a minor factor in MZ I (#12), MZ II (#11), MZ III (#15), MZ IV (#14), MZ VI (#7). However, within the western portion of the GRSG range (MZ III, IV, and V) disturbance was an important determinate of GRSG occurrence with GRSG habitat suitability significantly higher in areas with < 3% development (Knick et al. 2013).

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. 18, 19; Knick et al. 2011). Low-density exurban developments support lower native species abundance, and more human-commensal bird and mammal species and invasive plants, than comparable unfragmented sagebrush ecosystems (Maestas et al. 2003).

Recreation

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

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

Infrastructure

Although interstate and major paved highways cover an estimated 0.1% of the land cover in the MZs, they influence 38% of the sagebrush land cover (fig. 19; table 12.3; effect area of 4.3 mi (7 km); Knick et al. 2011). Secondary roads, railroads, and especially power lines have additional fragmentation effects, with the greatest overall influence on sagebrush area in the Columbia Basin, Wyoming Basins, and Colorado Plateau (table 12.3, Knick et al. 2011; Manier et al. 2014b). The COT Report ranked infrastructure a present and widespread threat in 14 of 15 populations in the eastern range and 20 of 29 populations in the west (USFWS 2013).

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

Interactions Among Land Use and Development and Persistent Ecosystem Threats

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

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

The cumulative effects of anthropogenic development and persistent ecosystem threats may be most evident for sites with relatively warm or dry soil temperature and moisture regimes with relatively low resilience and resistance, and may increase as the climate warms. Both current climate and climate change trends are important factors driving the negative effects of habitat loss and fragmentation on species density and/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 exacerbate the effects of land-use on species population trends (Lemoine et al. 2007). Populations in fragmented landscapes are more vulnerable to environmental drivers, such as climate change, than those in continuous, intact landscapes (Travis 2003; Opdam and Wascher 2004). Also, the pattern of habitat loss is likely to determine the threshold of climate change below which species extinction occurs or populations severely decline (Opdam and Wascher 2004).

Livestock Grazing

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

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 (RAS), 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 RAS. 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 affect plant responses to grazing (Briske and Richards 1995). In Cold Deserts, defoliation of perennial grasses during inflorescence development (late spring) occurs when moisture is becoming limited and plant regrowth and recovery can be compromised (Briske and Richards 1995). In the Western Cordillera and West-Central Semiarid Prairies, precipitation during the growing season may allow greater tolerance to grazing, but cool-season grasses can be eliminated by seasonal use that impacts them yet allows warm-season plants to remain ungrazed.

The greatest potential for livestock grazing to affect GRSG habitat is by changing composition, structure, and productivity of herbaceous plants used for nesting/early brood-rearing (Beck and Mitchell 2000; Hockett 2002; Cagney et al. 2010; Boyd et al. 2014b). Empirical studies and meta-analysis have reported that GRSG nest and early brood micro-habitat selection and brood-rearing success are closely tied to areas with greater sagebrush and grass canopy cover and height than are randomly available in sagebrush landscapes (Thompson et al. 2006; Hagen et al. 2007; Kirol et al. 2012; Doherty et al. 2011a; Doherty et al. 2014; Dinkins et al. 2016). Grass height in particular has been reported to influence nest success for GRSG (Gregg et al. 1994, Sveum et al. 1998, Popham and Gutierrez 2003, Coates and Delahanty 2010, Kaczor et al. 2011, Doherty et al. 2011a; 2014, Lockyer et al. 2015) and GUSG (Stanley et al. 2015). However, Holloran et al. (2005) and Dinkins et al. (2016) reported weak, if any, effects of grass height on GRSG nest success in MZ 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 MZ 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 (Herman-Brunson et al. 2009; Doherty et al. *in press*), suggesting greater reliance by breeding GRSG on herbaceous cover in MZ 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 and manage grazing on western rangelands can contribute to collision related mortality, particularly when located on flat terrain in close proximity to leks (Stevens et al. 2012; Coates et al. 2016a). Coates et al. (2016 b) found that the odds of raven occurrence, a pervasive sage-grouse nest predator, increased by approximately 46% in areas where livestock were present, which the authors suggested may be partially due to the presence of certain features such as stock ponds and troughs and associated perching features (e.g. windmills, tanks, fences, etc.) that may also increase raven presence.

Free-Roaming Equids

Free-roaming equids (horses [*Equus caballus*] and burros [*E. asinus*]), like all large-bodied herbivores, can alter sagebrush ecosystem structure and composition and affect habitat quality for sagebrush obligate species (Beever et al. 2003; Beever and Herrick 2006; Beever and Aldridge 2011). Free-roaming equids were considered a present and widespread threat in only 1 of 15 populations in the eastern portion of the range (Parachute-Piceance-Roan Basin, MZ VII), but in 11 of 29 populations in the west in the COT Report (USFWS 2013). BLM herd management areas that overlap with GRSG occur in the Northern Basin and Range, Central Basin and Range, and Wyoming Basins (MZs II, III, and IV) (Beever and Aldridge 2011).

Current legislation considers free roaming equids an integral part of the natural system on public lands, and requires that these animals are neither hunted nor actively managed with fences (Public Law 92-195, The Wild Free-Roaming Horses and Burros Act of 1971). Equid effects on ecosystems vary with elevation, stocking density, and season and duration of use but can be widespread (Beever and Aldridge 2011). A research study showed that across 11,585 mi^2 (3.03 million ha) of the western Great Basin, horse occupied sites had lower grass, shrub and overall plant cover; higher cover of unpalatable forbs and abundance of cheatgrass; lower densities of ant mounds; and 3 to 17 times greater penetration resistance in soil surfaces than sites from which horses had been removed 10 to 14 years earlier (Beever et al. 2008). These effects may be especially pronounced during droughts and may interact with effects of livestock grazing (Beever and Aldridge 2011).

1.5 Resilience to Disturbance and Resistance to Invasive Annual Grasses in Sagebrush Ecosystems

An understanding of the factors that determine resilience to stress and disturbance and resistance to invasion by nonnative plants can be used to address persistent ecosystem and anthropogenic threats to sagebrush habitats (Wisdom and Chambers 2009; Brooks and Chambers 2011; Chambers et al. 2014a,b, *in press*). In sagebrush ecosystems resilience to stress and disturbance changes along climatic and topographic gradients at both landscape and local scales (fig. 20, 21, 22, 23). At landscape scales higher precipitation and cooler temperatures typically result in greater resource availability, more favorable environmental conditions for plant growth and reproduction, and higher ecosystem productivity (Alexander et al. 1993; Dahlgren et al. 1997). In contrast, lower precipitation and higher temperatures result in reduced resource availability for plant growth and reproduction and thus lower ecosystem productivity (West 1983a,b; Smith and Nowak 1990). Higher levels of available resources coupled with greater productivity generally result in increased ecosystem resilience to both disturbances and management treatments (Chambers et al. 2014a,c). More resilient ecosystems typically exhibit smaller changes following disturbances and recover more rapidly than less resilient ecosystems (Davies et al. 2012; Chambers et al. 2014c). These relationships also are observed at local scales where aspect, slope, and topographic position affect solar radiation, effective precipitation, and erosion processes, and thus soil development and vegetation composition and structure (Johnson and Miller 2006; Condon et al. 2011).

Resistance to nonnative invasive plant species depends on environmental factors and ecosystem attributes and is a function of (1) the invasive species' physiological and life history requirements for establishment, growth, and reproduction, and (2) interactions with the native perennial plant community including interspecific competition and response to herbivory and pathogens. Soil temperature and moisture regimes strongly influence resistance to nonnative plant species. The importance of soil temperature and moisture regimes in determining invasibility is well illustrated for nonnative invasive brome grasses which are among the most widespread and problematic invasive plant species in sagebrush ecosystems (fig. 20, 22; Brooks et al. 2016; Chambers et al. 2007; Chambers et al. 2016). 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 (Meyer et al. 2001; Chambers et al. 2007). In contrast, red brome is found primarily on warm and dry salt desert sites (Salo 2005). Field brome (*B. arvensis*) is limited on warm and dry as well as cold sites but is relatively abundant on cool and moist sites (Baskin and Baskin 1981). Slope, aspect, and soil characteristics modify soil temperature and water availability and influence resistance to brome grasses at landscape to plant community scales (Salo 2005; Chambers et al. 2007; Condon et al. 2011; Mealor et al. 2012, 2013; Reisner et al. 2013, 2015).

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

The type, characteristics, and historical range of variability of stress and disturbance strongly influence both resilience and resistance. Disturbances like improper grazing of perennial plants by livestock or free roaming equids and atypical fire regimes are outside of the natural range of conditions 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. 2014a) and cover of biological soil crusts (Reisner et al. 2013). Changes in abiotic and biotic attributes can result in decreased resistance to nonnative invasive annual grasses. Increased resource availability or altered habitat suitability can both influence an invasive species' ability to establish and persist and/or compete with native species (Chambers et al. 2007; Chambers et al. 2014c). Examples of these types of interactions are illustrated in the state-and-transition models (STMs) in Appendix 3 and 4. 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).

1.6 Integrating Resilience and Resistance with Species Habitat Requirements to Prioritize Areas for Management and Determine Effective Management Strategies

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

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

Resilience to stress and disturbance and resistance to invasive annual grasses are a function of the biophysical conditions of the planning area. Soil temperature and moisture regimes are key determinants of sagebrush ecological types and are strongly related to ecosystem resilience and resistance (Chambers et al. 2007; Condon et al. 2011; Chambers et al. 2014c). In the Science Framework, the predominant sagebrush ecological types are characterized according to soil temperature and moisture regimes, typical vegetation, and resilience to disturbance and resistance to invasive annual grass species (table 6). To facilitate landscape analyses and prioritization, relative resilience and resistance are categorized as high, moderate, or low based on soil temperature regime and moisture regime subclasses. (An explanation of soil temperature and moisture regimes and a cross-walk between soil temperature and moisture regimes and relative resilience and resistance are in Appendix 2.) State and transition models have been developed for the predominant ecological types that are based on soil temperature and moisture regimes and the relative resilience and resistance of the sagebrush ecological types (Appendix 3, 4). These STMs provide information on the alternative states, ranges of variability within states, and processes that cause plant community shifts within states as well as transitions among states.

In general, higher resilience and resistance occurs with ***cool*** to ***cold*** (frigid to cryic) soil temperature regimes and ***moist*** (udic), ***winter moist*** (xeric) or predominantly ***summer moist*** (ustic) soil moisture regimes, while lower resilience and resistance occur with ***warm*** (mesic) soil temperatures and relatively ***dry*** (aridic) or ***summer moist bordering on dry*** (ustic bordering on aridic) soil moisture regimes (fig. 6, 20, 22; Chambers et al. 2014a,b,c, *in press*; Maestas et al. 2016a). High soil moisture typically equates to elevated productivity and thus increased resilience (Chambers et al. 2014a), while cold soil temperatures typically limit growth and reproduction of nonnative invasive annual grasses and thus increase resistance to these species (Chambers et al. 2007, 2016). 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; Bradley et al. 2016). 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) that likely create a more competitive environment and result in greater resistance to annual grass invasion and spread (Bradford and Lauenroth 2006; Bradley 2009; Chambers et al. 2016).

The ecoregions and MZs differ in soil temperature and moisture regimes and, consequently, in dominant ecological types and relative resilience and resistance (fig. 20, 22; table 6). Much of the West-Central Semiarid Prairies (MZ I) is characterized by moderate to high resilience and resistance as indicated by relatively cool and summer moist regimes (fig. 6; table 6). However, the southeastern part of this ecoregion has low to moderate resilience and resistance as indicated by warm and drier regimes. The dominant ecological types are comprised of varying amounts of cool season and warm season grasses, Wyoming big sagebrush, and plains silver sagebrush (table 6). The Western Cordillera in MZs II and VII grades into the foothills of the Wyoming Basin and Colorado Plateau and is characterized by cold and wet to cool and summer moist soil temperature and moisture regimes with generally high to moderate resilience and resistance (fig. 6; table 6). Ecological types are typically comprised of mountain big sagebrush, snowberry and other shrubs, and cool season grasses (table 6). The Cold Deserts in MZs II and VII encompass a broad range of soil temperature and moisture regimes - cool bordering on cold and summer moist bordering on dry to warm and dry with generally moderate to low resilience and resistance (fig. 6; table 6). 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. The Cold Deserts in MZ III, IV, V, and VI (primarily the northern and central Great Basin and Columbia Plateau) differ from those of the Wyoming Basin and Colorado Plateau largely because most precipitation is received in winter (fig. 6; table 6). Soil temperature and moisture regimes range from cool bordering on cold and winter moist to warm and dry with generally moderate to low resilience and resistance. The ecological types are characterized by mountain big sagebrush and mountain brush on the coolest sites, and Wyoming big sagebrush on the warmest and driest sites. Cool season grasses predominate in these ecoregions.

Greater Sage-grouse Breeding Habitat Probabilities and Population Indices

The GRSG Breeding Habitat Model. Two sets of models were recently developed for the USFWS status assessment (Doherty et al. *in press*) to quantify GRSG breeding habitat probabilities and create a population index to spatially identify population centers of breeding male GRSG within each MZ. The Occupied Breeding Habitat Distribution Model (hereafter, breeding habitat model) was developed to more accurately portray important breeding areas for GRSG (Doherty et al. *in press*), because current information available to the USFWS regarding occupied GRSG range was developed at a broad scale and included large areas of unsuitable habitat. The breeding habitat model used GRSG lek data (2010 to 2014) as a proxy for landscapes important to breeding birds, because leks are central to the breeding ecology of GRSG and the majority of nests occur close (within 4 mi; 6.3 km) to leks (Holloran and Anderson 2005; Coates et al. 2013). The breeding habitat model evaluated characteristics such as vegetation (i.e., land cover), climate, landform, and disturbance variables around leks, i.e., within a radius of 4 mi (6.4 km; Doherty et al. *in press*). The model provided an estimate of the probability of occupied breeding habitat at a spatial resolution of 120 x 120 m based on habitat characteristics for each MZ (fig. 24). Breeding habitat for GUSG in MZ VII was recently modeled following the same methodology used by Doherty et al. (*in press*) for GRSG (see Chambers et al. *in press*; Doherty et al. *in process*).

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

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

The Population Index Model. Doherty et al. (*in press*) also developed a Population Index Model (hereafter, population index) to spatially identify areas that contain population centers of breeding male GRSG based on 2010 to 2014 lek data (fig. 25). Past work has shown that GRSG populations are highly clumped. Relatively small areas can contain a disproportionate number of males attending leks (Doherty et al. 2011b), and large differences in the density of birds can occur even within the high GRSG breeding habitat probability category. The population index serves as a proxy for relative abundance, which allows for better spatial understanding of how threats, such as land use and development or conifer expansion, and management strategies to address threats can be evaluated based on population concentration centers of GRSG.

Use and Limitations of the Breeding Habitat Models. Partial probability plots were used to elucidate habitat relationships among the variables in the final breeding habitat model for GRSG (Doherty et al. *in press*). These types of figures demonstrate how the probability of the landscape supporting a breeding population of GRSG changes relative to specific habitat variables (fig. 26). Partial probability plots of habitat relationships can also be used to identify thresholds in which non-habitat features exceed the tolerance of a species. However, because the habitat characteristics of species are defined by multiple variables (e.g., James 1971), use of a spatially explicit model is preferred over using threshold values of a single habitat variable such as that identified in fig. 26. However, graphing the probability of lek occurrence relative to a single variable can be used to evaluate the effect of the variable of interest.

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

Landscape Cover of Sagebrush as an Indicator of Habitat

In the absence of spatially explicit habitat models such as those developed by Doherty et al. (*in press*), habitat variables such as type and extent of land cover and type and magnitude of predominant disturbances can provide a viable alternative for assessing the probability of suitable habitat and informing management decisions. Landscape cover of sagebrush has been shown to be an important predictor of persistence of GRSG and other sagebrush obligate species (Rowland et al. 2006; Aldridge et al. 2008; Wisdom et al. 2011; Hanser et al. 2011; Knick et al. 2013; Donnelly et al. *in press*). Sagebrush landscape cover is typically derived from remotely sensed land cover data such as LANDFIRE (USGS 2013) using a moving window analysis (fig. 27, 28; see Appendix 5 for an explanation of landscape cover and moving window analyses). Analyses of the landscape cover of sagebrush around GRSG leks in various portions of the range (Aldridge et al. 2008; Wisdom et al. 2011; Knick et al. 2013) indicated that the relative probability of lek persistence can be estimated using percentage landscape sagebrush cover. In general, low GRSG lek persistence occurs with 1 to 25% landscape cover of sagebrush, intermediate persistence with 25-65%, and high persistence with >65% (Chambers et al. 2014b). These three categories of landscape cover of sagebrush were used to indicate the potential of an area to provide GRSG habitat in the western range (MZs III, IV, V) GTR that was published in 2014 (Chambers et al. 2014b) prior to development of the multi-variate breeding habitat models developed by Doherty et al. (*in press*). This approach was subsequently incorporated into the "Greater Sage-grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment" (USDI BLM 2014). In the analyses described in the GTR (Chambers et al. 2014b) and implemented in the assessment (USDI BLM 2014), landscape cover of sagebrush was evaluated in conjunction with the GRSG breeding density data as in the Doherty et al. (*in press*) breeding habitat suitability model. In the Doherty et al. (*in press*) breeding habitat suitability model, landscape cover of sagebrush was among the top predictor variables in MZs III, IV, and V (table 5). Thus, while the Doherty et al. (*in press*) models may have provided additional information to inform the western range GTR and assessment, it is likely that highly similar results would have been obtained. Analyses based on landscape cover of sagebrush and species population abundance can be used for other sagebrush obligate species until multi-variate models are developed for these species. For example, a recent range-wide analyses of sagebrush obligate passerine birds indicates that there is a threshold of about 40% landscape cover of sagebrush for predicted counts of several species (Brewer's sparrow, *Spizella breweri*; sagebrush sparrow, *Artemisiospiza nevadensis*; sage thrasher, *Oreoscoptes montanus*) (fig. 29; Donnelly et al. i*n press*).

Landscape cover of sagebrush is less informative for the North-Central Semiarid Prairies (MZ I) than for other ecoregions (MZ II, III, IV, V, VI) because of the difficulty of using remote sensing to assess land cover of sagebrush in plains ecoregions. Analyses conducted in MZ I show that active leks are distributed across all of the above landscape sagebrush cover categories (when measured within 6.4 km of leks) (Chambers et al. *in press*). This indicates that selection of breeding habitat by GRSG occurs across a broader range of sagebrush landscape cover in MZ I than in other MZ's. This finding reflects the fact that sagebrush land cover is only 14% in MZ I, compared to 45% in MZ II (Knick et al. 2011), where most active GRSG leks occur in areas of high sagebrush land cover.

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

Sage-Grouse Habitat Resilience and Resistance Matrix

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

Management strategies can be determined by considering (1) an areas resilience to disturbance and resistance to nonnative invasive plants, (2) GRSG breeding habitat probabilities, and (3) the predominant threats to both sagebrush ecosystems and their associated GRSG populations. Management strategies for sagebrush ecosystems have been organized by threat and are found in table 9. 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, wildlife, and others may all contribute to vegetation management strategies designed to address persistent ecosystem and land use and development threats.

The sage-grouse habitat resilience and resistance matrix is a decision support tool that allows land managers to better evaluate risks at mid to local scales (table 2) and decide where to focus specific activities to promote desired species and ecosystem conditions (table 8; Chambers et al. 2014c, *in press*). Areas with high GRSG breeding habitat probabilities and high concentrations of birds are typically comprised of intact habitats and thus are high priorities for management (table 8, 1C, 2C, 3C). Protective management can be used in and adjacent to these areas to maintain habitat connectivity and ecosystem resilience and resistance. Protective management can include a diverse set of strategies such as reducing or eliminating disturbances from land uses and development, establishing conservation easements, utilizing an Early Detections and Rapid Response (EDRR; USDI 2016) approach, or suppressing fires (table 9). Areas with high GRSG breeding habitat probabilities but lower resilience and resistance are slower to recover following fire and surface disturbances and are more susceptible to invasive plant species than areas with higher resilience and resistance (Chambers et al. 2014a).

Consequently, these low resilience and resistance areas are at greater risk of habitat loss than areas with moderate to high resilience and resistance and are among the highest priorities for protective management (table 8, 3C; Chambers et al. 2014c; *in press*).

Areas with moderate GRSG breeding habitat probabilities are comprised of habitat that supported a higher proportion of leks in the past than currently (table 7) and that may be improved through various management strategies (table 8, 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 9). 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; Roundy et al. 2014) as well as enhance habitat connectivity (Baruch-Mordo et al. 2013). The relative resilience and resistance of an area strongly influences its response to management strategies such as conifer removal or post-fire rehabilitation and the likelihood of nonnative annual grass invasion (Chambers et al. 2014a, b; 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 8, 3B; Chambers et al. 2014c; *in press*).

Areas with low GRSG breeding habitat probabilities are characterized by habitat that supported active GRSG leks in the past, but that currently support few leks (table 8, 1A, 2A, 3A). If land use and development threats such as oil and gas development or cropland conversion are causing low GRSG breeding habitat probabilities, then habitat improvement may not be feasible. However, if the area has the capacity to respond to management treatments and if breeding populations are close enough for recolonization, improvement of these areas to increase breeding habitat probabilities may still be possible. Managers may decide to restore critical habitat in these types of areas, but the degree of difficulty and time-frame required for habitat restoration increase as resilience and resistance decrease (Chambers et al. 2014c*, in press*). 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 2015a,b). Also, areas with low GRSG breeding habitat probabilities may support other resource values or at-risk species (Rowland et al. 2006) that could benefit from management strategies designed to improve habitat. Knowledge of the locations of other priority resources and at-risk species and their response to management treatments can help ensure that treatments are located and strategies are implemented in a manner that will also benefit these other resources and species.

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

The management strategies associated with the sage-grouse habitat matrix are designed to maintain or restore large contiguous areas of sagebrush habitat and to recover species distributions and population abundance. Consequently, the priorities and strategies are applicable to all sagebrush obligate species that benefit from large extents of intact sagebrush habitat. Adapting the habitat matrix for species other than GRSG first requires accurately delineating the occupied range of the species to ensure that management strategies and treatments target the right locations. It then requires identifying the probability of suitable habitat for the focal species. Ideally, this would be based on the suite of land cover, climate, landform and disturbance variables that characterize species habitat. However, range-wide habitat probability models that incorporate these variables have only been developed for GRSG and GUSG (Doherty et al. *in press;* Chambers et al. *in press*). The majority of other sagebrush-associated species have poorly defined range maps. Until range-wide models are developed for other species, models developed at the ecoregion scale can help guide habitat management strategies for individual species or species groups. For example, in the Wyoming Basins Ecoregion, models for three sagebrush obligate passerines (Brewer's sparrow, sagebrush sparrow, and sage thrasher) have been developed (fig. 30; Aldridge et al. 2011). Both the scale and strength of the relationship between density and landscape cover of sagebrush differ among these species, and these models highlight the challenge of utilizing a single metric to characterize the landscape for multiple species within the sagebrush biome (fig. 30). However, all three species were more likely to occur, and increase in abundance, in areas with higher landscape cover of sagebrush. Thus, improving overall extent and condition of sagebrush land cover will likely benefit all three species. Development of range-wide models for these species using Breeding Bird Survey data (Pardiek et al. 2016) is underway (Donnelly et al. *in press*). Preliminary results indicate that thresholds for occurrence exist at finer spatial scales (250-m radius) and that three occurrence probability categories could be developed at this scale: low = 0-40%, moderate = 40-70%, and high = 70-100% (fig. 29). For other sagebrush-associated species that do not currently have these types of models, developing habitat requirements will likely involve deriving categories of landscape cover of sagebrush for the species of interest (see Chambers et al. 2014b). If data are available, an evaluation of the appropriate scale for measuring sagebrush land cover and the strength of the species' relationship to sagebrush land cover would help ensure that the spatial scale and habitat management strategies represent landscapes appropriate for the species. In addition, depending on the species habitat requirements, other landscape and/or local factors, such as soil characteristics or water availability, may also be needed to support other sagebrush dependent species. The WAFWA/USFWS Sagebrush Science Initiative hopes to facilitate the development of habitat suitability models for additional sagebrush-obligate species in the near future.

1.7 Delineating Habitats for Targeted Management Intervention at the Biome and Ecoregion/MZ Scale

Effective conservation of sagebrush habitat and sagebrush obligate species benefits from an approach that prioritizes the best management practices in the most appropriate places. This section describes an approach for targeting areas for management based on four types of data: (1) species distribution and population abundance; (2) species habitat requirements; (3) ecosystem resilience and resistance; and (4) persistent and land use and development threats. The approach involves a geospatial analysis in which the four types of data are overlaid to spatially link species populations and habitat requirements with habitat conditions. 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 6.

Assessing Priority Areas for Habitat Management – Key Data Layers

Priority Areas for Conservation of GRSG. Priority Areas for Conservation (PACs) have been delineated using available habitat and population data to identify areas critical for conserving GRSG populations (USFWS 2013). These areas can be used as a first filter in prioritizing management actions for these species. Habitats outside of PACs 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 for GRSG. 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. 24; table 5; Doherty et al. *in press*), and the categorical break points show the proportion of active and inactive leks in each MZ for GRSG (table 7). These areas can be used to prioritize areas for management based on the probability of an area providing breeding habitat. The categorized breeding habitat probabilities overlaid with lek locations shows the relationship of modeled breeding habitat probabilities and active breeding locations (fig. 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. 25; Doherty et al. *in press*). Because the output of the population index model is a continuous surface or map, it can be used to focus conservation efforts on specified portions of GRSG populations identified by stakeholders (e.g., highest 25% or 85% of the population). For the purposes of this report, the population index model was classified into two categories (0-80% and the remaining 80-100% 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) ensure that habitat restorations outside of breeding concentration areas occur in close enough proximity to allow successful recolonization of reclaimed habitat (Coates et al. 2016a).

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

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

Landscape cover of sagebrush. In the absence of spatially explicit habitat models like those developed for GRSG (Doherty et al. *in press*) and GUSG (Chambers et al. *in press*), landscape cover of sagebrush can provide important information on species habitat requirements (fig. 5, 27, 28). Landscape cover of sagebrush is a measure of large, contiguous patches of sagebrush on the landscape and is calculated from remote sensing databases such as LANDFIRE (see Appendix 5). Categories of sagebrush landscape cover required to sustain species populations can be developed as illustrated for Brewer's sparrow, sagebrush sparrow, and sage thrasher (fig. 29). Sagebrush landscape cover datasets can be created using a moving window to summarize the proportion of area dominated by sagebrush that surrounds each 30-m pixel (radius determined by species habitat requirements), and then assigning those areas to the different categories (fig. 27, 28; see Appendix 5). Because available sagebrush cover from sources such as LANDFIRE does not exclude recent fire perimeters, it is necessary to either include these in the analysis of landscape cover of sagebrush or display them separately. The time required for a burned area to provide desired GRSG habitat will depend on the resilience and resistance of the area and post-fire management.

*Resilience to disturbance and resistance to nonnative invasive plants***.** Resilience and resistance data allow managers to predict the ecological responses of sagebrush ecosystems to both disturbance and management actions and to determine appropriate management strategies (table 8, 9). These data provide the foundation for targeting areas for management. Soil temperature and moisture regimes are strong indicators of both ecological types and of resilience to disturbance and resistance to nonnative invasive plants (Chambers et al. 2014a,b,c, *in press*; Maestas et al. 2016a) (fig. 6, 20, 22, table 6). The available data for soil temperature and moisture regimes were recently compiled for the western and eastern range of GRSG (Maestas et al. 2016a; Appendix 2), and relative resilience and resistance categories were developed from soil temperature and soil moisture subclass data (table 6, fig. 6, 31; Appendix 2; Maestas et al. 2016a). These data allow managers to predict the ecological responses of sagebrush ecosystems to both disturbance and management actions. Soil temperature and moisture regimes are two of the primary determinants of ecological types and are used in developing detailed ESDs (see "Determining Appropriate Management Treatments at Local Scales").

*Habitat threats***.** Assessing the magnitude of persistent ecosystem and land use and development threats provides important insights into target areas for treatment and the most appropriate management strategies. Although habitat threats are considered in GRSG breeding habitat and in the GRSG population index models (Doherty et al. *in press*), depicting threats to different populations is necessary to assess the magnitude of the threats and determine viable management strategies. Depicting threats is also necessary for determining management strategies for other sagebrush obligate or dependent species. The threats and data sources considered in this report largely follow those in IGSDMS (2014) and are in Appendix 6.

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

Assessing Priority Areas for Habitat Management – Overlaying Data Layers

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

The ecoregions and MZs within the sagebrush biome have differences and similarities in (1) resilience and resistance (table 6; fig. 31), (2) persistent ecosystem threats (e.g., fig. 7, 10, 13, 15, 17, 19), and (3) GRSG breeding habitat probabilities (fig. 24) and breeding populations (fig. 25). An understanding of these differences can help to inform resource needs and budget prioritization at the sagebrush biome scale. A summary of relative resilience and resistance, GRSG breeding habitat probabilities, and GRSG breeding populations is provided for each MZ and the PACs within each MZ in Appendix 7. In addition, a summary of wildfire area is provided as one example of a widespread persistent ecosystem threat that differs across MZs, but that significantly influences management strategies in those MZs with high wildfire areas (Appendix 8). In the final version of the Science Framework, the intent is to also include a summary of the invasive annual grass threat and climate change projections.

Overlaying breeding habitat probabilities with resilience and resistance categories for the PACs in each MZ provides information on the capacity of the MZs to support breeding populations and the relative risk of persistent ecosystem threats such as invasive annual grasses and wildfire (fig. 32, Appendix 7). In the eastern part of the range (MZ I, II, VII), a large amount of the area with high to moderate breeding habitat probabilities has high to moderate resilience and resistance indicating that much of this area has the capacity to recover from disturbances given appropriate management. In the western part of the range (MZ III, IV, V, VI), large areas with high to moderate breeding habitat probabilities are characterized by low resilience and resistance (fig. 32, Appendix 7). The implications of these differences in resilience and resistance are detailed in sections 1.5 and 1.6. In general, areas with low resilience and resistance are more susceptible to invasive annual grasses like cheatgrass and require longer periods for recovery from either disturbances or management treatments (Miller et al. 2013; Chambers et al. 2014a,c; Pyke et al. 2015a,b). However, invasive annual grasses are an emerging threat in warmer and drier areas of the eastern part of the range (Baker et al. 2011; Mealer et al. 2013; Knight et al. 2014; Brooks et al. 2015) and often increase on sites disturbed by anthropogenic development (Nielson et al. 2011; Manier et al. 2011; 2014a,b).

Overlaying wildfire area from 1984 to1999 and from 2000 to 2014 with resilience and resistance categories and evaluating differences in fire numbers and size for the PACs in each MZ provides information on the differences in the magnitude of the threat among MZs. In the western part of the range (MZ III, IV, V), total fire area, numbers of fires, and fire size have increased from 1984-1999 to 2000-2015 (Appendix 8). Fire area within the PACs doubled to tripled from 1984-1999 (8%, 6%, and 4%, respectively) to 2000-2015 (19%, 17%, and 13%, respectively) (fig. 33; Appendix 8). The exception was MZ III which remained at about 4% from 1984-1999 to 2000-2015. In contrast, in the eastern portion of the range (MZ I, II, VII), fire area within the PACs showed little change from 1984-1999 (0.4%, 1.5%, and 0.3%, respectively) to 2000-2015 (1.6%, 1.2%, and 0.3%) (fig. 33). Several large, severe fires have burned in sagebrush and grass ecosystems or sagebrush ecosystems exhibiting piñon and juniper expansion in the east since 2000, including: Alkali (CO, 2014; 22,000 ac [8,903 ha]); Wolf Den (UT, 2012; 19,865 ac [8,039 ha]); Cato (WY, 2012; 27,680 ac [11,202 ha]); Sheep Mountain (WY, 2000; 34,346 ac [13,899 ha]); and Wildhorse Basin (WY, 2000; 36,762 ac [14,877 ha]) (Marco Perea, BLM, *personal communication*). Overall, this analysis is largely consistent with fire areas obtained by Brooks et al. (2015) and with their recent analyses showing that the western part of the range is exhibiting more fire than the eastern part of the range.

Climate change and other human-induced factors, including more extreme fire weather, invasive annual grasses, and human-caused fire starts, are resulting not only in increases in fire area but also in individual fires of unprecedented size (McKenzie et al. 2004; Brooks et al. 2015). Since 1984, 1021 fires over 1000 ac (4 km^2) burned within PACs in the western portion of the range, but just twelve large fires, 100,000 ac (405 km^2) to 500,000 ac (2020 km^2) in size, accounted for 27% of the area burned (table 10). An additional 187 fires, 10,000 ac (40.5 km^2) to

100,000 ac (405 km^2) in size accounted for 47% of the area burned. The majority of the fire area was concentrated during years of large fires as found elsewhere (Brooks et al. 2015).

A relatively high percentage of total fire area (37% or more) in the western portion of the range has been in the low resilience and resistance category (fig. 34). Historically, areas with low resilience and resistance typified by Wyoming big sagebrush burned less frequently than higher resilience and resistance areas characterized by mountain big sagebrush and mountain brush due to lower productivity and thus lower fuel loads (Miller et al. 2013). This summary indicates that these low resilience and resistance areas currently appear to be burning at least as frequently as the higher resilience and resistance areas. Similarly, recently analyses provide strong evidence for increased fire area for all sagebrush types (based on LANDFIRE biophysical settings; Rollins 2009) combined in the Snake River Plain and Columbia Plateau (Brooks et al. 2015).

Prioritizing Areas for Management at Ecoregion and Management Zone Scales

Assessments of priority areas for management are typically conducted at the scale of ecoregions or MZs (fig. 1; table 2) because of similarities in biophysical characteristics and thus management strategies and treatments. The process involves overlaying key data layers in a geospatial analysis to both visualize and quantify (1) species locations and abundances, (2) the probability that an area has suitable habitat, (3) the likely response to disturbance or management treatments, and (4) the dominant threats. The maps and analyses from this process are an essential component of prioritizing areas for management actions and developing management strategies. The steps in the geospatial analysis are based on those identified in table 1. The maps used to illustrate the steps are from the GRSG range.

1. Determine focal species/resources and delineate their distribution/area using the best information available. For GRSG, this includes PACs, breeding habitat probabilities, the population index (Doherty et al. *in press*), and breeding bird densities (fig. 24, 25).

2. Determine the probability of suitable habitat. For GRSG, this is the breeding habitat probability (table 7; low = 0.25 to <0.50, moderate = 0.50 to <0.75, high = 0.75 to 1.0). For other species, measures of the probability of suitable habitat will need to be developed. For many sagebrush obligate species, the probability of suitable habitat will likely be based on landscape cover of sagebrush until models similar to the breeding habitat model for GRSG are developed (Doherty et al. *in press*).

3. Create the resilience and resistance layer using categorized soil temperature and moisture regimes (fig. 6, 31; Appendix 2; Maestas et al. 2016a).

4. Overlay resilience and resistance categories with the probability of suitable habitat for the assessment area (fig. 32). This layer provides information on how areas that can support focal species/resources 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, or PACs within MZs for GRSG, can help identify target areas for management.

5. Overlay resilience and resistance with species population abundance measures. For GRSG, this is the breeding bird densities (fig. 35). 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, or PACs within MZs for GRSG, can further refine areas for management of GRSG habitat.

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/MZ. 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 a focal species or resource and incorporating these into the geospatial analyses can further inform prioritization of areas for management. For example, ability of GRSG to maintain active leks decreases significantly when conifer canopy exceeds 4% in the immediate vicinity (within 1000 m) of the lek (Baruch-Mordo et al. 2013), and most active leks average less than 1% conifer cover at landscape scales (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 8) are used to determine target 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, this is the breeding habitat probability and breeding bird density (table 8; 1B, 2B, 3B, 1C, 2C, 3C).

b. The area is at risk due to low resilience and resistance but has high conservation value for the focal species (table 8; 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 8; 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 8) are also used to determine management strategies. At the scale of the ecoregion, or PACs within MZs for GRSG, management strategies are developed that require inter-agency coordination at the mid-scale, e.g., State, National Forest, etc. Examples of these types of strategies include: (1) prepositioning firefighting resources within fire-prone areas that provide suitable habitat and support species populations as is being done for areas in the Great Basin with high fire risk (USDI BLM 2015); (2) coordinating efforts to use EDRR to prevent expansion of invasive annual grasses and other weeds; and (3) assessing habitat connectivity among PACs and species populations to develop coordinated approaches to management strategies, such as conifer removal and other habitat improvements, to decrease fragmentation (e.g., Coates et al. 2016b).

1.8 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 9).

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; Pyke et al. 2015a,b for detailed descriptions of this process). Anticipating changes like climate warming and monitoring management outcomes can be used to adapt management over time. A general approach is available that uses questions to identify the information required in each step (table 11). These questions can be modified to include the specific information needed for each project area and for treating different ecological site types. This format is used in the field guides described above.

Ecological site descriptions. Ecological site descriptions (ESDs) and their associated STMs provide essential information for determining treatment feasibility and type of treatment. Ecological site descriptions are part of a land classification system that describes the potential of a set of climate, topographic, and soil characteristics and natural disturbances to support a dynamic set of plant communities (Bestelmeyer et al. 2009, Stringham et al. 2003). The NRCS soil survey data (http://soils.usda.gov/survey/), including soil temperature/moisture regimes and other soil characteristics, are integral to ESD development. Ecological site descriptions have been developed by the NRCS and their partners to assist land management agencies and private landowners with making resource decisions, and are often available for the MZs. 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 (table 6). Within a particular ESD, there is a similar level of resilience to disturbance and resistance to nonnative invasive species and 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/). It provides managers with necessary information to assess the soil characteristics of a project area and determine the area's relative resilience to disturbance and management treatments and resistance to nonnative invasive annual grasses.

State-and-transition models. State and transition models are a central component of ESDs that are widely used by managers to illustrate changes in plant communities and associated soil properties, causes of change, and effects of management interventions (Stringham et al. 2003; Briske et al. 2005; USDA NRCS 2015) including in sagebrush ecosystems (Forbis et al. 2006; Barbour et al. 2007; Boyd and Svejcar 2009; Holmes and Miller 2010; Chambers et al. 2014c). 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 ESDs (Stringham et al. 2003; see Appendix 1 for definitions). The reference state is based on the natural range of conditions associated with the historical range of variation and often includes several plant communities (***phases***) that differ in dominant plant species relative to type and time since disturbance (Caudle et al. 2013). Alternative states describe new sets of communities that result from factors such as inappropriate livestock use, invasion by nonnative species, or changes in fire regimes. Changes or transitions among states often are characterized by ***thresholds*** or conditions that may persist over time without active intervention, potentially causing irreversible changes in community composition, structure, and function. ***Restoration pathways*** are used to identify the environmental conditions and management actions that will facilitate return to a previous state. Generalized STMs that follow current interagency guidelines (Caudle et al. 2013) and that are aligned with the dominant ecological types in table 6 are provided in Appendix 3, 4. These STMs are generally applicable to MZ I (West-Central Semiarid Prairies), MZs II and VII (Wyoming Basin and Central Middle Rockies; Colorado Plateau and Southern Rockies), and MZs III, IV, and V (Central Basin and Range, Northern Basin and Range, and Snake River Plain).

Examples of How to Apply the Concepts and Tools

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

Example #1: East-central Montana. This area is characterized primarily by cool and summer moist bordering on dry soil temperature and moisture regimes (fig. 36) with moderate resilience and resistance (table 8; 2A, 2B, 2C). Most of the area is privately owned (fig. 37), and large cropland areas exist adjacent to PACs with moderate to high GRSG populations (fig. 38a, 39). Areas supporting high breeding habitat probabilities such as a higher proportion of sagebrush on the landscape and high population concentration centers on private lands could be targeted for conservation easements, term easements, or other conservation tools to keep native rangelands intact. USDA and state-based initiatives may provide incentives for transitioning expiring Conservation Reserve Program (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. 38b; Smith et al. 2016).

A generalized STM for the dominant ecological type in this area identifies the alternative states and transitions for this type (Appendix A3.3). Following prolonged drought, improper grazing, and frequent sagebrush control treatments, the site can transition to an alternative state that is dominated by low statured cool season and sod-forming grasses (Appendix A3.3). In the absence of fire and sagebrush control treatments, the site can transition to heavy sagebrush dominance with few grasses and forbs. These altered states are susceptible to a variety of nonnative invasive plants such as Russian Knapweed (*Cenaurea repens*), field brome, and cheatgrass (see http://invader.dbs.umt.edu/queryarea.asp for a complete county list), and EDRR can be used in all areas with high to moderate habitat probabilities and breeding bird concentrations to limit establishment of these invasive species (see table 9). Livestock management that maintains a balance of native perennial grasses (cool and warm season species) and forbs 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. 40). Surface land management is primarily USFS, BLM, and private (fig. 41). The area has wide-spread oil and gas development along with high GRSG concentration areas (fig. 42, 43). 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 8; 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. 44).

Because of the wide range of soil temperature and moisture regimes, the area supports several ecological types. Relevant STMs for these types are in the Appendix (A.3.5, A.3.6, A.3.7, A.3.9, 3.10.) 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 which is highly susceptible to nonnative invasive species. Fire is rare, but multiple chemical or mechanical treatments or biological disturbances that reduce sagebrush can result in a sprouting shrub state. For these states, livestock grazing strategies can be designed to improve the condition of native plant communities and decrease nonnative invasive plant species. Strategies that include periodic 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.

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 9). 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). The spread of large weed infestations from areas with lower habitat probabilities can be prevented to protect higher quality habitat.

For disturbances that remove vegetation and cause soil disturbance such as well pads and roads, impacts can be minimized through best management practices identified in state and federal conservation plans, such as top soil banking, using certified weed-free (including annual bromes) seed mixes, appropriate seeding technologies, and monitoring. 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, and seeding these species for reclamation or restoration of sagebrush habitat can be avoided, especially in cooler and moister areas where native species establish well.

Example #3: Northeastern Nevada. This area is characterized by mountainous terrain with sagebrush ecosystems that range from cold and moist to warm and dry (fig. 45) and thus from high to low resilience and resistance. Surface land management is primarily BLM, FS, and private (fig. 46). Many mid to high elevation areas are exhibiting conifer expansion, primarily Utah juniper, and low to mid elevation areas are exhibiting cheatgrass invasion and spread (fig. 47). Since 2000, a relatively large portion of the area has burned in wildfires (fig. 47) in and around areas with high concentrations of breeding birds (fig. 48). Since 1984 about 30% of the total area burned; 20% of the total area burned since 2000. This suggests that the primary management considerations include: (1) retaining large extents of remaining sagebrush and promoting recovery of former sagebrush areas that have burned; (2) fire suppression in and around large, contiguous areas of sagebrush and successful habitat restoration or post-fire rehabilitation treatments; and (3) fuels management focused on strategic placement of fuel breaks to reduce loss of large sagebrush stands by wildfire without jeopardizing existing habitat quality (Maestas et al. 2016b).

Relevant STMs for dominant ecological types are in the Appendix (A.4.2, A.4.3, A.4.4, A.4.5). 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. In turn, increases in woody fuel loads may result in higher fire severity, while increases in invasive annual grasses may cause more frequent and continuous fires and result in conversion to alternative states dominated by annuals (Miller et al. 2013). Proper management of livestock and wild horse and burro grazing can promote native perennial grass and forb growth and reproduction and maintain or enhance resilience to wildfires and resistance to invasive annual grasses.

In the eastern portion of the area, conifer expansion is occurring (fig. 47) that can result in an alternative state dominated by trees and depending on soils, slope, and understory species an eroded state. Here, a primary management consideration is targeted tree removal in early to mid-phase (Phase I and II), post-settlement piñon and juniper expansion areas to maintain shrub/herbaceous cover and prevent conversion to a tree dominated state as well as reduce fuel loads (table 9). Guidance for selecting sites for treatment and evaluating treatment types is in Miller et al. 2014.

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

In areas with lower resilience and resistance and high breeding bird densities, large, contiguous areas of sagebrush with intact understories are a high priority for conservation (table 8, C3). In these areas, emphasis is on maintaining or increasing habitat conditions by minimizing stressors and disturbance (table 9). Post-fire rehabilitation and restoration activities focus on areas that increase connectivity among existing large areas of sagebrush. Because of low and variable precipitation, more than one intervention may be required to achieve restoration or rehabilitation goals. Management aimed at restoring understory grasses and forbs may increase resilience and resistance to both drought and fire given climate warming. Monitoring, such as the

Bureau of Land Management Assessment, Inventory, and Monitoring Program, will provide the necessary information to track change and adapt management.

Sources of Management Information

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

Information is available on grazing management from university extension services at Montana State University (http://animalrangeextension.montana.edu/range/grazing-management.html), the University of Wyoming (Cagney et al. 2010), and Colorado State University (http://extension.colostate.edu/topic-areas/natural-resources/). Additional information on livestock management can be found on websites such as http://www.grazinglands.org/ and Grass: The Stockman's Crop. The different agencies have guidelines for livestock grazing (e.g., BLM Standards for Rangeland Health and Guidelines for Grazing Management;

http://www.blm.gov/style/medialib/blm/mt/blm_programs/grazing.Par.83445.File.dat/MCSG.pdf).

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

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

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

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

Table 2. Scales and areas included in the strategic approach for managing threats to sagebrush ecosystems, sage-grouse, and other sagebrush obligate species and the data/tools/models and processes considered at each scale/area.

Area	Geographic scale	Map Extent	Data/Tools/Models	Process
Sagebrush biome and multiple MZs	Broad	West-wide	Habitat Soils Population data and models Priority resource data Fire and other threat data Climate change projections	Budget Prioritization within DOI for Rangewide Consistency
Sage-grouse MZs and ecoregions	Mid	State/National Forest	Above + Assessments & planning docs Regional data & models Regional tools	Assessments at Ecoregion/MZ Scales for Prioritization of Management Actions
Local planning areas	Local	District/Field/Office or Project Area	Above + Local data & models	Selection of Treatment Types within Prioritized Project Areas

Table 3. Environmental characteristics of the Level III Ecoregions (Griffith 2010) in the sagebrush biome.

	Temperature range (°F)	Frost-free days	Precipitation range (in)	Dominant Landforms	Elevation range (ft)	Soil Temp Regimes	Soil Moisture Regime
Cold Deserts							
Columbia Plateau	36 to 52	10 to 140	19 to 138	Tableland, plateaus, hills	985 to 8202	Cryic to Mesic	Xeric
Northern Basin & Range	41 to 48	30 to 140	6 to 39	Tableland, mts, basins, valleys	2625 to 9845	Frigid, Mesic	Xeric, Aridic
Snake River Plain	42 to 50	50 to 170	4 to 26	Mts, basins, valleys	2100 to 6450	Mesic	Xeric, Aridic
Central Basin & Range	36 to 57	15 to 200	4 to 39	Mts, basins, valleys	3346 to 13120	Frigid, Mesic	Xeric, Aridic
Wyoming Basins	32 to 46	30 to 130	5 to 20	Intermontane basins	4000 to 9450	Frigid, Mesic	Aridic-ustic
Colorado Plateau	41 to 59	50 to 220	5 to 32	Tableland	2950 to 9840	Frigid, Mesic	Aridic-ustic
Western Cordillera							
E. Cascades Slopes & Foothills	36 to 52	10 to 140	20 to 138	Mountains, plateaus	984 to 8202	Cryic to Mesic	Xeric
Idaho Batholith	28 to 46	30 to 140	8 to 60	Mountainous plateau	-	Cryic, Frigid	Udic, Xeric
Blue Mountains	30 to 50	30 to 160	9 to 80	Mountains & foothills	1000 to 9843	Cryic to Mesic	Udic, Xeric
Wasatch & Uintah Mts	28 to 46	40 to 200	6 to 55	Mountains & plateaus	4790 to 13527	Cryic to Mesic	Udic, Xeric, Aridic
Middle Rockies	23 to 46	25 to 140	12 to 98	High mts & foothills	-	Cryic, Frigid	Udic, Ustic
Southern Rockies	25 to 52	25 to 150	10 to 69	High mts & foothills	5085 to 14403	Cryic, Frigid	Udic, Ustic
Northwestern Great Plains							
West-Central Semiarid Prairies	37 to 47	-	10 to 21	Plains	-	Frigid	Ustic
Northwestern Glaciated Plains	37 to 45	95 to 170	10 to 22	Plains	-	Frigid, Mesic	Ustic, Aridic
Upper Gila Mountains							
AZ/NM Plateau	41 to 61	50 to 250	5 to 15	Plateaus, canyons	5 to 9842	-	-
AZ/NM Mountains	37 to 66	60 to 280	11 to 39	Basin & range	4265 to 12467	Frigid, Mesic	Ustic, Aridic

Table 4. List of persistent ecosystem and anthropogenic threats to sagebrush ecosystems and associated management objectives (based on the Greater Sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report (USFWS 2013) and the Greater Sage-Grouse Monitoring Framework (IGSDMS 2014).

Threats	**Management Objective**
Isolated/Small Population Size	Landscape Connectivity and Resilient Populations
Sagebrush Elimination	Sagebrush Land Cover Sufficient to Support Sagebrush Dependent Species
Altered Fire Regimes	Fire Regimes/Sizes in Historic Range of Variability
Conifer Expansion	Conifer Reduction where Appropriate to Support Sagebrush Dependent Species
Weeds/Invasive Grasses	Minimal Weeds
Climate Change	Effective Adaptation
Cropland Conversion	Low Fragmentation
Energy Development	Low Fragmentation
Mining	Low Fragmentation
Urban & Exurban Development	Low Fragmentation
Recreation	Little to No Impact
Infrastructure	Low Impact Disturbance
Livestock Grazing	Desired Plant Community Composition and Structure
Free-Roaming Equids	Desired Plant Community Composition and Structure

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

Management Zone	1st Variable	2nd Variable	3rd Variable	4th Variable	5th Variable
I	Conifer Cover (-)	All Sagebrush (+)	Roughness (negative quadratic)	Topographic Wetness (positive quadratic)	Gross Primary Production (positive quadratic)
Importance	1.00	0.63	0.57	0.55	0.45
II	All Sagebrush (+)	Conifer Cover (-)	Annual Drought Index (negative quadratic)	Degree Days > 5°C (positive quadratic)	Mean Annual Precipitation (positive quadratic)
Importance	1.00	0.73	0.68	0.59	0.49
III	All Sagebrush (+)	Degree Days > 5°C (positive quadratic)	Elevation (positive quadratic)	Annual Drought Index (negative quadratic)	Conifer Cover (-)
Importance	1.00	0.79	0.70	0.54	0.48
IV	Conifer Cover (-)	Annual Drought Index (negative quadratic)	All Sagebrush (+)	Degree Days > 5°C (positive quadratic)	Gross Primary Production (positive quadratic)
Importance	1.00	0.60	0.59	0.51	0.50
V	All Sagebrush (+)	Annual Drought Index (negative quadratic)	Low Sagebrush (+)	Mean Annual Precipitation (positive quadratic)	Degree Days > 5°C (positive quadratic)
Importance	1.00	0.96	0.91	0.79	0.65
VI	Elevation (positive quadratic)	Degree Days > 5°C (positive quadratic)	Grassland/ Herbaceous (+)	Annual Drought Index (negative quadratic)	All Sagebrush (+)
Importance	1.00	0.42	0.41	0.27	0.22
VII (GRSG)	All Sagebrush (+)	Low Sagebrush (+)	Human Disturbance Index (-)	Oil & Gas Wells (-)	
Importance	1.00	0.67	0.48	0.4	

Table 6. Predominant sagebrush ecological types in the West-Central Semiarid Prairies (MZ I), Cold Deserts in the eastern portion of the range (Wyoming Basin, Colorado Plateau, and associated Western Cordillera; MZs II, VII) and Cold Deserts in the western portion of the range (Snake River Plain, Northern Basin and Range, Central Basin and Range; MZs III, IV, V). The ecological types are characterized by soil temperature and moisture regimes (to moisture subclass), vegetation, resilience to disturbance, and resistance to invasive annual grasses. Relative abundance of sagebrush species and composition of understory vegetation vary depending on Major Land Resource Area (MLRA) and ecological site type. An explanation of the soil temperature and moisture regimes is in Appendix 2. State-and-transition models (STMs) for the majority of these ecological types are in Appendices 3 and 4. Definitions of MLRAs, ecological types, STMs, and ecological sites are in Appendix 1. A detailed description of how to use this information is in the section on "Determining the Most Appropriate Management Treatments at the Project Scale" 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 MT	Precipitation: 10-14 inches Typical Vegetation: *Green needlegrass, wheatgrasses, needle-and-thread, plains silver sagebrush* Grass dominated - cool season grasses 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 extensive club moss cover.
Cool/Summer moist (Frigid/Ustic) Representative Area: Northwestern Great Plains – MLRA 60A in SD	Precipitation: 13-18 inches Typical Vegetation: *Western wheatgrass, green needlegrass, blue and sideoats grama, buffalograss, plains silver sagebrush, Wyoming big sagebrush on shallow and 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 MT and 58D in SD, 58C in ND	Precipitation: 10-14 inches Typical Vegetation: *Wyoming big sage, plains silver sage, wheatgrasses, green needlegrass, needle-and-thread, and blue grama*	*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.

	Shrub dominated - cool season grasses with some warm season grasses	
Warm/Summer moist (Mesic/Ustic) Representative Area: Northwestern Great Plains – wetter portions of MLRA 58B in WY 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 WY, but could also apply to warmer portions of 58A, Land Resource Unit (LRU) E in southeastern MT	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.

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 WY and MT; 48A in CO; MLRA 47 in UT **Applies to GUSG and GRSG habitat**	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 WY and MT; MLRA 48A in WY and Northern CO; MLRA 49 in WY	Precipitation: 15-19 inches Typical Vegetation: *mountain big sagebrush, bitterbrush, snowberry, serviceberry, mahogany, aspen, fescues, needlegrasses, bluebunch wheatgrass*	*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

Applies to GUSG and GRSG habitat	Shrub dominated - cool season bunchgrasses	to aspect with lower resistance on south-facing aspects.
Cool/Summer moist (Frigid/Ustic) Representative Area: Uinta Mountains (MLRA 47 Land Resource Unit C) in UT and WY; Southern Rockies in CO and UT – MLRA 48A; **Applies to GUSG and GRSG habitat**	Precipitation: 16-22 inches Typical Vegetation: *mountain big sagebrush, serviceberry, snowberry, bitterbrush, western wheatgrass, needlegrasses, bluegrasses* Shrub dominated - cool season grasses (some warm season grasses in southern part of range)	*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 UT (MLRA 47)	Precipitation: 12-22 inches Typical vegetation: *Mountain big sagebrush, antelope bitterbrush, snowberry, and/or low sagebrush, bluebunch wheatgrass, basin wildrye, Nevada bluegrass* Piñon pine and juniper potential in some areas Shrub dominated – cool season grasses	*Resilience* – **Moderately high**. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions 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 bordering on cold/ Summer moist bordering on dry (Frigid bordering on Cryic/Ustic bordering on Aridic) Representative Area: Wyoming Basin - MLRA 34A in WY west of continental divide into Rich Co., UT	Precipitation: 9-14 inches Typical Vegetation: *Wyoming big sagebrush, Gosiute sagebrush, mountain big sagebrush, basin big sagebrush in drainages, Indian ricegrass, needle-and-thread, wheatgrasses* Shrub dominated – cool season grasses	*Resilience* **– Moderate to low.** Effective precipitation and cold temperatures can limit site productivity and plant establishment. *Resistance* – **Moderately high.** Climate suitability to invasive annual bromes is relatively low due to low soil temperature.
Cool/Summer moist bordering on dry (Frigid/Ustic bordering on Aridic) Representative Area:	Precipitation: 10-14 inches Typical Vegetation: *Wyoming big sagebrush; basin big sagebrush or silver sagebrush in drainages, wheatgrasses,*	*Resilience* - **Moderate**. Precipitation and productivity are moderate. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience.

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

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

Ecological type	**Characteristics**	**Resilience and resistance**
Cold/Moist (Cryic/Xeric)	Precipitation: 14 inches + Typical vegetation: *Mountain big sagebrush, snowfield sagebrush, snowberry, serviceberry, silver sagebrush, and/or low sagebrush, slender wheatgrass, Idaho fescue, needlegrasses, bromes* Shrub dominated – cool season grasses	*Resilience* – **Moderately high.** Precipitation and productivity are generally high. Short growing seasons can decrease resilience on coldest sites. *Resistance* – **High.** Low climate suitability to invasive annual grasses
Cool/Moist (Frigid/Xeric)	Precipitation: 12-22 inches Typical vegetation: *Mountain big sagebrush, antelope bitterbrush, snowberry, and/or low sagebrushes, slender wheatgrass, Idaho fescue, June grass, needle grasses, bromes* Piñon pine and juniper potential in some areas Shrub dominated – cool season grasses	*Resilience* – **Moderately hig**h. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. *Resistance* – **Moderate.** Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.
Warm/Moist (Mesic/Xeric)	Precipitation: 12-16 inches Typical vegetation: *Basin big sagebrush, Bonneville big sagebrush, and/or low sagebrush, Bluebunch wheatgrass, needle grasses, bromes* Piñon pine and juniper potential in some areas Shrub dominated – cool season grasses	*Resilience* – **Moderate.** Precipitation and productivity are moderately high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. *Resistance* – **Moderately low.** Climate suitability to invasive annual grasses is moderately low, but increases as soil temperatures increase.
Cool/Dry (Frigid/Aridic)	Precipitation: 6-12 inches Typical vegetation: *Wyoming big sagebrush, black sagebrush, and/or low sagebrushes, Bluebunch wheatgrass, needle grasses, Sandberg's bluegrass, bottlebrush squirreltail* Shrub dominated – cool season grasses	*Resilience* – **Low.** Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. *Resistance* – **Moderate.** Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.

Warm/Dry (Mesic/Aridic, bordering on Xeric)	Precipitation: 8-12 inches Typical vegetation: *Wyoming big sagebrush, black sagebrush and/or low sagebrushes, Sandberg's bluegrass, bottlebrush squirreltail, needleandthread, Indian ricegrass* Shrub dominated – cool season grasses	*Resilience* – **Low.** Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. Cool season grasses susceptibility to grazing and fire, along with hot dry summer fire conditions, promote cheatgrass establishment and persistence. *Resistance* – **Low.** High climate suitability to cheatgrass and other invasive annual grasses. Resistance generally decreases as soil temperature increases, but establishment and growth are highly dependent on precipitation.

Table 7. Breeding habitat model probabilities (Doherty et al. *in press*) for all MZs grouped into ranges relative to their probability of supporting sage-grouse leks. Percentage (sample size) of active and inactive GRSG leks from Colorado, Idaho, Montana, North Dakota, South Dakota, Utah, and Wyoming were calculated to develop probability breaks (unsuitable, low, moderate, and high) for the breeding habitat probabilities. Habitat probabilities for GRSG were modeled by comparing habitat characteristics within 4 mi (6.4 km) around active leks and pseudo-absence locations (Doherty et al. *in press*).

Percentage of Leks	**Breeding Habitat Probabilities**			
	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* = 1680)
Inactive (%)	6.2 (*n* = 51)	24.5 (*n* = 202)	39.6 (*n* = 326)	29.7 (*n* = 244)

Table 8. Sage-grouse habitat resilience and resistance matrix based on resilience and resistance concepts from Chambers et al. (2014a, b, *in press*), and GRSG breeding habitat probabilities from Doherty et al. (*in press*). 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 6. Columns show the landscape-scale sage-grouse breeding habitat probability based on table 7 (A = 0.25 to < 0.5 probability; B = 0.5 to < 0.75 probability; C = ≥ 0.75 probability). Use of the matrix is explained in text. Potential management strategies for persistent ecosystem threats, anthropogenic threats, and climate change are in table 9 for the West-Central Semiarid Prairies (MZ I), Western Cordillera, and Cold Deserts (MZ II, III, IV, V, VI, VII).

Landscape-Scale Sage-Grouse Breeding Habitat Probability

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.

Ecosystem Resilience to Disturbance and Resistance to Invasion

Low------------Moderate------------High

High — 1A, 1B, 1C

Potential for favorable perennial herbaceous species recovery after disturbance without seeding is typically high.

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

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

Seeding/transplanting success is typically high.

Recovery following inappropriate livestock use is often possible given changes in management.

Moderate — 2A, 2B, 2C

Potential for favorable perennial herbaceous species recovery after disturbance without seeding is usually moderately high, especially on cooler and moister sites

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

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

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

Recovery following inappropriate livestock use depends on site characteristics and management.

Low — 3A, 3B, 3C

Potential for favorable perennial herbaceous species recovery after disturbance without seeding is usually low.

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

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

Recovery following inappropriate livestock use is unlikely without active restoration.

Table 9. 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, III, IV, V, VI, VII). Recommendations are provided for prioritizing and targeting strategies based on cells in the sage-grouse habitat resilience and resistance matrix (table 8). Threats and strategies are cross-cutting and affect multiple program areas. While many of these fall under the broad umbrella of vegetation management, a coordinated and integrated approach will likely be used in addressing threats. For example, it is expected that multiple agency program areas such as nonnative invasive plant management, fuels management, range management, wildlife, and others will contribute to strategies that use vegetation manipulation to address persistent ecosystem and anthropogenic threats.

<table>
<tr><th>Threat</th><th>Management Strategies</th></tr>
<tr><td>Nonnative Plant Invasive Species</td><td>

Apply integrated vegetation management practices to manage nonnative invasive plant species, using an interdisciplinary and coordinated approach in designing and implementing projects and treatments.
Prioritize areas where resources are likely available to ensure successful management in the long-term.
Use resilience and resistance categories and knowledge of invasive plant distributions to select appropriate management approaches.

Protect high quality (relatively weed-free) sagebrush communities with moderate-to-high sage-grouse habitat probabilities (cells 1B, 1C, 2B, 2C, 3B, 3C):

Focus on preventing introduction and establishment of invasive plant species, especially in low resistance areas with high susceptibility to annual grass invasion (in and adjacent to cells 3B, 3C);
Avoid seeding introduced forage species (crested wheatgrass, smooth brome, etc.) in post-fire rehabilitation or restoration in moderate to high resilience and resistance areas because these species can dominate sagebrush communities; and
Practice Early Detection-Rapid Response (EDRR) approaches for emerging invasive species of concern (in and adjacent to cells 1B, 1C, 2B, 2C, 3B, 3C).

Where weed populations already exist, seek opportunities to maximize treatment effectiveness by prioritizing restoration within relatively intact sagebrush communities (cells 1B, 1C, 2B, 2C, 3B, 3C). Restoration will likely be easier at locations in cooler and moister ecological types with higher resilience and resistance.

Prioritize sites with sufficient native perennial herbaceous species to respond to release from invasive plant competition;
Manage grazing to reduce invasive species and promote native perennial grasses. In the West-Central Semiarid Prairies and other cool and moist areas, manage grazing to reduce crested wheatgrass, Kentucky bluegrass, smooth brome, and other introduced forage species and to promote native cool season perennial grasses (see grazing strategies).

Restrict spread of large weed infestations located in lower breeding habitat probability areas (cells 1A, 2A, 3A) to prevent compromising adjacent higher quality habitats (cells 1B, 1C, 2B, 2C, 3B, 3C).

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<tr><td>Conifer Expansion</td><td>

Addressing localized conifer expansion requires an interdisciplinary approach and necessarily involves multiple program areas.
Apply integrated vegetation management practices to treat conifer expansion, using an interdisciplinary approach in designing projects and treatments.
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o Focus tree removal on early to mid-phase (e.g., Phases I, II) conifer expansion into sagebrush ecological sites to maintain shrub/herbaceous cover.
o Use prescribed burning cautiously and selectively in moderate to high resilience/resistance (cells 1A, 1B, 2A, 2B) to control conifer expansion.
o Prioritize for treatment:

Areas with habitat characteristics that can support sage-grouse with moderate to high resilience and resistance (cells 1B, 1C, 2B, 2C), especially near leks. (Note: cells 3B and 3C are generally too warm and dry to support conifers.)
Areas where conifer removal will provide connectivity between sagebrush habitats.
Areas where sufficient native perennial grasses and forbs exist to promote recovery and limit increases in invasive plant species.

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<tr><td>Wildfire</td><td>
The wildfire threat is generally addressed through fire operations, fuels management (mechanical treatments, prescribed burning, chemical and seeding treatments), and post-fire rehabilitation.
Fire Operations: Protection of areas supporting sagebrush is important for maintaining sagebrush habitat. The types and locations of GRSG habitats have been incorporated into decision support, dispatch, and initial attack procedures, and represent key considerations for fire managers.
If resources become limiting, consider the following prioritization:

Fire suppression - typically shifts from low to moderate priority when resilience and resistance categories shift from high to moderate, but varies with large fire risk and landscape condition (cells 1B, 1C, 2B, 2C). In low resilience and resistance areas, the priority shifts from moderate to high as sage-grouse habitat probability increases (cell 3B, 3C). Scenarios requiring high priority may include:

o Areas of sagebrush that bridge large, contiguous expanses of sagebrush and that are important for providing habitat connectivity;
o Areas where sagebrush communities have been successfully reestablished through seedings or other rehabilitation investments; and
o All areas during critical fire weather conditions, where fire growth may move into valued sagebrush communities. These conditions may be identified by a number of products including, but not limited to: Predictive Services National 7-Day Significant Fire Potential products; National Weather Service Fire Weather Watches and Red Flag Warnings; and fire behavior analyses and local fire environment observations.

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

Conifer removal conducted to decrease woody fuels and reduce the loss of large, contiguous sagebrush stands are high priority in areas with high breeding habitat probabilities and moderate to high resilience and resistance (cells 1B, 1C, 2B, 2C),

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	and shift to low in areas with low breeding habitat probabilities (cells 1A and 2A). In these areas, the focus is primarily on conifer expansion areas with sufficient native perennial understory species for recovery. • Management activities may include: o Tree removal in early to mid-phase (Phases I, II) post-settlement conifer stands to maintain shrub/herbaceous cover and reduce fuel loads; o Tree removal in later phase (Phase III) post-settlement conifer stands to reduce risks of large or high severity fires; and o Herbicide and/or seeding associated with mechanical treatments to reduce invasive species and restore native perennial herbaceous species where native perennial species are depleted. <u>Mechanical Treatments - Fuel Breaks</u> Fuel breaks are strategically placed treatments where vegetation is modified in order to change fire behavior, making fire control efforts safer or more effective. Common types of fuel breaks include road maintenance/roadside disking (brown strips), mowed fuel breaks, and vegetative fuel breaks (greenstrips). • In areas of low resilience and resistance, fuel breaks may increase in priority as sage-grouse habitat probability increases (cells 3B, 3C). Repeated treatments may be necessary to maintain functional fuel breaks. • Key management considerations for the design and placement of fuel breaks are: o Implemented where fire managers believe they will benefit suppression efforts; o Designed at large landscape scales, providing multiple options for fire managers; o Designed collaboratively with interdisciplinary specialists, private landowners, fire response partners, and other agencies; o Include plans for long-term monitoring and maintenance; o Designed to minimize habitat impacts, including nonnative invasive species introduction and spread, while maximizing potential fire management benefits. • Key ecological considerations for the design and placement of fuel breaks: o Design fuel breaks in an interdisciplinary setting which addresses the need, cumulative effects, alternative treatments, and possible undesired results; o Consider ecosystem resilience and resistance and place fuel breaks to minimize catastrophic ecological state changes; o Includes conservation buffers around sagebrush leks, habitat fragmentation thresholds and minimum habitat patch sizes; o Includes the influence on habitat connectivity between seasonal sage-grouse habitats; o Follow technical guidance related to recommended design features (see Maestas et al. 2016b). <u>Prescribed Burning</u> Prescribed burning to address the threat of wildfire includes burning to reduce woody biomass resulting from treatments, to control conifer expansion, to reduce hazardous fuels, and to create fuel breaks which augment fire suppression efforts. When setting priorities for prescribed burning, consider the following: • Consider alternatives to prescribed burning where other treatment alternatives may meet management objectives. • In low resilience and resistance areas, consider prescribed burning only after consultation with local biologists and land managers and when: o Site information, such as state-and-transition models, affirm that the post-burn trajectory will lead to functioning sagebrush communities. Most low

	resilience and resistance areas that receive < 12 in/yr (30.5 cm/yr) of precipitation do not respond favorably to burning (See Miller et al. 2014.) o Burning is part of multi-stage restoration projects where burning is required to remove biomass following chemical treatments for site preparation or for improved chemical applications. o Monitoring data validates that the pre-burn composition will lead to successful, native plant dominance post-burn • Use prescribed burning cautiously and selectively in moderate to high resilience and resistance areas, after consultation with local biologists and land managers and assessing site recovery potential and other management options based on the following: o Pre-burn community composition; o Probability of invasive species establishment or spread; 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. <u>Chemical Treatment of Nonnative Invasive Plant Species and Seeding</u> Chemical treatments and seedings are used to decrease invasive species composition and increase native species dominance in areas where native perennial grasses and forbs are insufficient for site recovery. Chemical and seeding treatments may be selectively applied in conjunction with prescribed burning or mechanical treatments. Typically, these treatments are in response to clear evidence of a nonnative invasive species threat. Areas of higher priority for chemical and seeding treatments: • Lower resistance and resilience cells (2A, 2B, 3A, 3B) lacking the ability for natural recovery; • Recently disturbed areas where recovery will not occur without chemical or seeding treatments; • Areas where investments have been made and objectives cannot be attained without chemical or seeding treatments. **Post-Fire Rehabilitation:** General considerations for prioritization of post-fire rehabilitation efforts are: • Priority generally increases as resilience and resistance decrease and habitat probability for sage-grouse increases. High priorities include areas of low to moderate resilience and resistance that (1) lack sufficient native perennial grasses and forbs to recover on their own and (2) have nearby areas still supporting sage-grouse habitat (cells 2B, 2C, 3B, 3C). Areas of low habitat probability for sage-grouse (cells 2A, 3A) are generally lower priority but may become higher priority in areas that support other resource values or that increase connectivity for GRSG populations. • Areas of higher priority across all cells include: o Areas where pre-fire perennial herbaceous cover, density, and species composition is inadequate for recovery (see Miller et al. 2015); o Areas where seeding or transplanting sagebrush is needed to maintain habitat connectivity for sage-grouse; o Areas threatened by nonnative invasive plants; and o Steep slopes and soils with erosion potential.
Livestock Grazing	• Manage livestock grazing to maintain a balance of native perennial grasses (warm and/or cool season species as described in Ecological Site Descriptions for that area), forbs, and biological soil crusts to allow natural regeneration and to maintain resilience and resistance to invasive plants. Ensure strategies prevent degradation and loss of native cool-season grasses in particular. Areas with low to moderate resilience and resistance may be particularly vulnerable (cells 2A, 2B, 2C, 3A, 3B, 3C).

	• Implement grazing strategies that incorporate periodic 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 plants. In ephemeral drainages and higher precipitation areas in the West-Central Semiarid Prairies that receive more summer moisture and have populations of nonnative invasive plant species, too much rest may inadvertently favor species such as field brome, Kentucky bluegrass, and smooth brome. Adjustments in timing, duration, and intensity of grazing may be needed to reduce these species.
Energy Development	• Avoid development, if feasible, in areas with high breeding habitat probability for sage-grouse and high sagebrush cover (cells 1C, 2C, 3C) and steer development in non-habitat areas (1A, 2A, 3A). • Minimize habitat fragmentation in areas with moderate and high breeding habitat probabilities for sage-grouse (cells 1B, 2B, 3B, 1C, 2C, 3C). • For disturbances that remove vegetation and cause soil disturbance, minimize and mitigate impacts (top soil banking, certified weed-free [including annual bromes] seed mixes, appropriate seeding technologies, and monitoring). Plan for multiple restoration interventions in areas with low resilience and resistance (cells 3B, 3C). • Minimize or co-locate energy transport corridors (e.g., roads, pipelines, transmission lines) and limit vehicle access, where feasible. • Maintain resilience and resistance of existing patches of sagebrush habitat by aggressively managing weeds that may require the following management practices (especially important in low resilience and resistant areas - cells 3A, 3B, 3C): o A weed management plan that addresses management actions specific to a project area; o Use certified weed-free (including annual bromes) gravel and fill material; o Assess and treat weed populations, if necessary, prior to surface disturbing activities; o Remove mud, dirt, and plant parts from construction equipment; o Address weed risk and spread factors in travel management plans; o Ensure timely establishment of desired native plant species on reclamation sites; o Use locally adapted native seed, whenever possible; o Intensively monitor reclamation sites to ensure seeding success, determine presence of weeds, and implement corrective actions as necessary; o Use mulch, soil amendments, or other practices to expedite reclamation success when necessary; and o Ensure weeds are controlled on stockpiled topsoil.
Urban and Exurban Development	• 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.
Cropland Conversion	• Secure Conservation Easements to maintain existing sagebrush grasslands and sage-grouse habitat and prevent conversion to tillage agriculture. Prioritize all areas supporting moderate-to-high sage-grouse habitat probability (cells 1B, 1C, 2B, 2C, 3B, 3C) in locations where tillage risk is elevated (see Sage Grouse Initiative, Cultivation Risk layer). • Secure term leases (e.g., 30 years) to maintain existing sagebrush grasslands and sage-grouse habitat and prevent conversion to tillage agriculture as a secondary strategy to Conservation Easements. Prioritize all areas supporting moderate-to-high sage-grouse

	habitat probability (cells 1B, 1C, 2B, 2C, 3B, 3C) especially in locations where tillage risk is elevated (see SGI Cultivation Risk layer). • Offer alternatives to farming on expired USDA Conservation Reserve Program (CRP) lands through federal and state programs. Prioritize lands in and around intact habitats (cells 1B, 1C, 2B, 2C, 3B, 3C). • Encourage enrollment in the USDA CRP 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).

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

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

Table 10. The number, area, and percentage of fires > 1000 acres (4 km^2) (MTBS 2014) by fire size within the Priority Areas for Conservation (PACs; USFWS 2013).

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

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

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

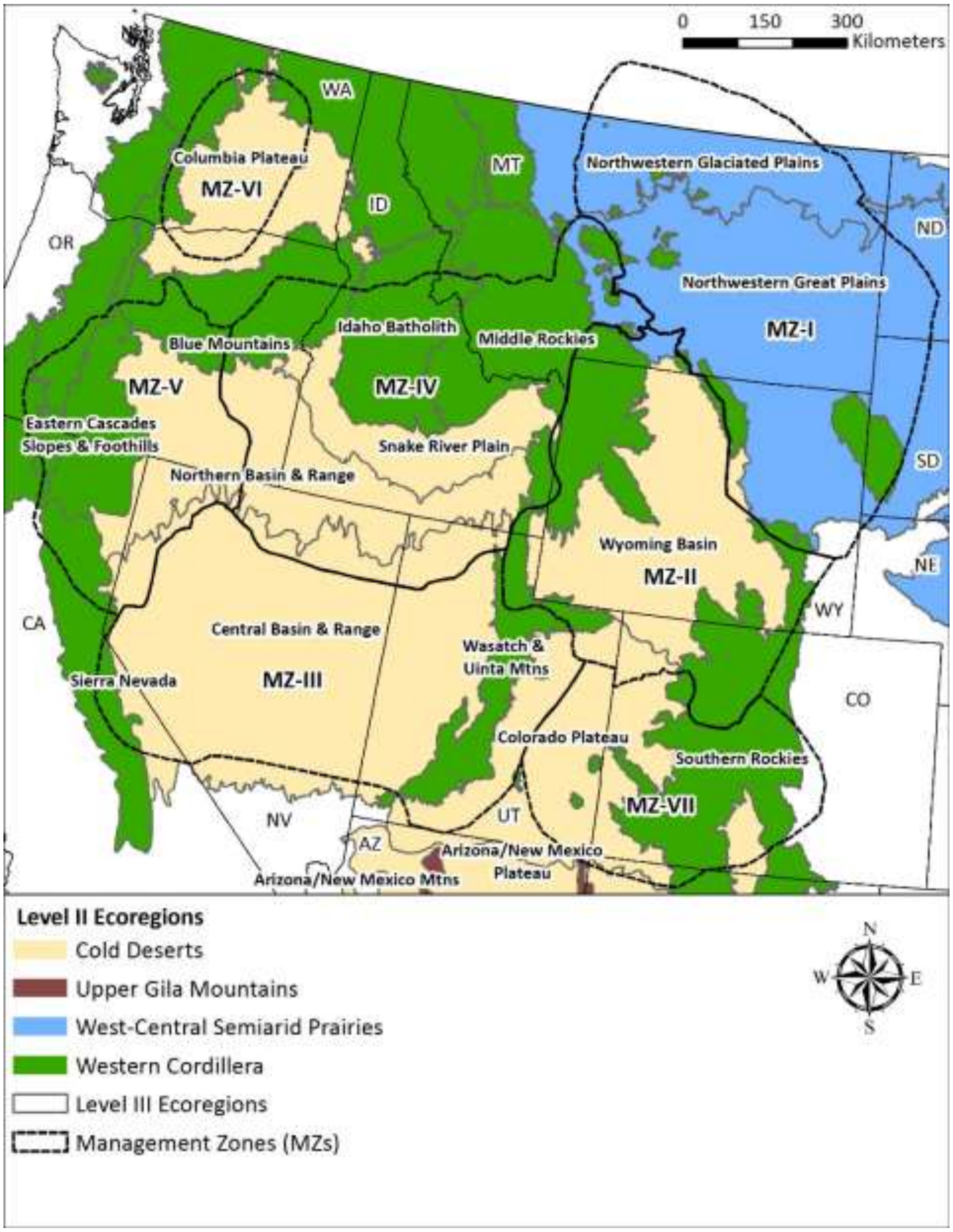


Figure 1. Environmental Protection Agency ecoregions (EPA 2016) and sage-grouse management zones (MZs; Stiver et al. 2006). Level II ecoregions are color coded and Level III ecoregions are labeled on the map.

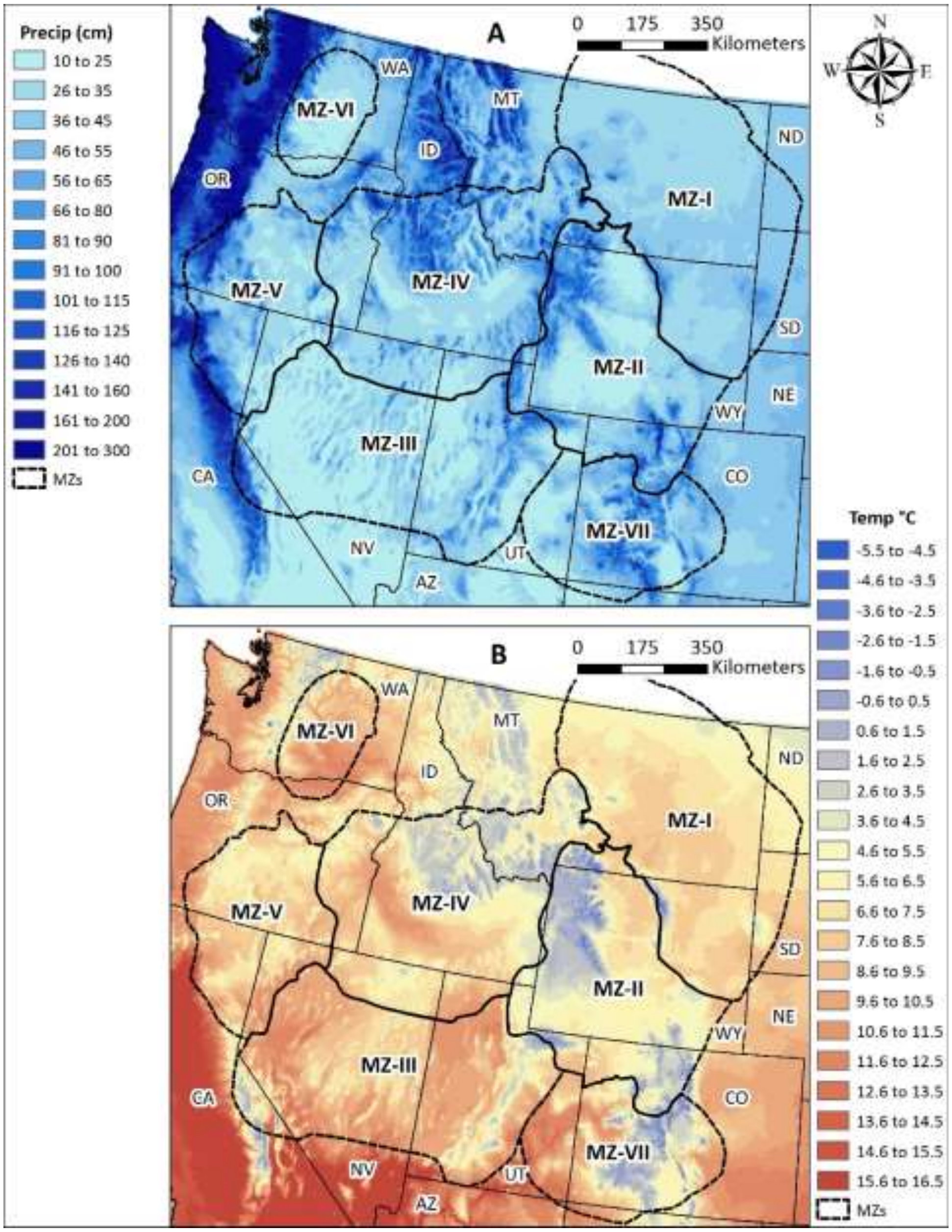


Figure. 2. The 30-yr normal annual values for (A) precipitation and (B) temperature (PRISM 2016) in the sage-grouse management zones (MZs; Stiver et al. 2006).

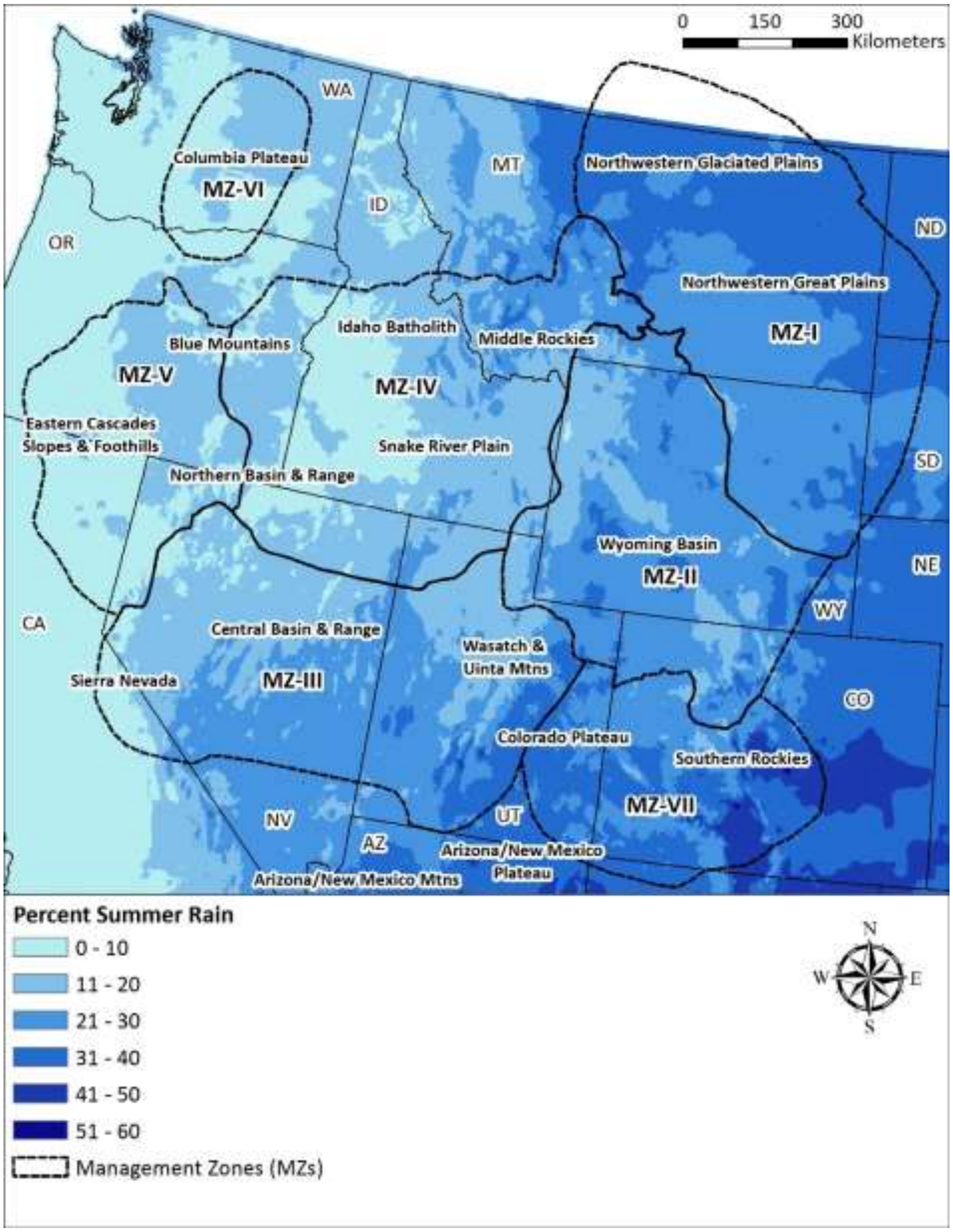


Figure 3. Percentage of annual precipitation occurring during the months of July, August, and September (PRISM 2016) in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

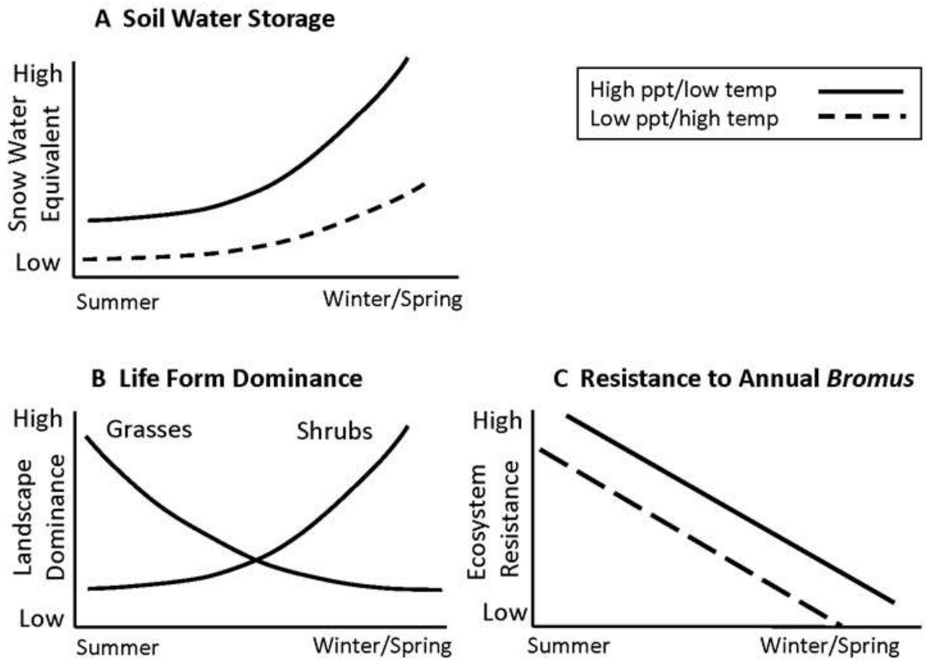


Figure. 4. Changes in soil water storage, life form dominance, and resistance to annual *Bromus* as seasonality of precipitation transitions from primarily summer to winter. (A) Soil water storage increases as winter/spring precipitation and snow water equivalent increase and these changes are relatively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

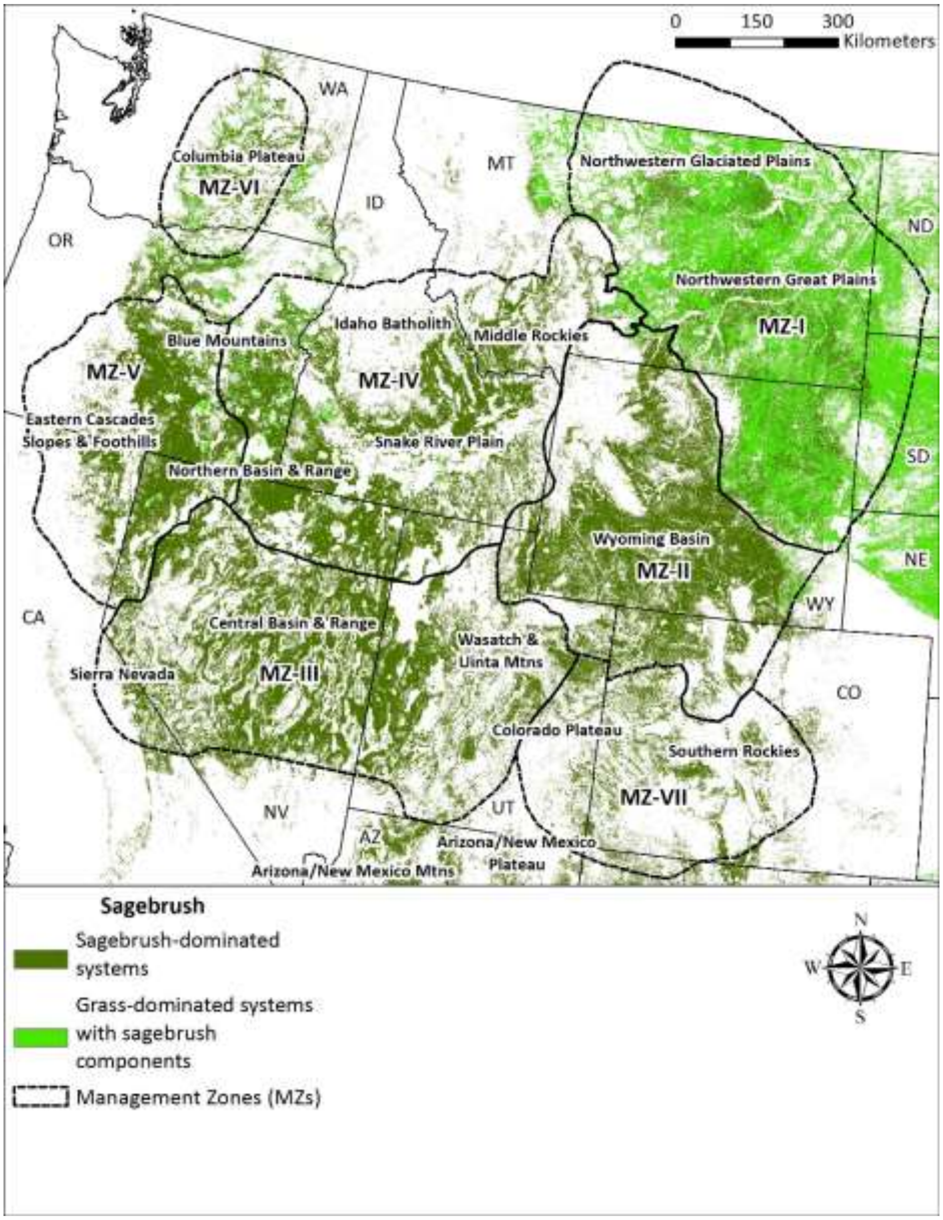


Figure 5. Landscape cover of sagebrush-dominated ecological systems and grass-dominated ecological systems with sagebrush components from LANDFIRE (USGS 2014) in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

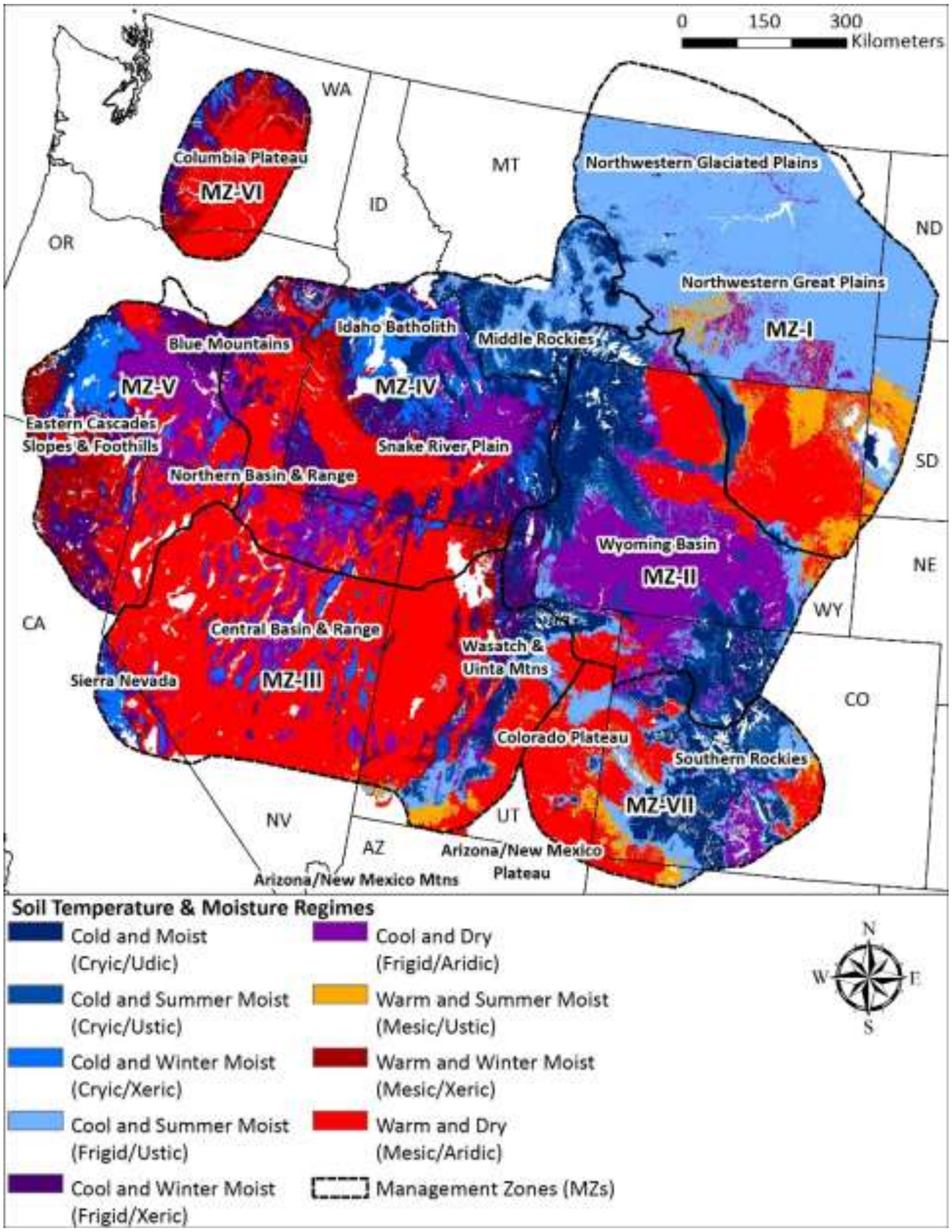


Figure 6. Soil temperature and moisture regimes by soil moisture subclass in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). See Appendix 2 for an explanation of the soil temperature and moisture regime data used in this report. The area near 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.

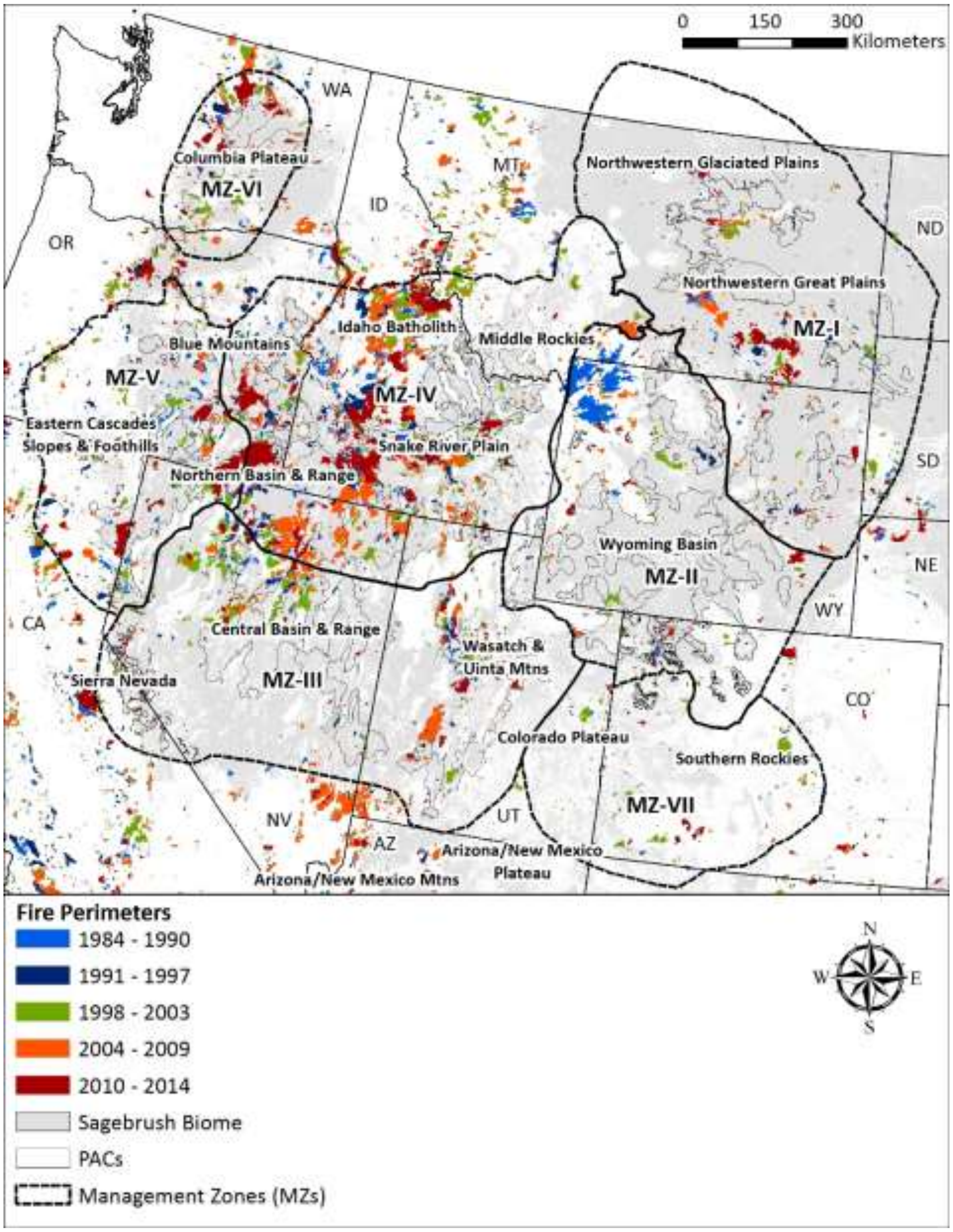


Figure 7. Perimeters of fires that have occurred since 2000 in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Priority Areas for Conservation (PACs; USFWS 2013) overlaid. Data for fires > 1000 acres are from MTBS (2014) and data for fires < 1000 acres are from GeoMAC (2015).

A

B

C

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

A

B

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

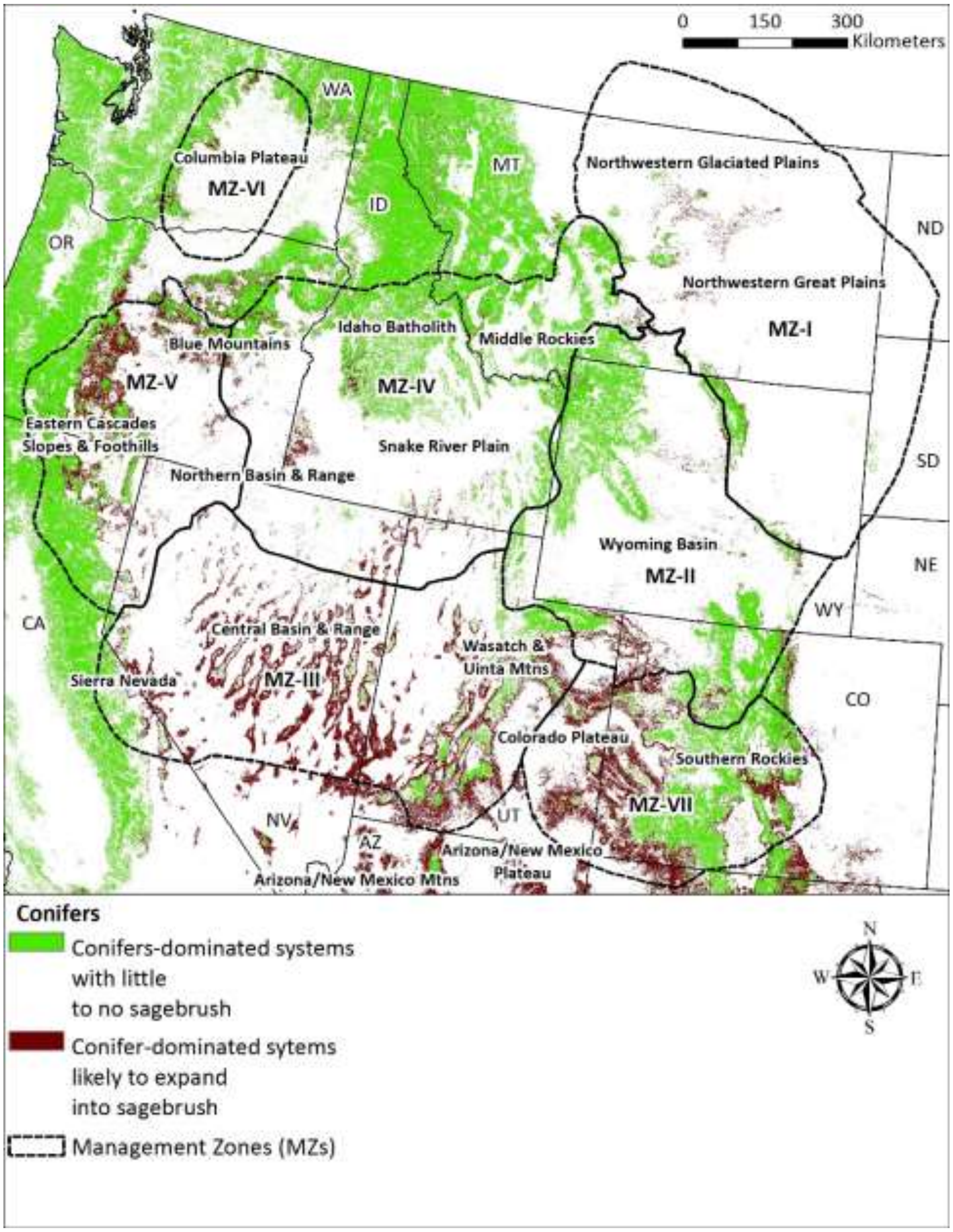


Figure 10. Landscape cover of conifer-dominated ecological systems from LANDFIRE (USGS 2014) in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). The dark brown colors represent conifer-dominated systems with the potential to expand into sagebrush-dominated systems (USDI BLM 2014).

A

B

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

Figure 12. A post-burn, Phase III, singleleaf piñon and Utah juniper dominated sagebrush ecosystem in which soils are highly erosive and few understory plants remain (photo by Jeanne C. Chambers).

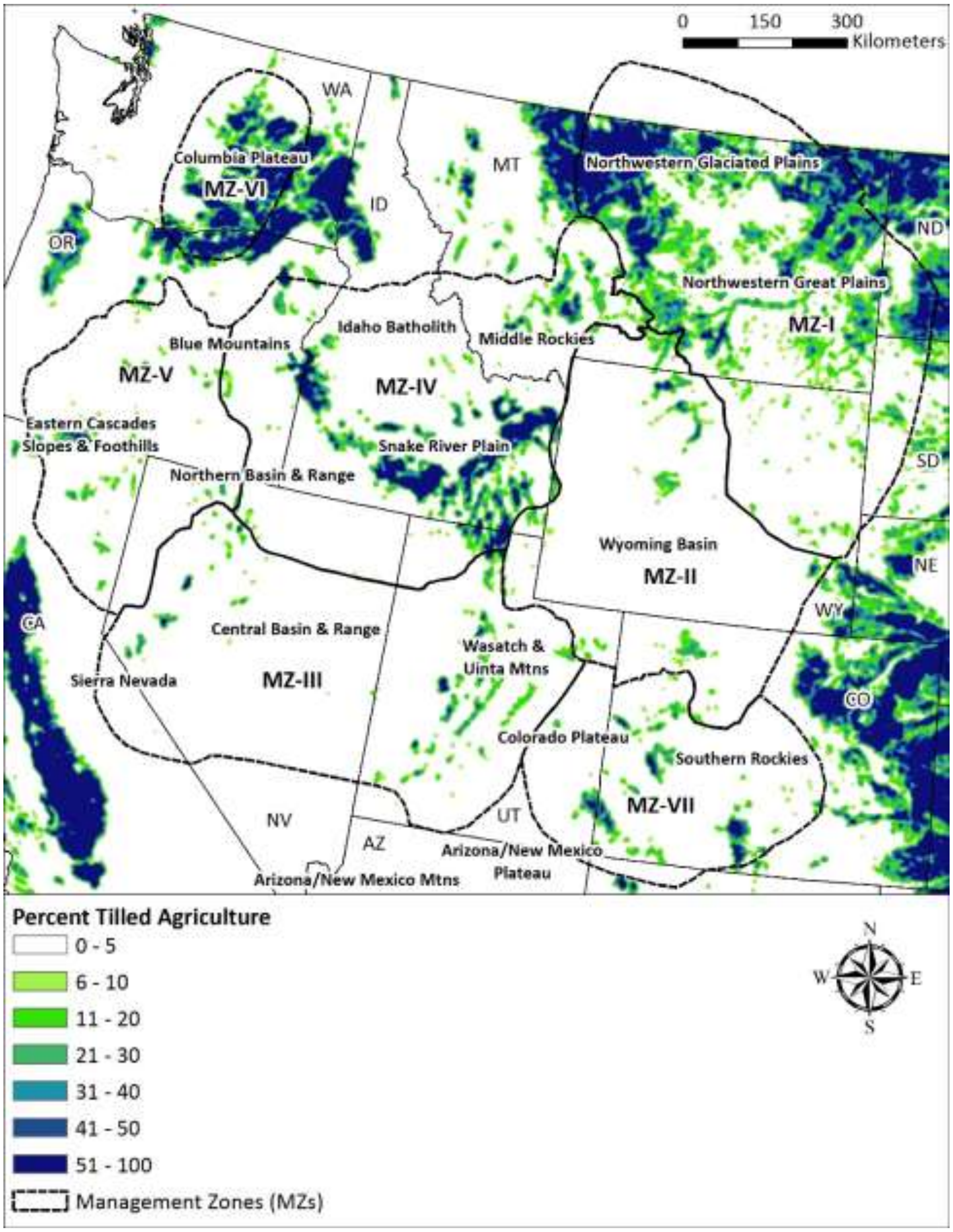


Figure 13. Percent annually tilled agricultural land (cropland; NASS 2014) within 5.0 km of each pixel in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

Figure 14. Conversion of a sagebrush ecosystem in the West-Central Semiarid Prairies to cropland (photo by John Carlson).

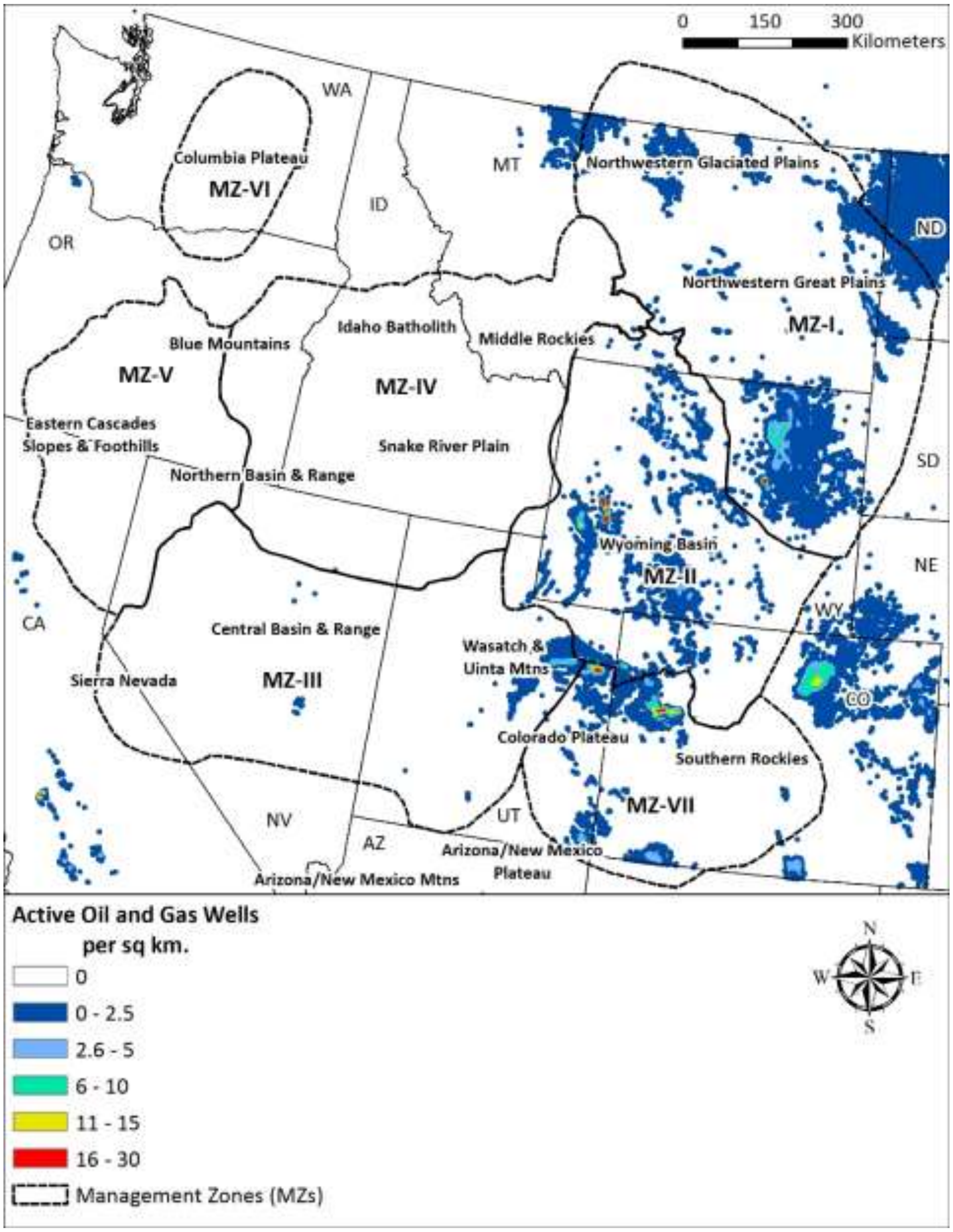


Figure 15. Number of active oil and gas wells per square kilometer (IHS; BLM [AFMSS]) in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

A

B

Figure 16. (A) Deep gas drill rig outside of Pinedale, Wyoming (photo by Thomas J. Christiansen), and (B) well pad (photo by Kenneth F. Henke).

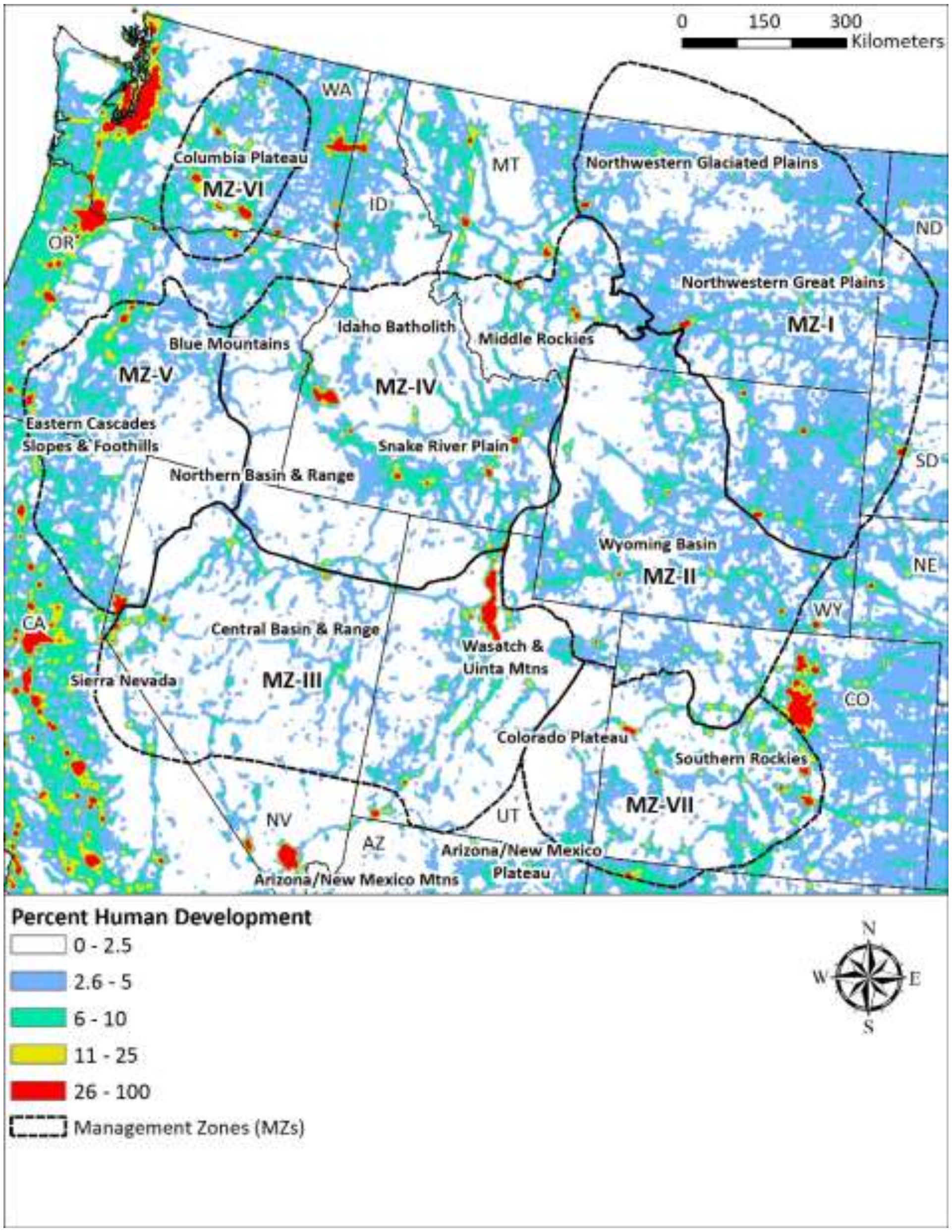


Figure 17. Percentage of developed land (NLCD 2011) within 5.0 km of each pixel in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

Figure 18. Rural subdivision in Sublette County, Wyoming (photo by Thomas J. Christiansen).

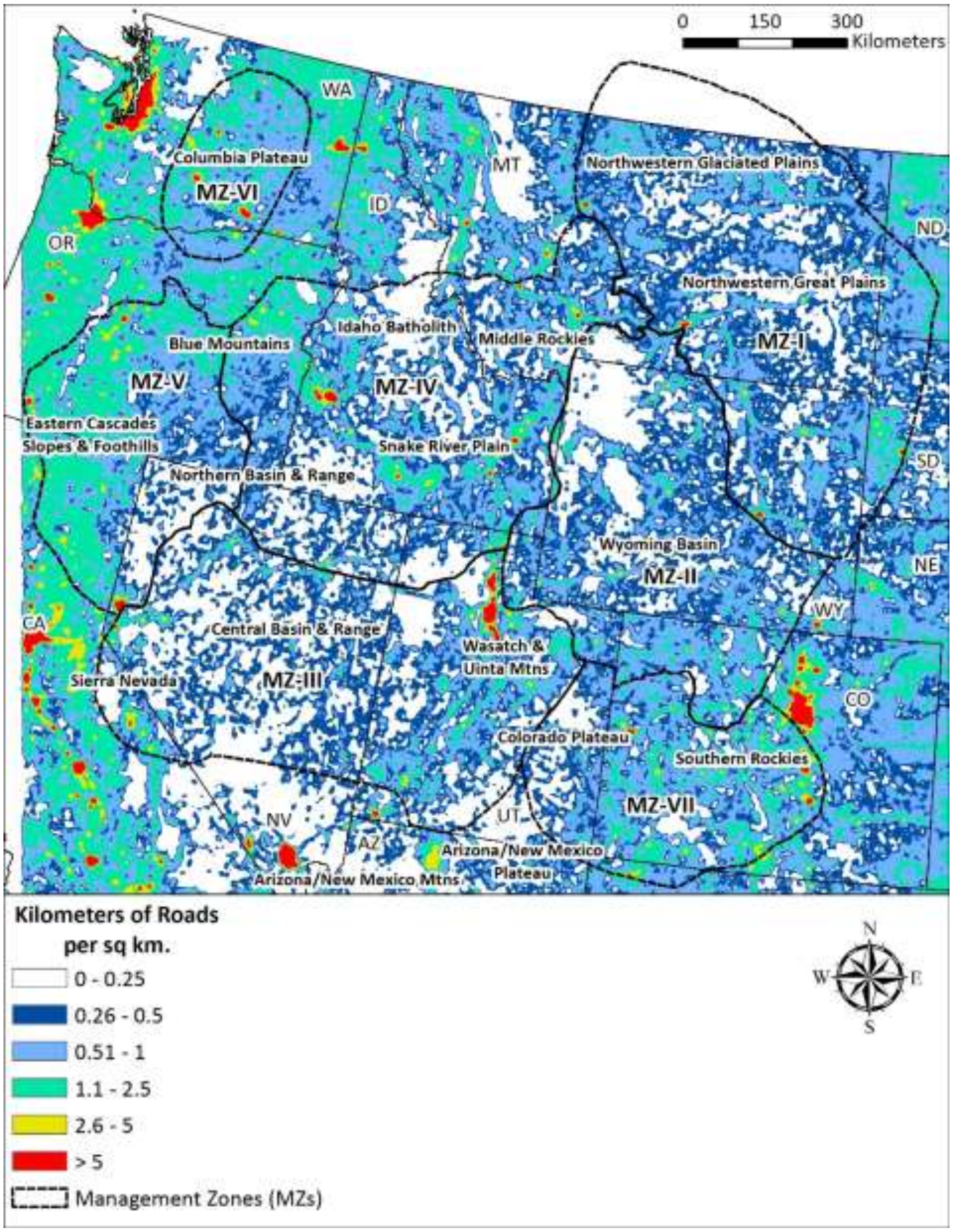


Figure 19. Density of all roads (surface roads, major roads, and interstate highways; ESRI Street Map Premium) in kilometers per square kilometer in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016).

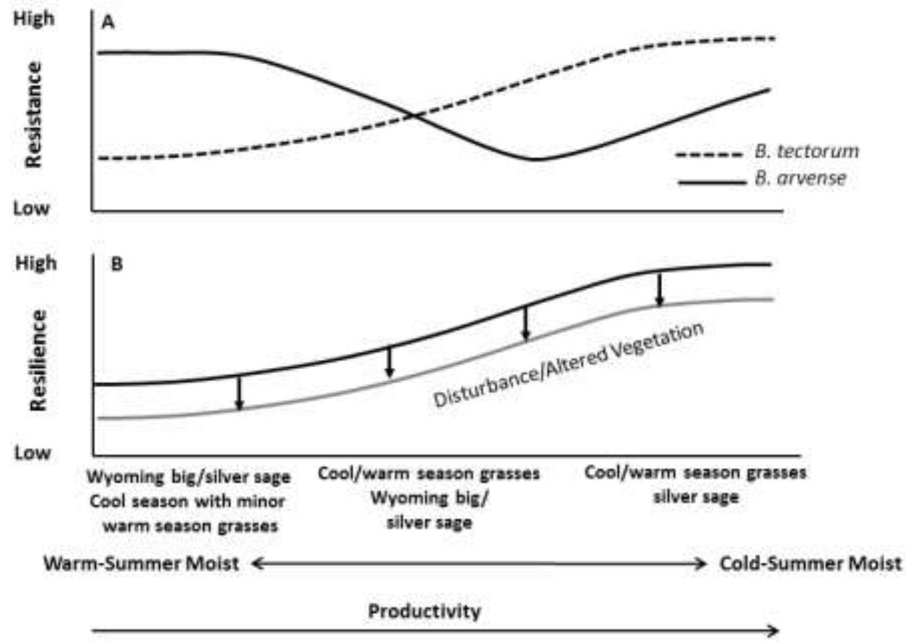


Figure 20. Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil moisture and temperature gradient in the West-Central Semiarid Prairies. Dominant ecological sites occur along a continuum from relatively warm and summer moist with Wyoming big sagebrush, 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 (modified from Brooks et al. 2016).

A

B

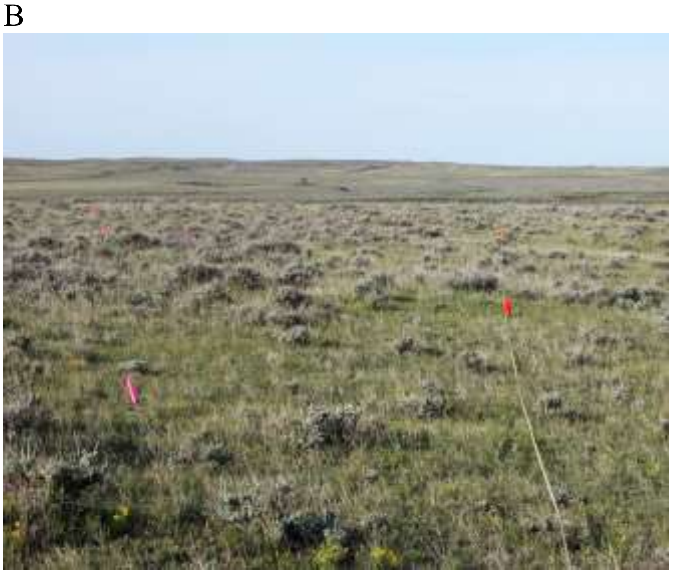


Figure 21. Representative sagebrush ecological types in the eastern portion of the range. (A) Cool and warm season grasses with silver sage characterized by high resilience and resistance. (B) Wyoming big and silver sage with cool and warm season grasses characterized by low resilience and resistance **(**Bureau of Land Management file photos).

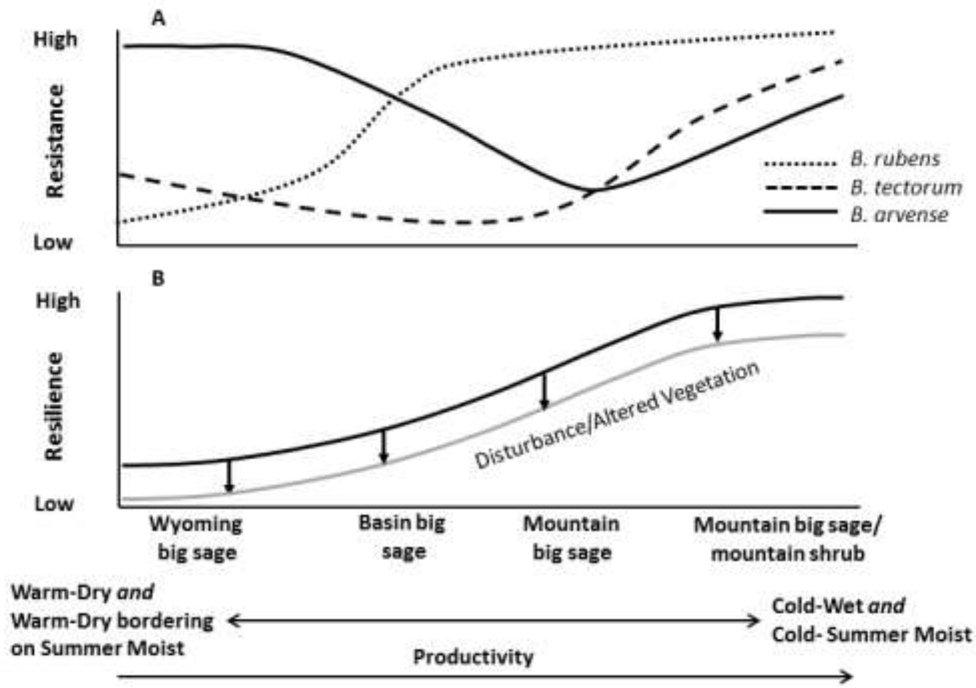


Figure 22. Resistance to invasive annual brome grasses (A) and resilience to disturbance (B) over a typical soil temperature and moisture gradient in the Cold Deserts. Dominant ecological sites occur along a continuum from relatively warm and dry to cold and wet conditions that includes salt desert shrub, Wyoming big sagebrush, basin big sagebrush, mountain big sagebrush, and mountain big sagebrush with root-sprouting shrubs. Resistance to annual brome grasses varies along the temperature and precipitation gradient as a function of their ecological amplitudes and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. Resilience also increases along the temperature and precipitation gradient and is influenced by site characteristics like soils and aspect (modified from Chambers et al. 2014a).

A

B

C

Figure 23. Representative sagebrush ecological types in the Cold Deserts. (A) Mountain big sagebrush/mountain brush type with relatively cold and moist soils characterized by high resilience and resistance, (B) mountain big sagebrush type with cool and moist soils and moderate resilience and resistance, and (C) Wyoming big sagebrush type with warm and dry soils and low resilience and resistance (photos by Jeanne C. Chambers).

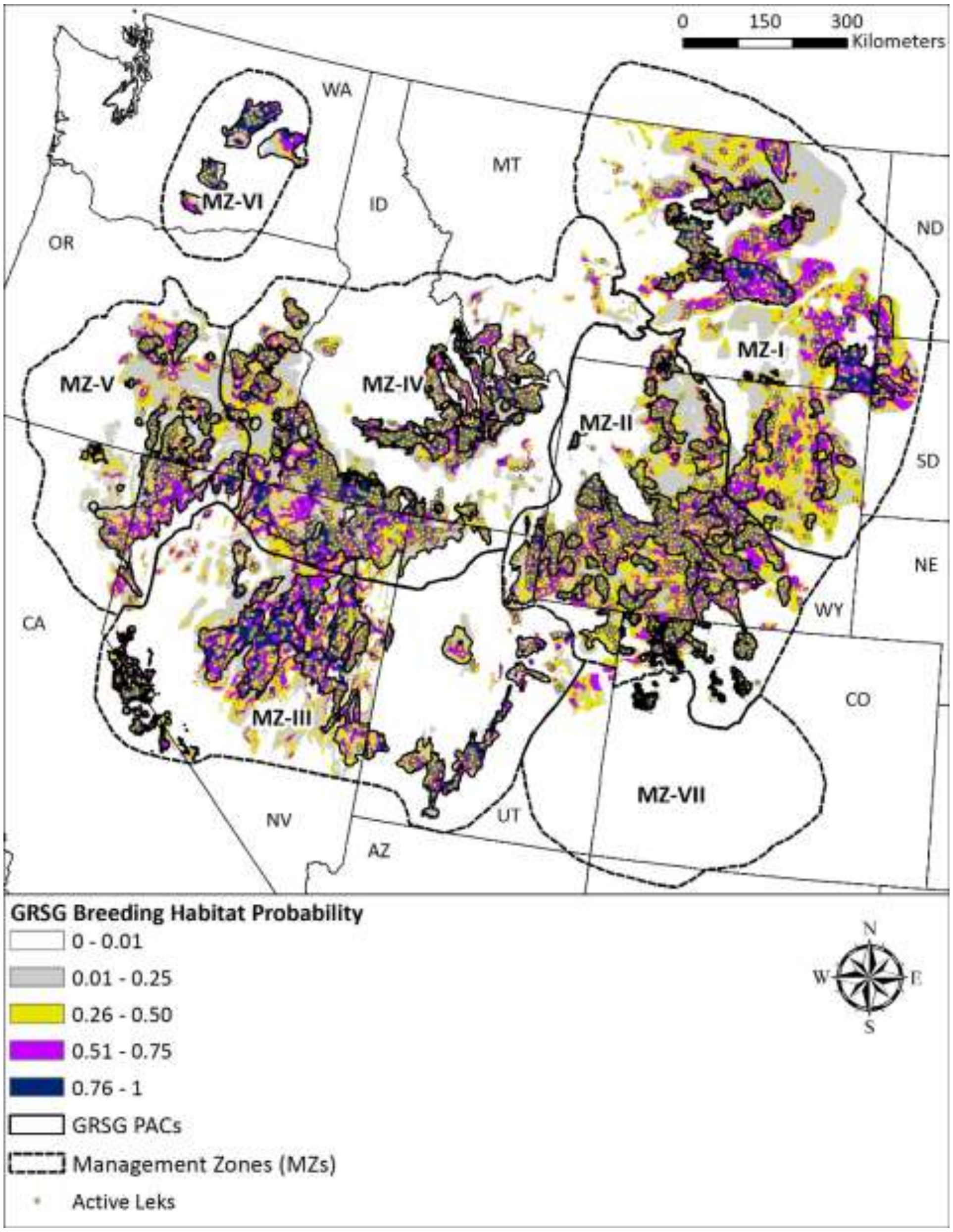


Figure 24. GRSG breeding habitat probabilities based on 2010 to 2014 lek data (Doherty et al. *in press*) in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Priority Areas for Conservation (PACs; USFWS 2013) and active leks are overlaid.

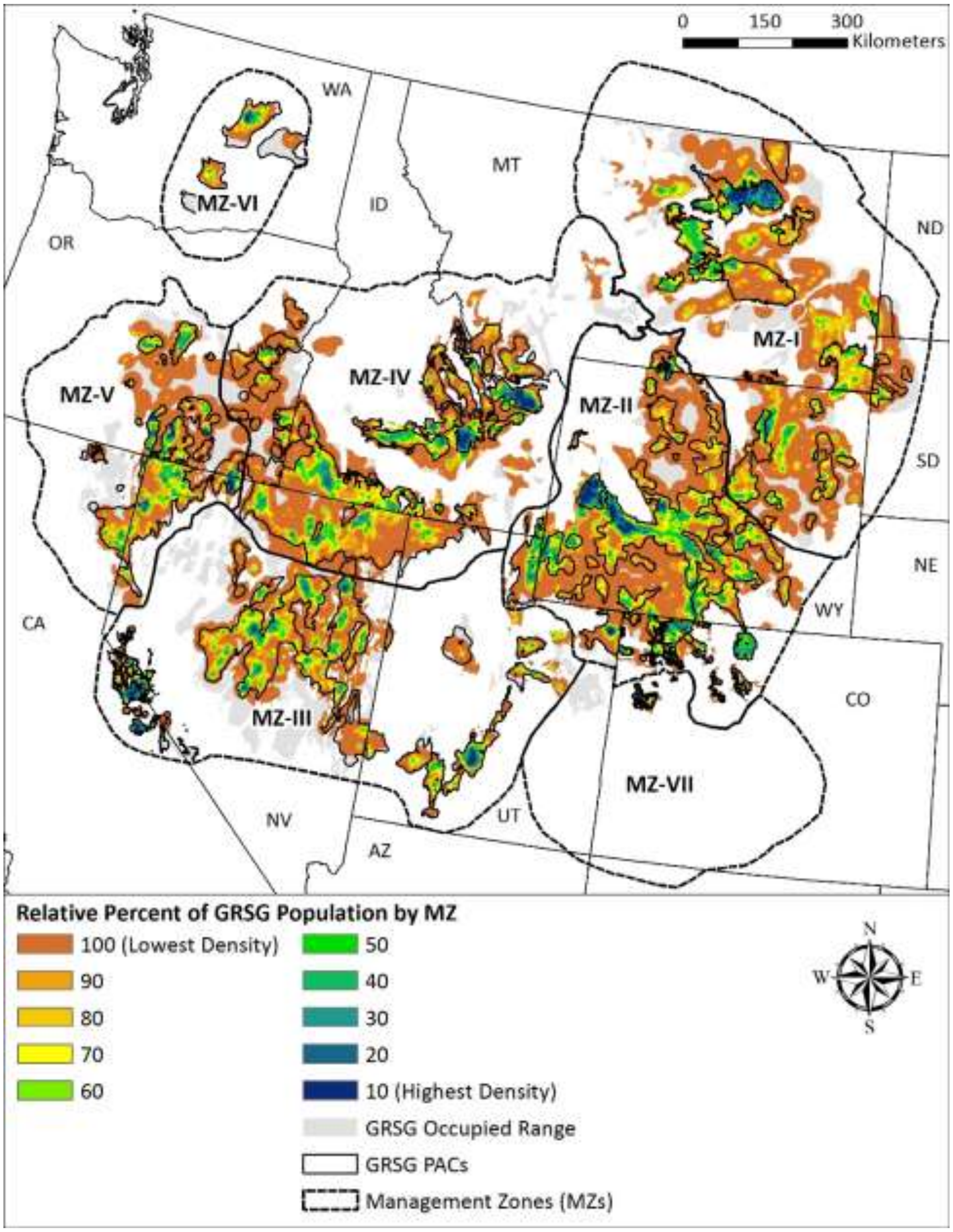


Figure 25. Relative percentage of the GRSG population based on breeding bird abundance during 2010-2014 (Doherty et al. *in press)* in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Priority Areas for Conservation (PACs; USFWS 2013) are overlaid. Population index values were calculated separately for each management zone. Sage-grouse population index areas represent spatial locations of the known breeding population in 10% bins differentiated by color. The darkest blue areas contain 10% of the breeding population. Because bins are additive, blue and green colored areas combined capture 60% of the population, etc.

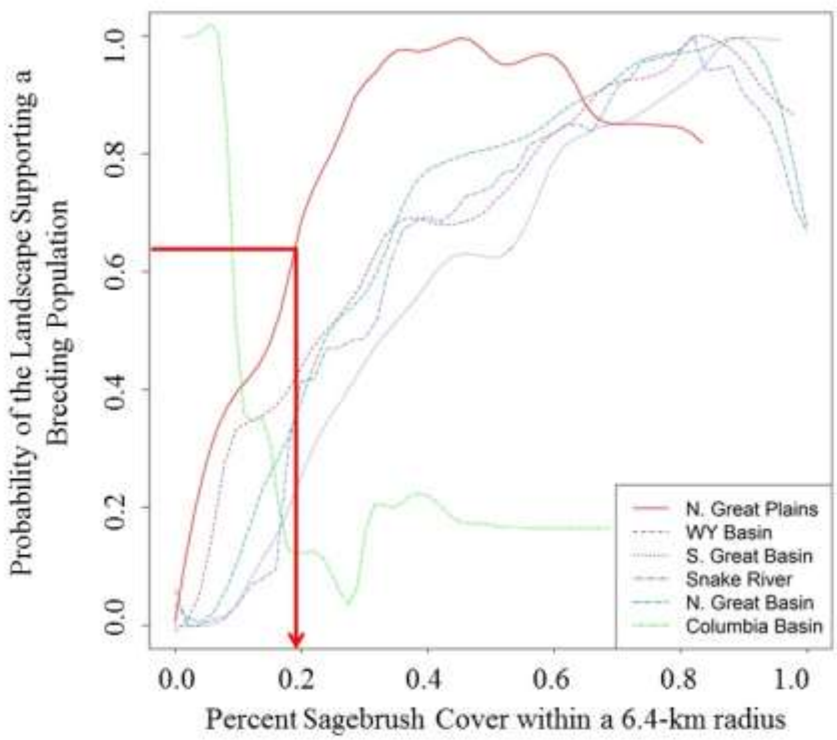


Figure 26. Partial probability plot depicting the effect of landscape cover of sagebrush on the probability of a landscape supporting a breeding population of GRSG (modified from Doherty et al. *in press*). The red line shows the minimum level of sagebrush landscape cover needed to support a breeding population of GRSG based on a 4 mi (6.4 km) radius. Landscape cover of sagebrush was derived from LANDFIRE (USGS 2014).

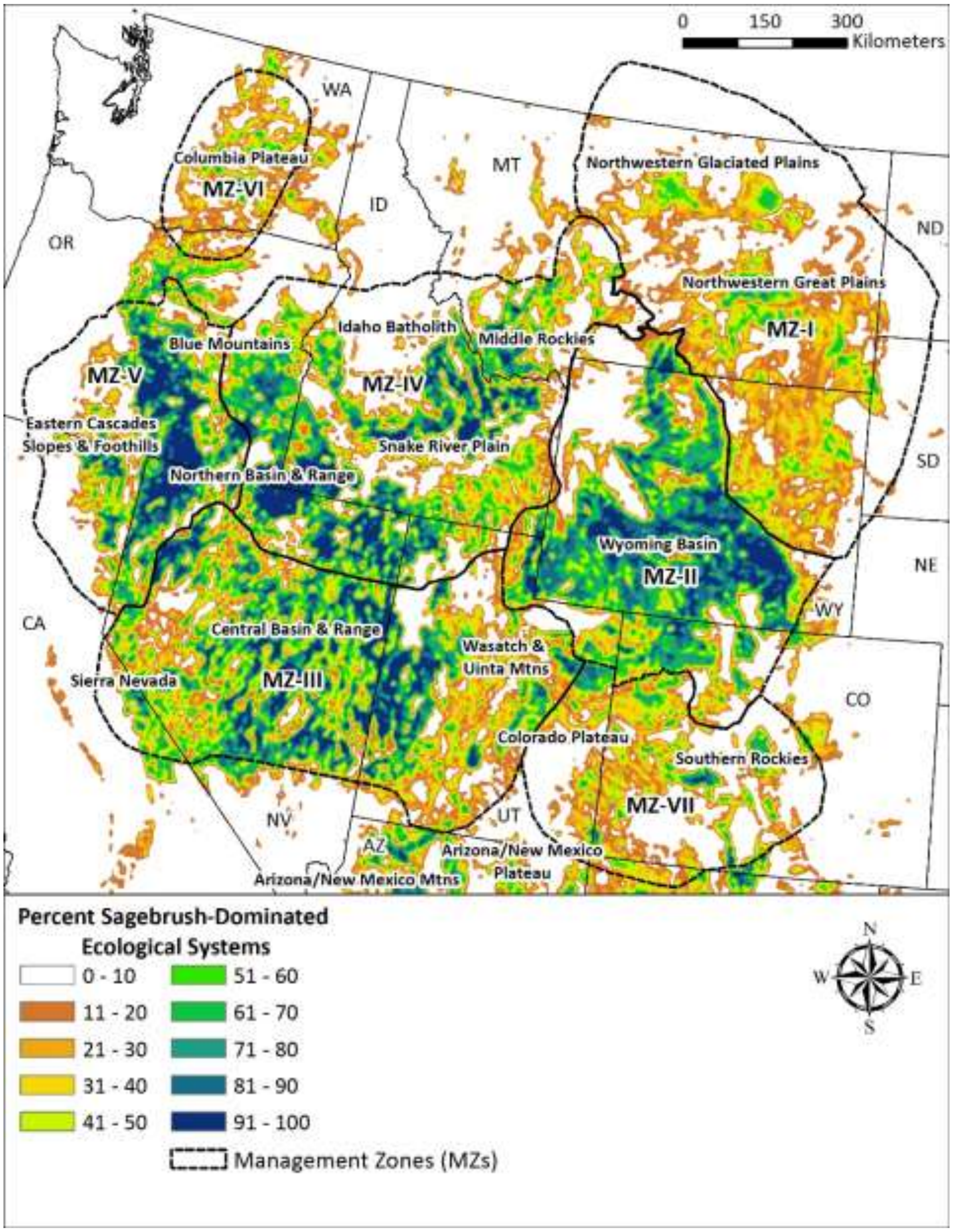


Figure 27. The landscape cover of sagebrush-dominated ecological systems (USGS 2014) displayed in 10% increments for the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Percentage of sagebrush within each of the categories was determined within 3.1 mi (5 km) radius of each sagebrush pixel.

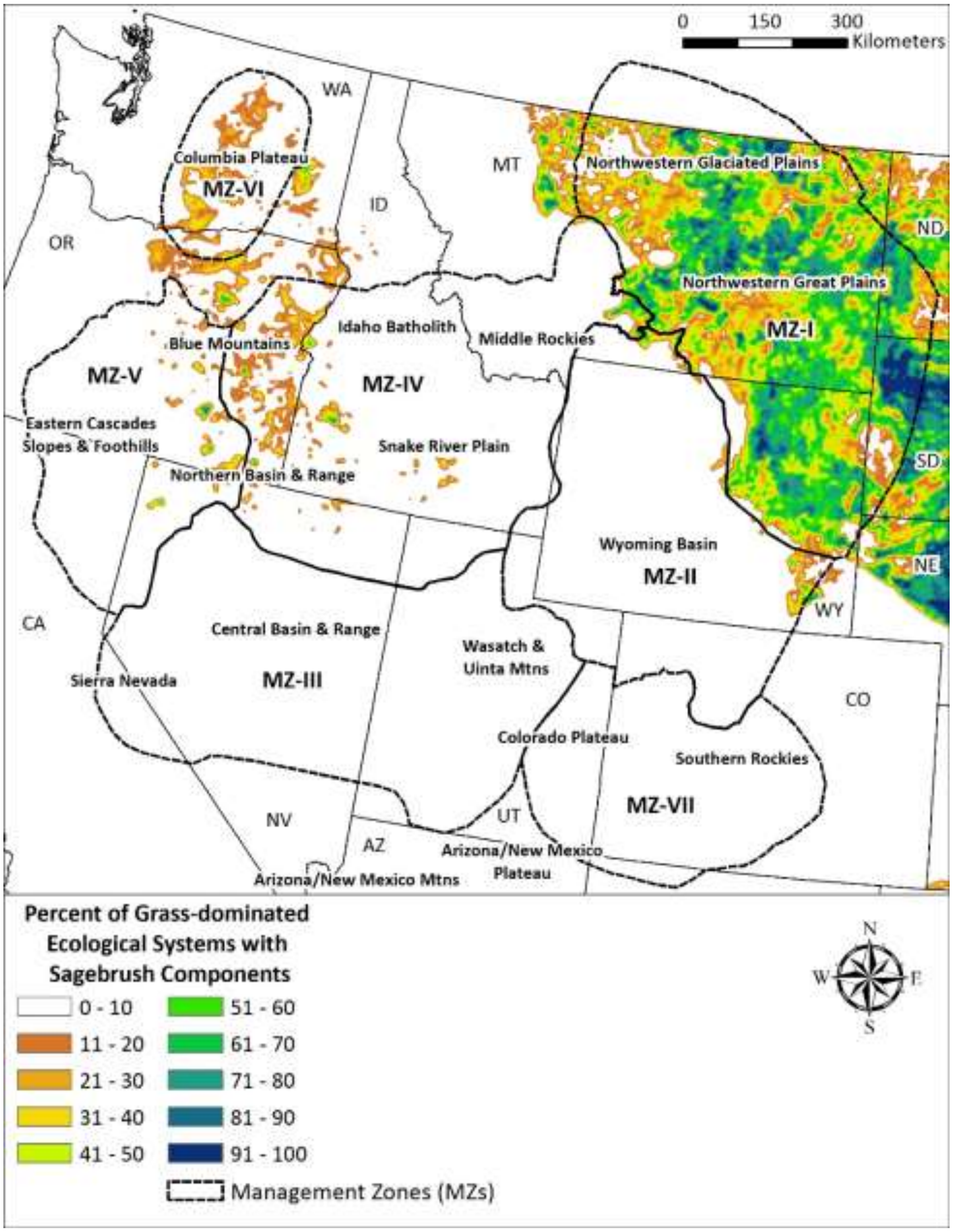


Figure 28. The landscape cover of grass-dominated ecological systems with grass components (USGS 2014) displayed in 10% increments for the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Percentage of sagebrush within each of the categories was determined within 3.1 mi (5 km) radius of each sagebrush pixel.

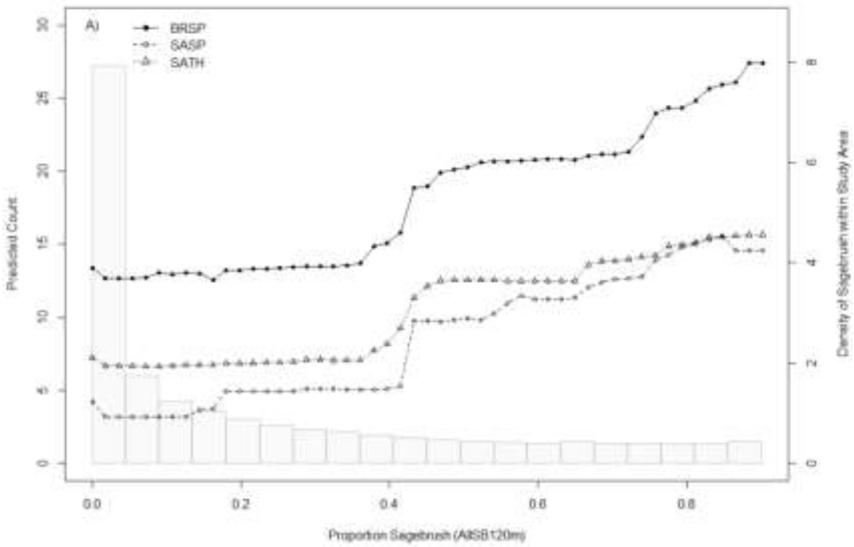


Figure 29. Partial dependence plot showing the predicted relationships among the proportion of sagebrush within a 120-m buffer and counts of Brewer's sparrow (BRSP), sagebrush sparrow (SASP), and sage thrasher (SATH) (Donnelly et al. *in press*). There is an apparent threshold value of 40% landscape 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).

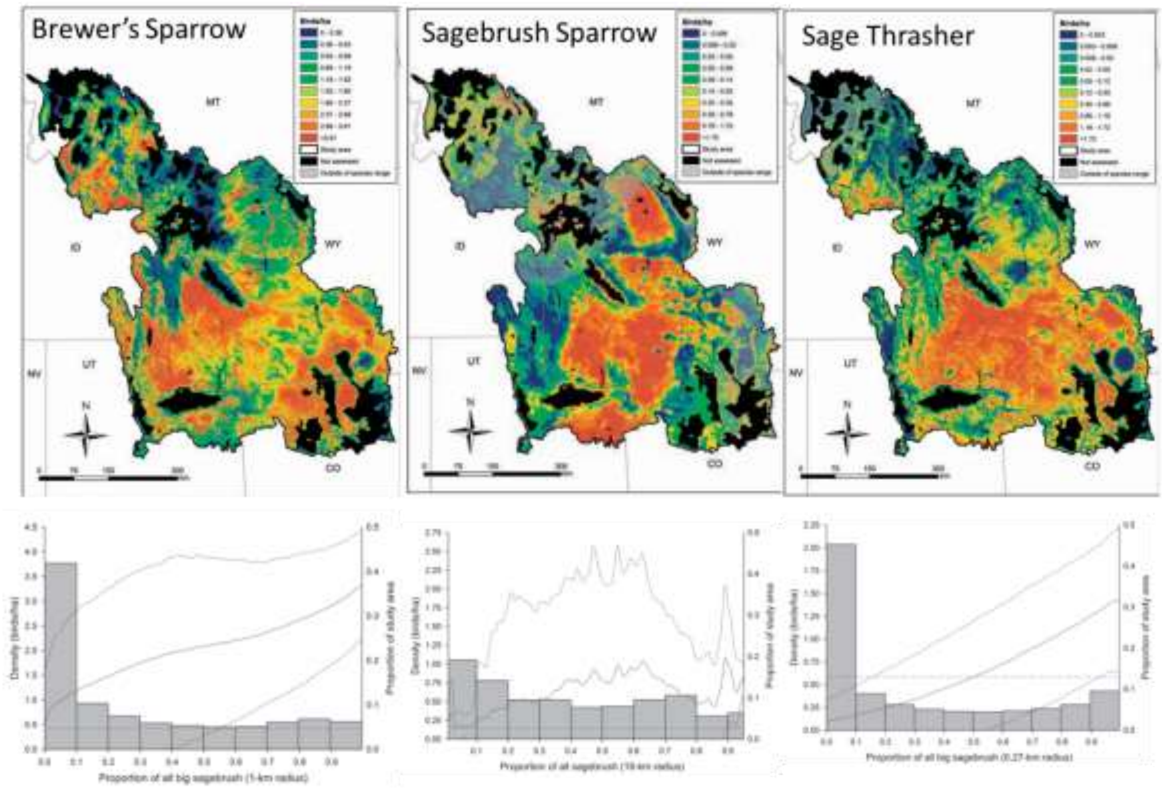


Figure 30. Model output depicting relative bird density for three sagebrush obligate passerine species (Brewer's Sparrow, Sagebrush Sparrow, and Sage Thrasher) in the Wyoming Basins Ecoregional Assessment area (Aldridge et al 2011). Relationship between bird density and landscape cover of sagebrush for each species and the availability of sagebrush in the landscape are shown in the graphs below the map for each species.

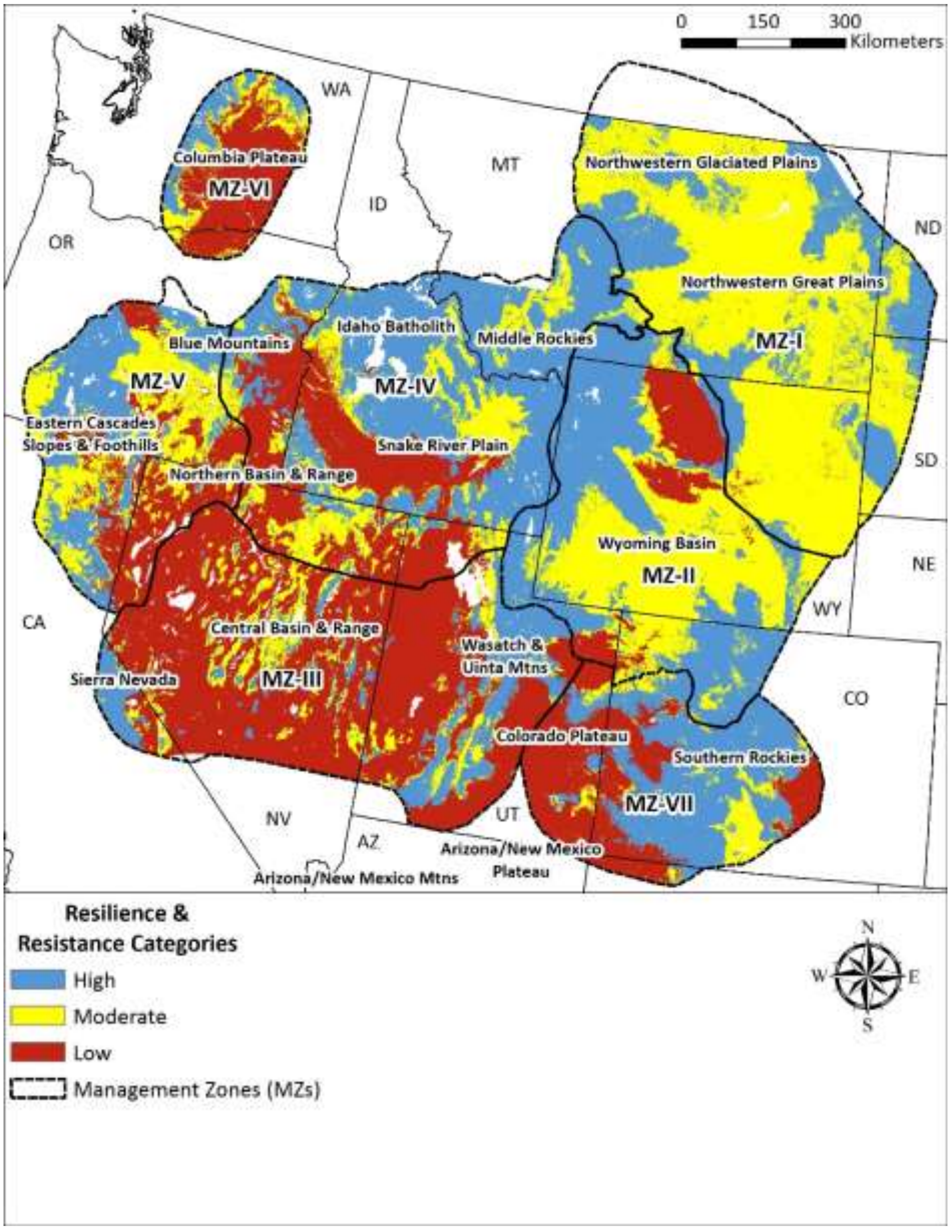


Figure 31. The soil temperature and moisture regimes categorized according to high, moderate and low resilience and resistance in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). The soil temperature and moisture regime data used in this report 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 6.

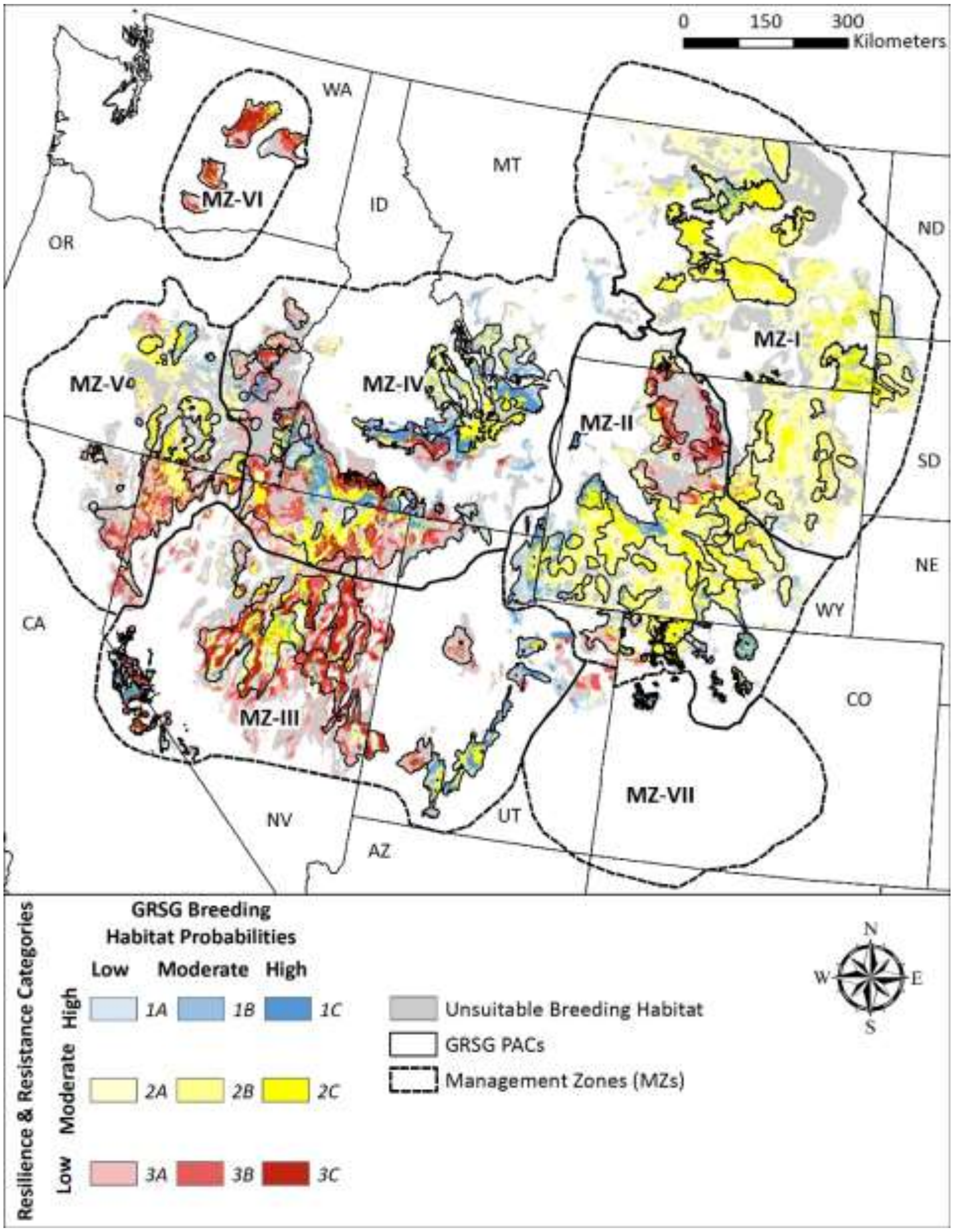


Figure 32. GRSG breeding habitat probabilities based on 2010 to 2014 lek data (Doherty et al. *in press*) intersected with resilience and resistance categories developed from soil temperature and moisture regimes in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Priority Areas for Conservations (PACs; USFWS 2013) are overlaid.

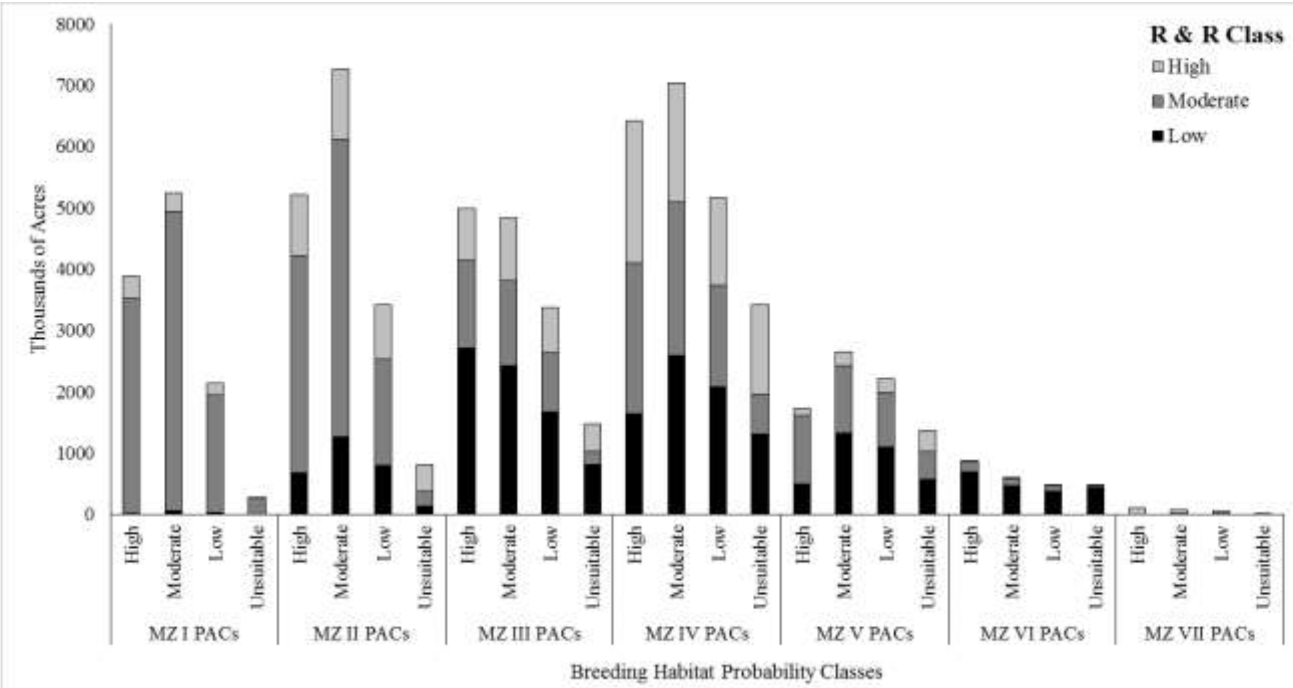
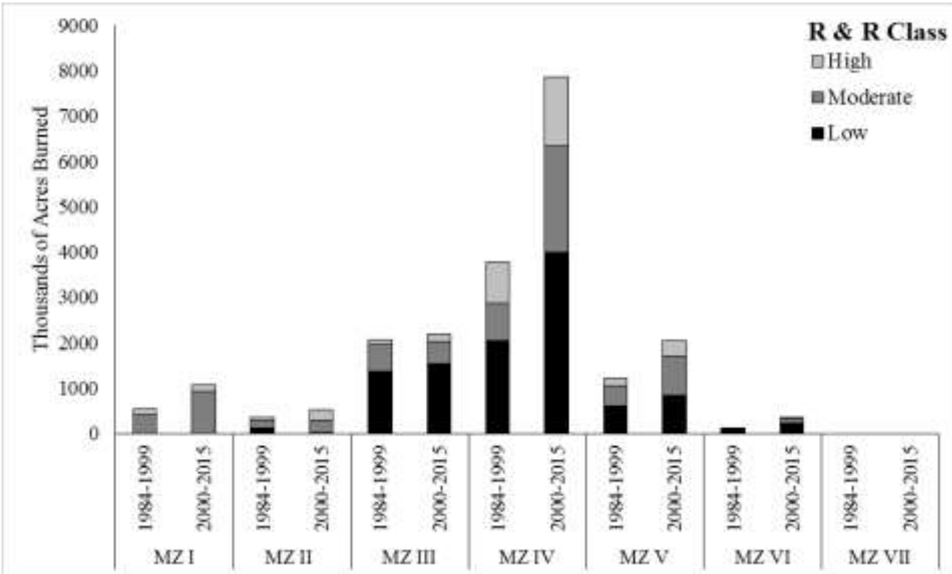


Figure 33. Breeding habitat probabilities by resilience and resistance category in thousands of acres for Priority Areas of Conservation (PACs; USFWS 2013) within the MZs (Stiver et al. 2006). GRSG breeding habitat probabilities were based on 2010–2014 lek data (Doherty et al. *in press*). The resilience and resistance categories are explained in Appendix 2.

A



B

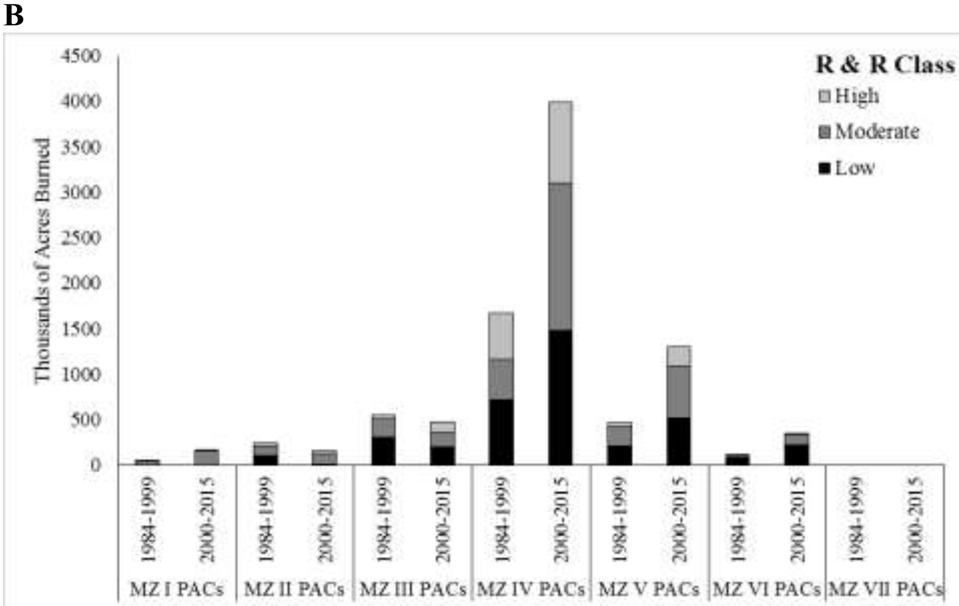


Figure 34. Thousands of acres burned by resilience and resistance class (A) within the occupied range and (B) within Priority Areas of Conservation (PACS; USFWS 2013) for each MZ (Stiver et al. 2006). Data are for fires > 1000 acres (MTBS 2014). The resilience and resistance categories are explained in Appendix 2.

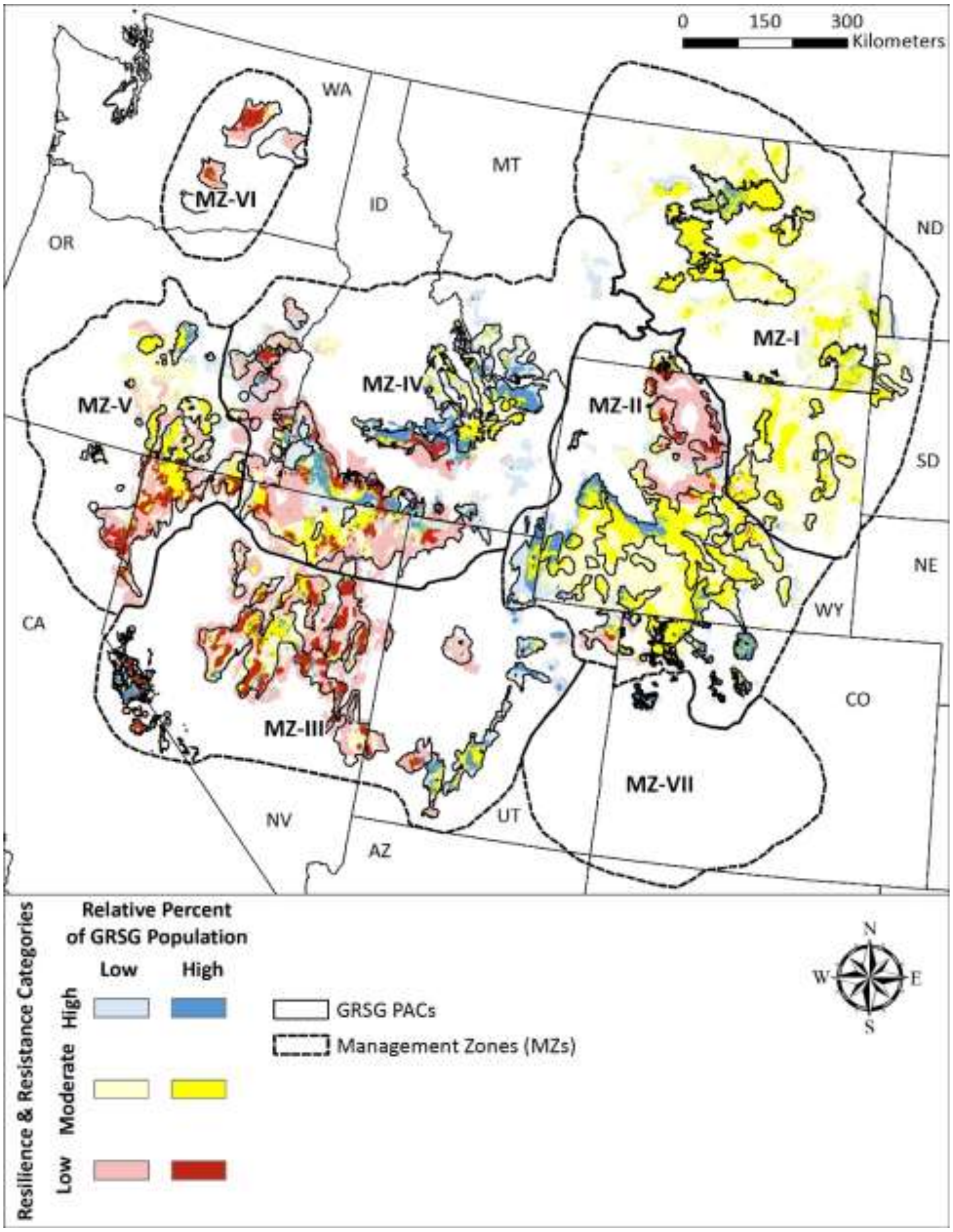


Figure 35. Relative percent of GRSG population based on breeding abundance during 2010 to 2014 (Doherty et al. *in press*) intersected with resilience and resistance categories developed from soil temperature and moisture regimes in the sage-grouse management zones (MZs; Stiver et al. 2006) and associated Level III ecoregions (EPA 2016). Priority Areas for Conservations (PACs; USFWS 2013) are overlaid. A threshold value of 80% is used to identify high breeding concentration centers.

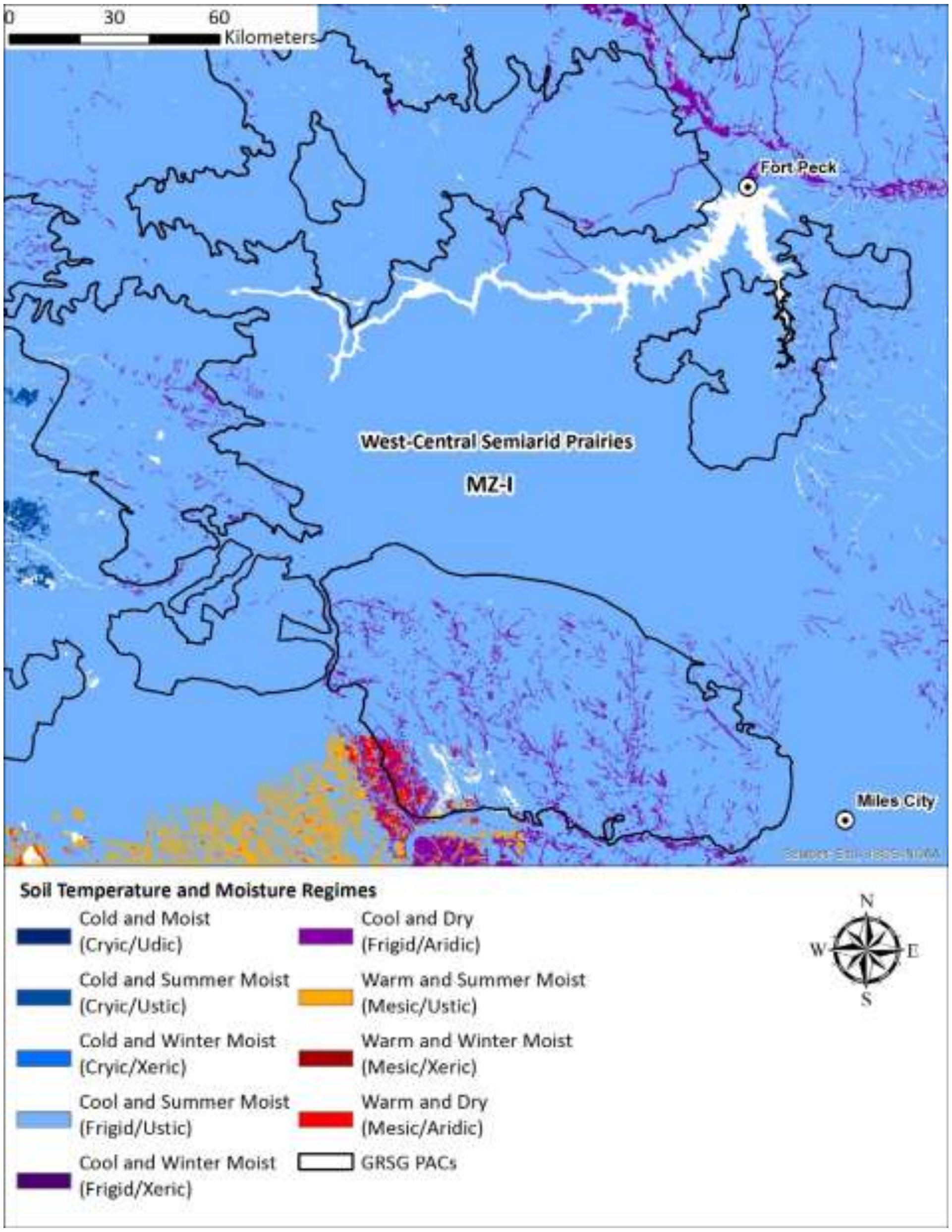


Figure 36. Soil temperature and moisture regimes by soil moisture subclass for an area in eastern Montana with Priority Areas for Conservations (PACs; USFWS 2013) overlaid. The soil temperature and moisture regime data used in this report are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 6.

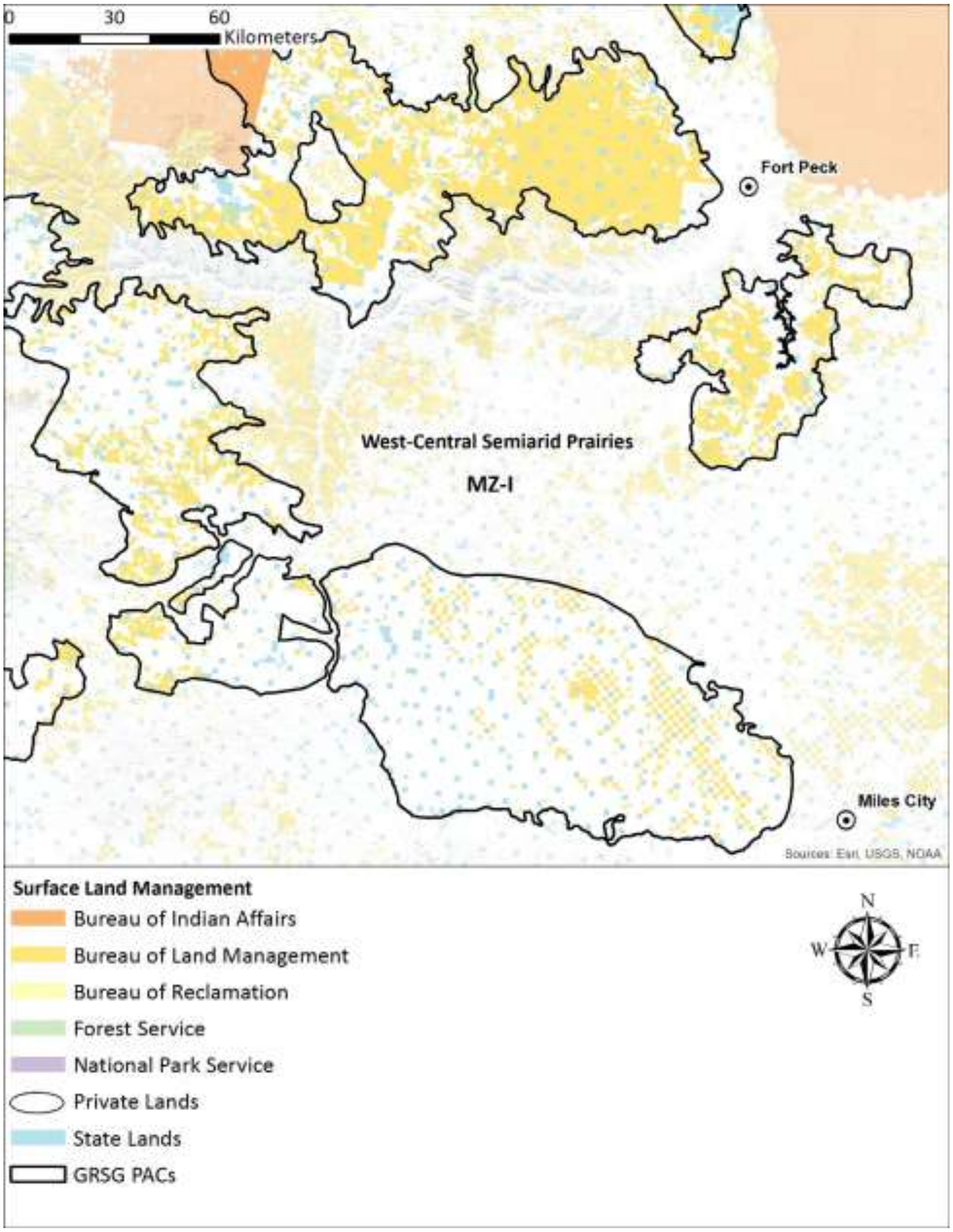


Figure 37. Surface land management for an area with agricultural conversion in eastern Montana (see Appendix 6 for data sources). Colors outside of GRSG Priority Areas for Conservation (PACs; USFWS 2013) are semi-transparent.

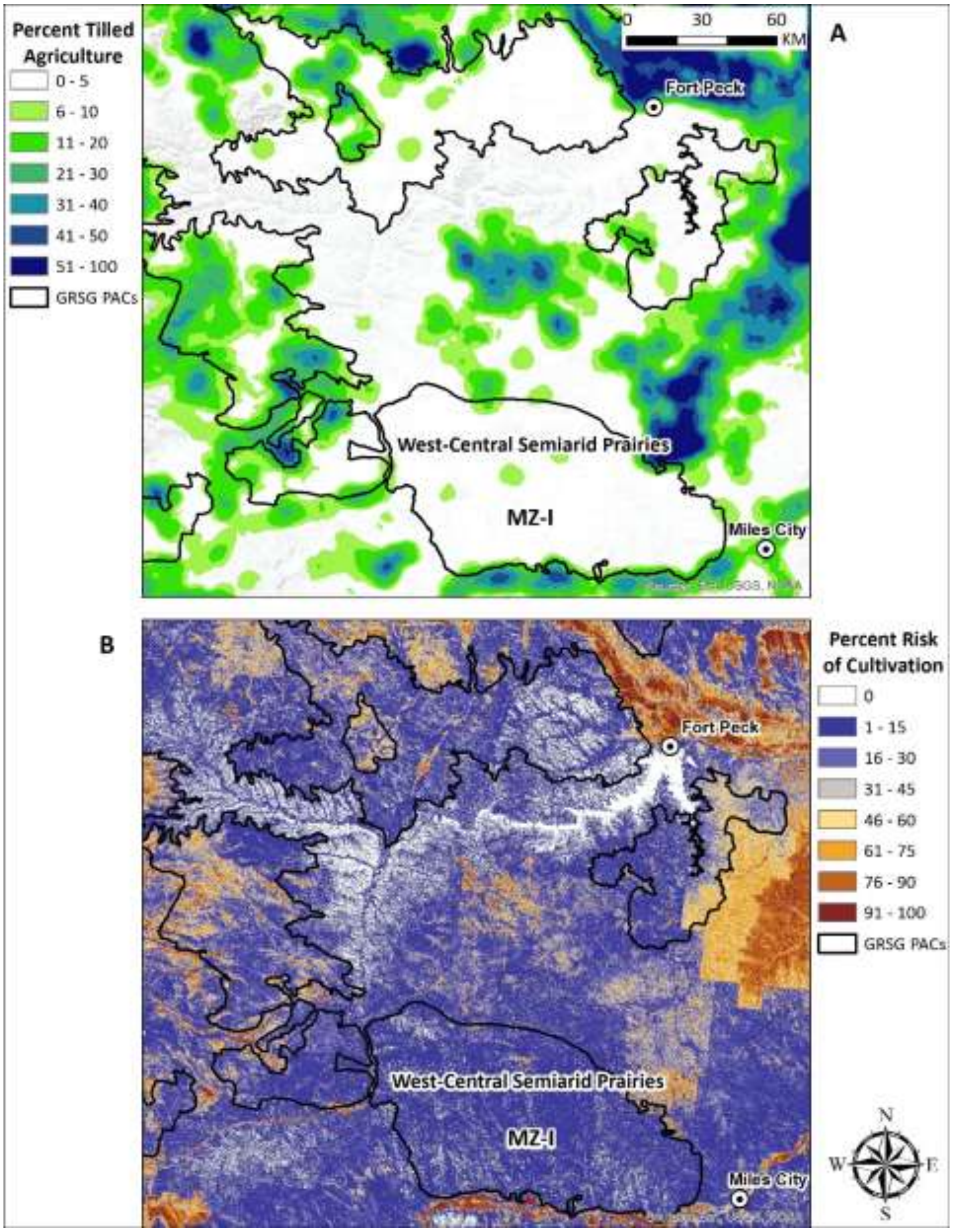


Figure 38. (A) Percent annually tilled agricultural land (NASS 2014) within 5.0 km of each pixel for an area in eastern Montana. (B) Percent risk of cultivation for the same area derived from the Sage-Grouse Initiative (SGI) cultivation risk mapping tool (http://map.sagegrouseinitiative.com/) which is based on climate, soils, and topography. Priority Areas for Conservations (PACs; USFWS 2013) are overlaid.

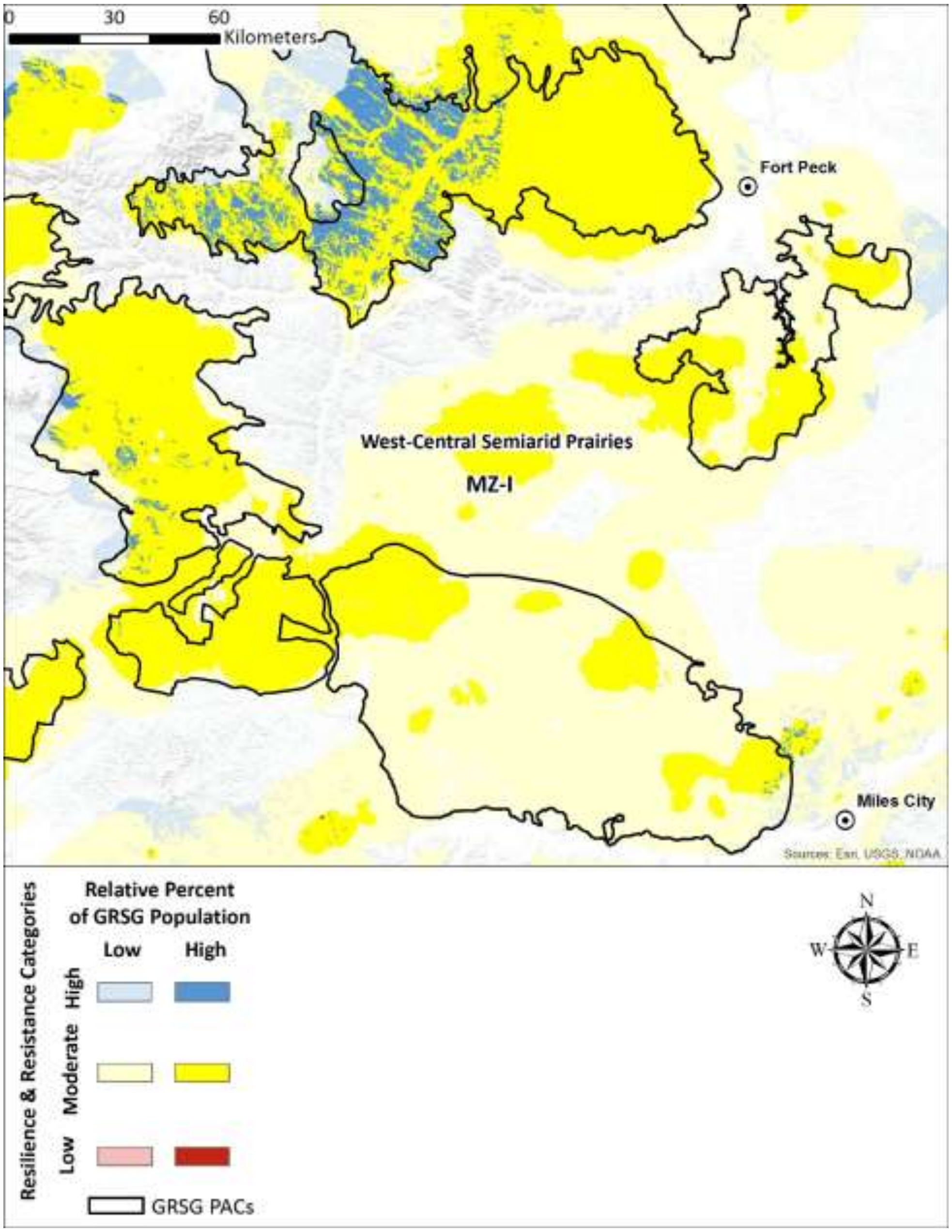


Figure 39. Relative percent of GRSG population based on breeding abundance during 2010 to 2014 (Doherty et al. *in press*) intersected with resilience and resistance categories developed from soil temperature and moisture regimes for an area in eastern Montana. Priority Areas for Conservations (PACs; USFWS 2013) are overlaid. A threshold value of 80% is used to identify high breeding concentration centers.

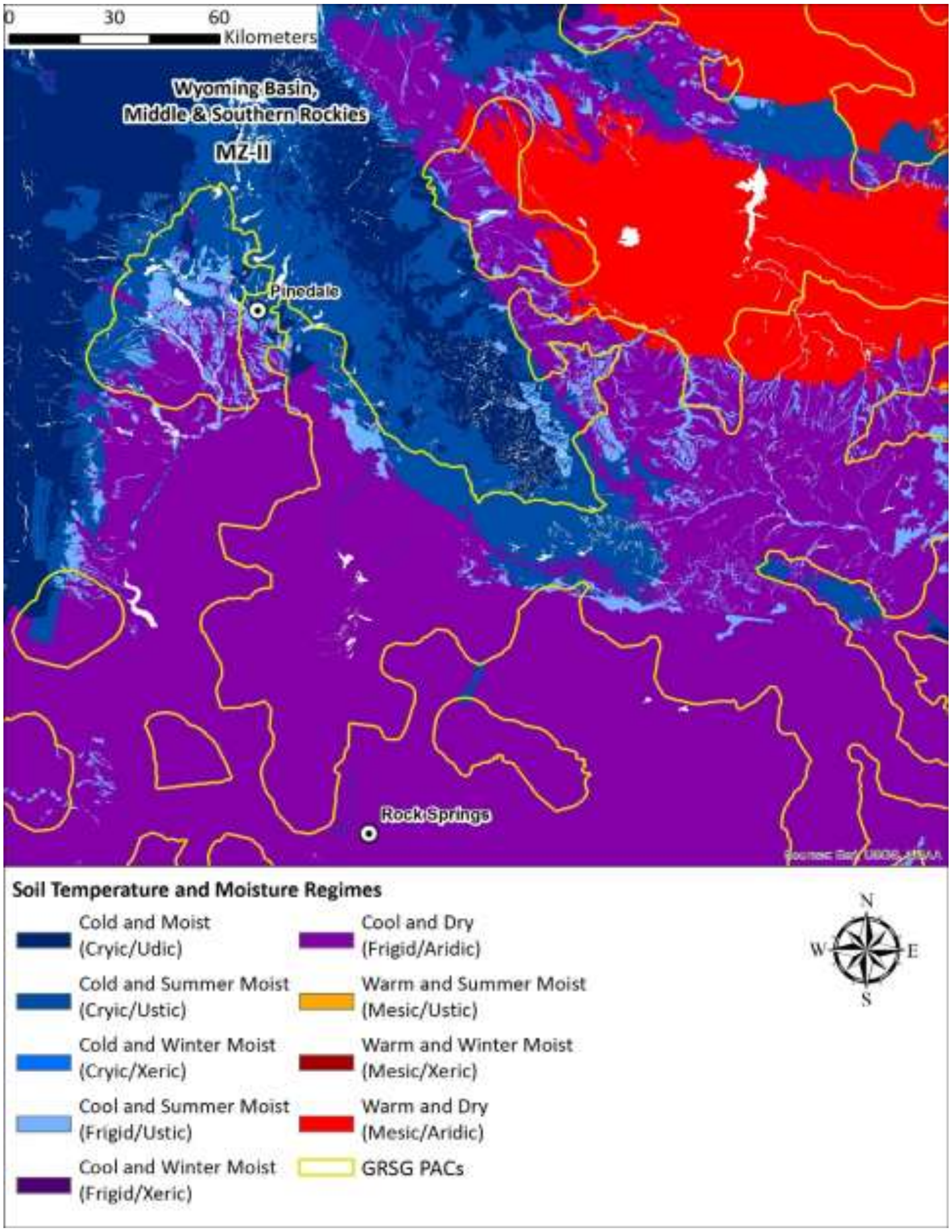


Figure 40. Soil temperature and moisture regimes by soil moisture subclass for an area in southwest Wyoming with oil and gas development with Priority Areas for Conservations (PACs; USFWS 2013) overlaid. The soil temperature and moisture regime data used in this report are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 6.

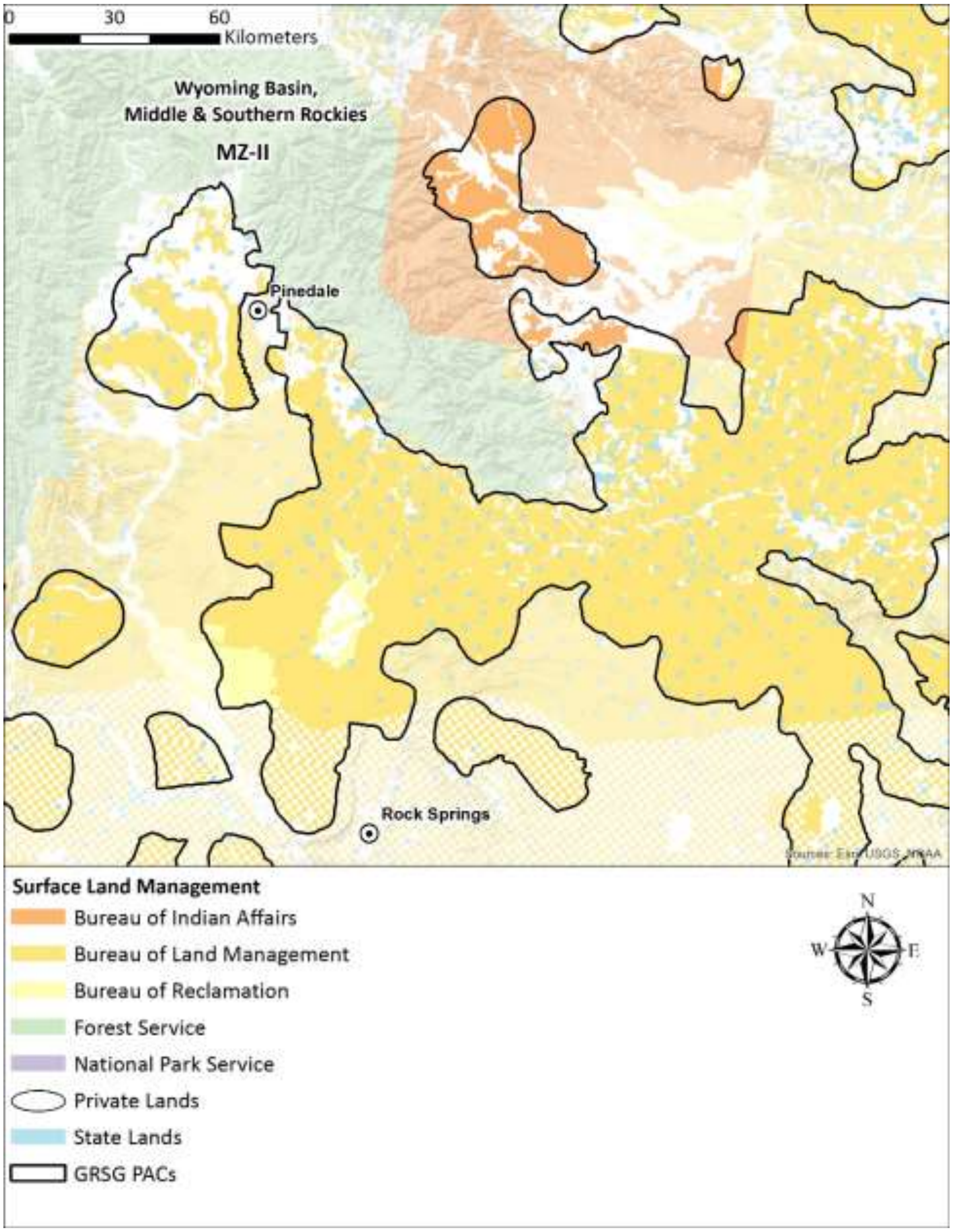


Figure 41. Surface land management for an area with oil and gas development in southwest Wyoming (see Appendix 6 for data sources). Colors outside of GRSG Priority Areas for Conservation (PACs; USFWS 2013) are semi-transparent.

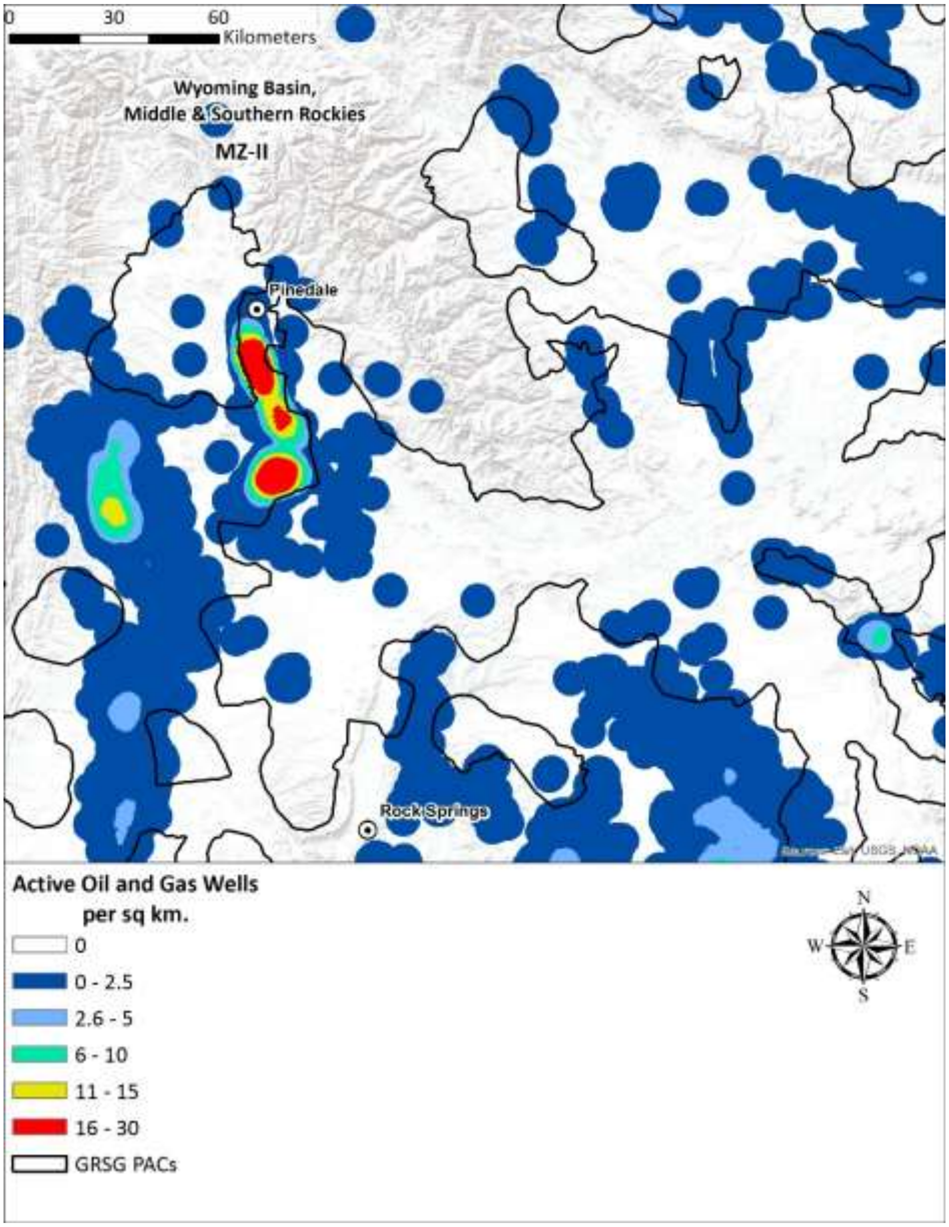


Figure 42. Number of active oil and gas wells per square kilometer (IHS; BLM [AFMSS]) for an area in southwest Wyoming with Priority Areas for Conservations (PACs; USFWS 2013) overlaid.

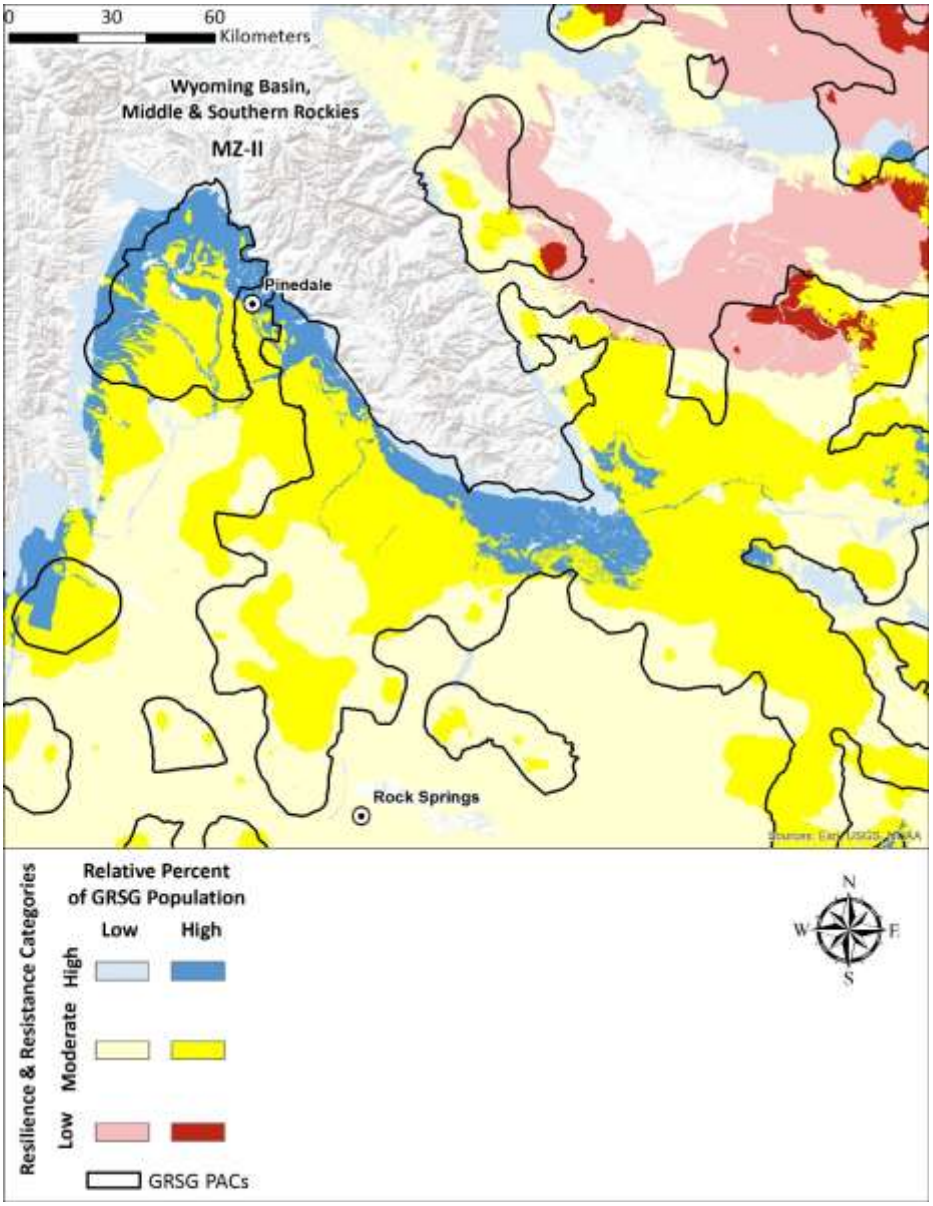


Figure 43. Relative percent of GRSG population based on breeding abundance during 2010 to 2014 (Doherty et al. *in press*) intersected with resilience and resistance categories developed from soil temperature and moisture regimes for an area in southwest Montana. Priority Areas for Conservations (PACs; USFWS 2013) are overlaid. A threshold value of 80% is used to identify high breeding concentration centers.

Figure 44. A conservation easement near Pinedale, Wyoming. Photo by Jeremy Roberts.

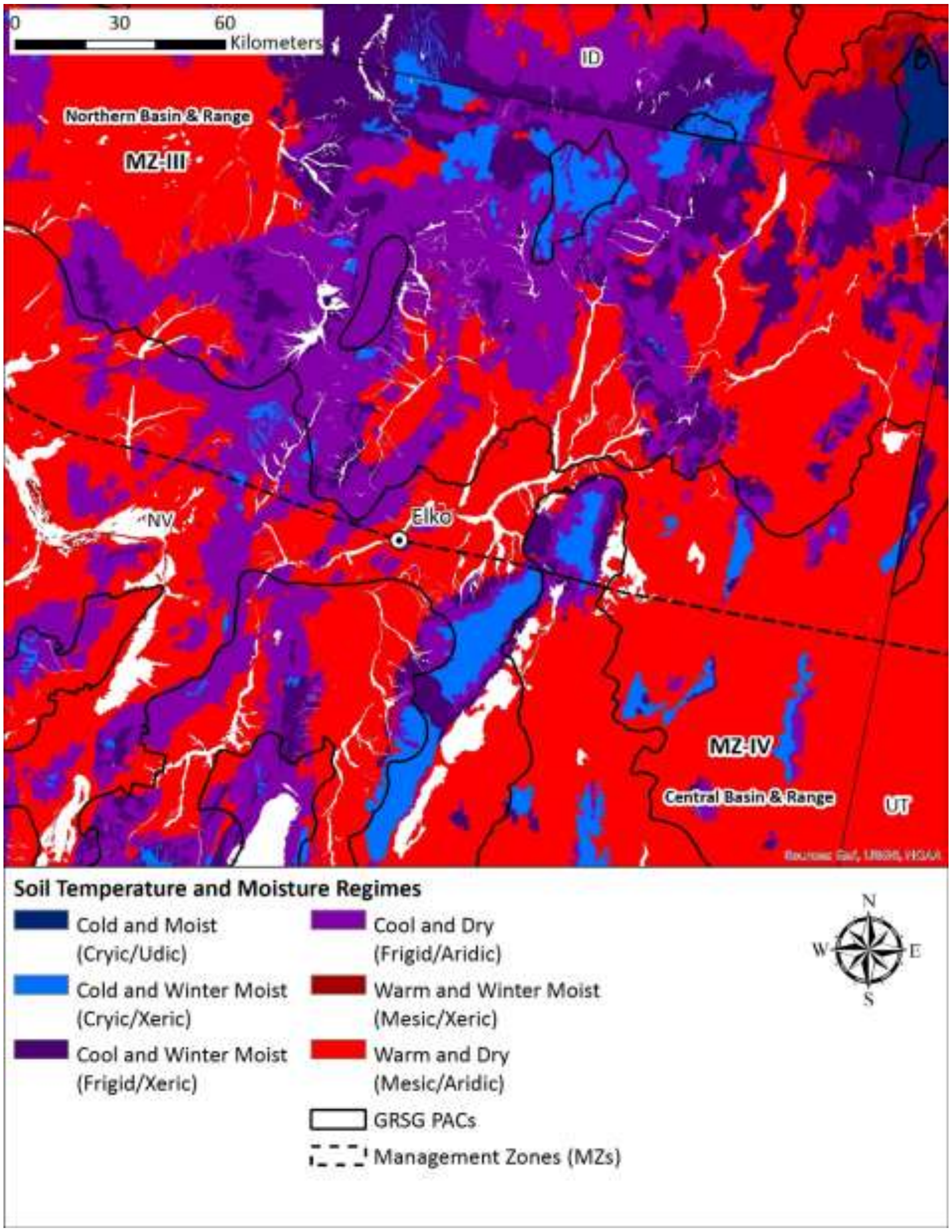


Figure 45. Soil temperature and moisture regimes by soil moisture subclass for an area in northeast Nevada with cheatgrass invasion and conifer expansion. Priority Areas for Conservations (PACs; USFWS 2013) are overlaid. The soil temperature and moisture regime data used in this report are explained in Appendix 2. The relationships of the soil temperature and moisture regimes to the predominant ecological types are in table 6.

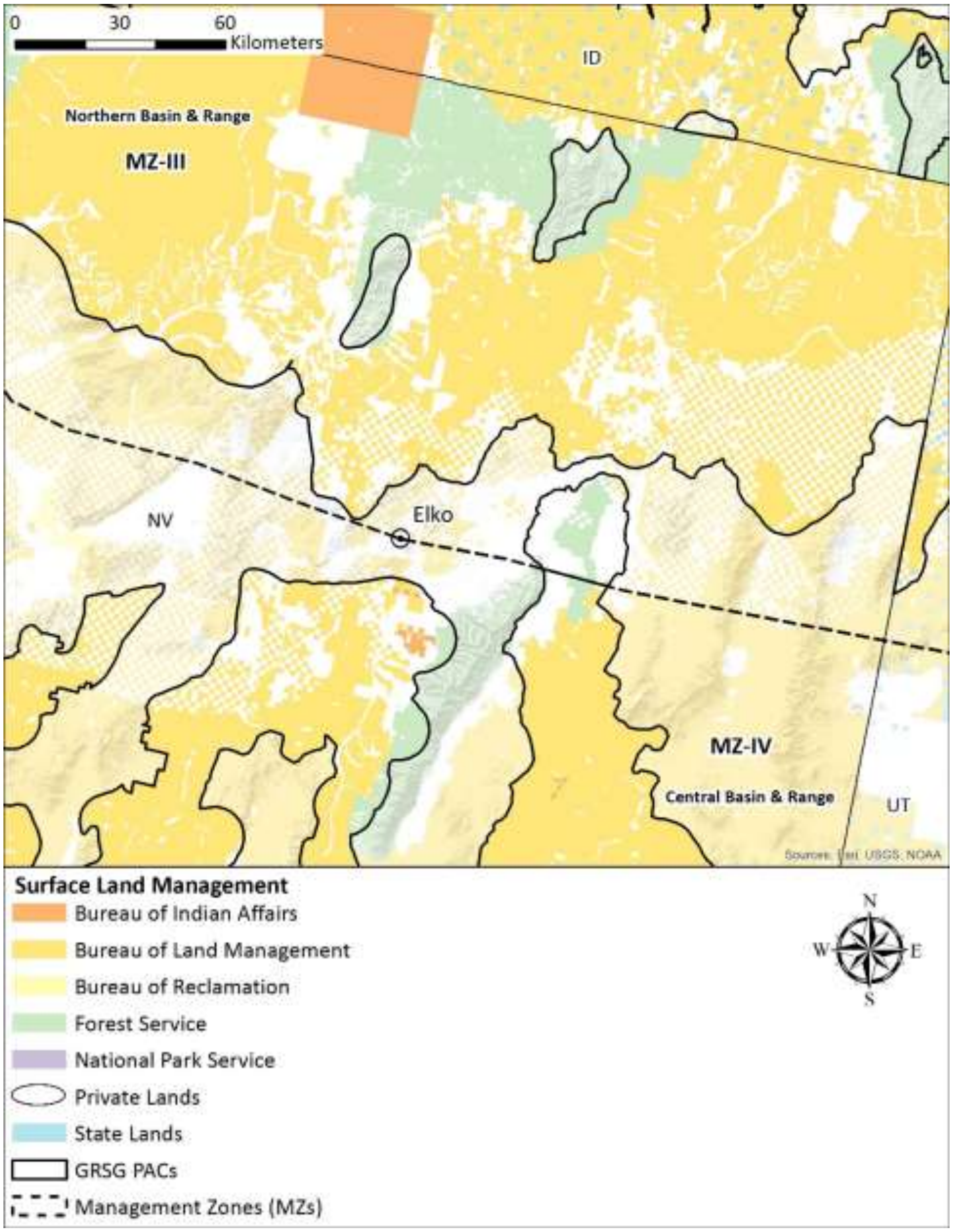


Figure 46. Surface land management for an area with cheatgrass invasion and conifer expansion in northeast Nevada (see Appendix 6 for data sources). Colors outside of GRSG Priority Areas for Conservation (PACs; USFWS 2013) are semi-transparent.

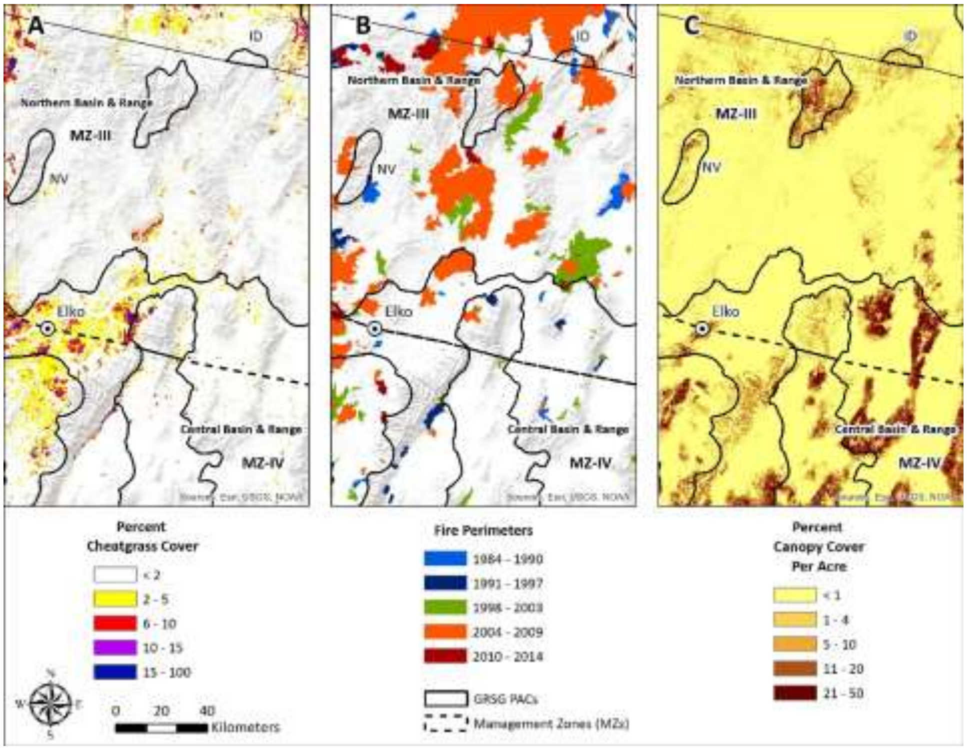


Figure 47. (A) Near-real-time percent of cheatgrass cover in northeast Nevada in 2015 at a 250 meter resolution (Boyte et al. 2015) (B) Perimeters of fires that occurred from 1984 to 2014 in an area in northeast Nevada. Data for fires > 1000 acres are from MTBS (2014) and data for fires < 1000 acres are from GeoMAC (2015). (C) Estimate of tree canopy cover per acre in northeast Nevada at a 30 meter resolution (Falkowski et al. *in press*). Priority Areas for Conservations (PACs; USFWS 2013) are overlaid.

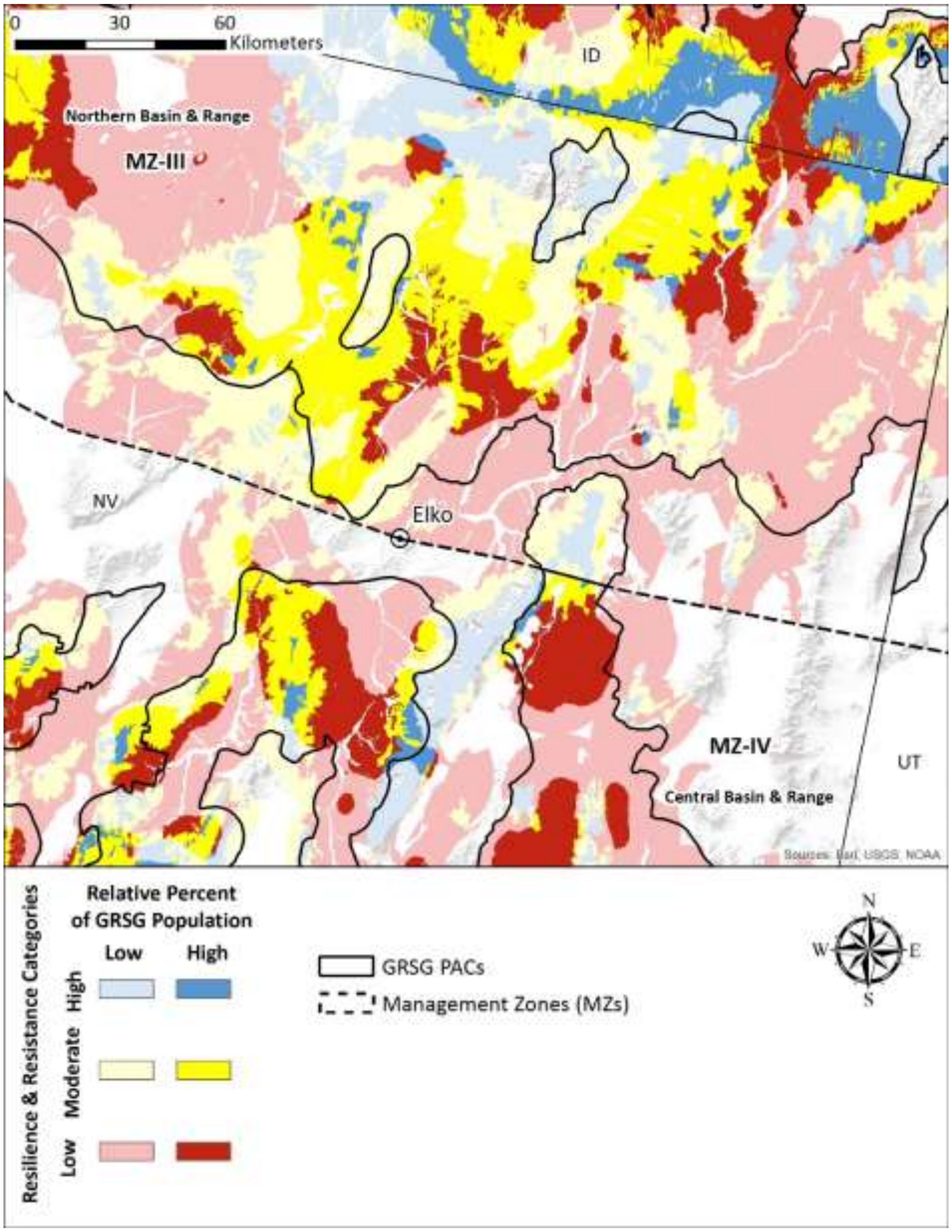


Figure 48. Relative percent of GRSG population based on breeding abundance during 2010 to 2014 (Doherty et al. *in press*) intersected with resilience and resistance categories developed from soil temperature and moisture regimes for an area in northeast Nevada. Priority Areas for Conservations (PACs; USFWS 2013) are overlaid. A threshold value of 80% is used to identify high breeding concentration centers.

Appendix 1. Definitions of Terms Used in This Document

At-Risk Community Phase — A community phase that can be designated within the reference state and also in alternative states. This community phase is the most vulnerable to transition to an alternative state (Caudle et al. 2013).

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

Ecological Site (ES) — An Ecological Site (ES) is 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).

Focal Species — Focal species include sagebrush obligate, near-obligate, dependent, or associated species identified as (1) at-risk, (2) influencing management actions and regional economies, (3) potentially being negatively influenced by management actions, and/or (4) serving as indicators of habitat quality or habitat niches such as riparian areas in sagebrush ecosystems.

Improper Livestock Grazing — Grazing that impedes progress toward or maintenance of ecological processes and the desired plant community composition and structure within a given set of site conditions and the natural range of variability, including climatic variability and natural disturbance regimes, expected within a management planning time horizon.

Invasive Plant Species — An invasive species is (1) nonnative (or alien) to the ecosystem under consideration and (2) its introduction causes or is likely to cause economic or environmental harm or harm to human health (from Presidential Executive Order 13112, February 1999).

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

Major Land Resource Area — A geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of agriculture.

Management Strategies — Coordinated management activities conducted at mid- to local scales to achieve vegetation and habitat objectives (e.g., strategically locating firefighting resources to protect habitat, coordinating Early Detection and Rapid Response activities for invasive plant species, positioning treatments to increase connectivity).

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

Projects — Projects are comprised of multiple treatments.

Reference State — The reference state describes the ecological potential and natural or historical range of variability of the ecological site.

Resilience — Ability of a species and/or its habitat to recover from stresses and disturbances. Resilient ecosystems 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 state is 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). The alternative states, ranges of variability within states, and processes that cause plant community shifts within states as well as transitions among states are described in a diagram and accompanying text.

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).

Treatments — Local scale management actions that directly manipulate vegetation to achieve a vegetation or habitat objective (e.g., conifer removals, invasive annual grass controls, fuel treatments, or seeding plants).

Woodland (Piñon and Juniper) Phase I, II, III – In phase I trees are present but shrubs and herbs are the dominant vegetation influencing ecological processes on the site; in phase II trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes; in phase III trees are the dominant vegetation on the site and the primary plant layer influencing ecological processes on the site (Miller et al. 2005, 2014).

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

Soil climate regimes (temperature and moisture) are used in soil taxonomy to classify soils. They are important to consider in land management decisions because of their influence on (1) amounts and kinds of vegetation and (2) response to disturbance and management actions. Soil temperature and moisture regimes are assigned to soil map unit components as part of the National Cooperative Soil Survey program. Abbreviated definitions of predominant soil temperature and moisture regime classes are listed below. 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).

Table A2.1. Definitions of the Dominant Soil Temperature and Moisture Regimes in the Sagebrush Biome.

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 range of sage-grouse (all MZs; 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. For example, the area near the border between southeastern Montana and northeastern Wyoming is in a transition zone between the frigid and mesic soil temperature regimes, which has resulted in an apparent abrupt change in temperature regime at the state border. Future updates to soil survey information will resolve these 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, soil temperature and moisture regimes, and relative resilience and resistance (table 5) 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, and Cold Deserts in MZ III, IV, V, and VI the rankings for these ecoregions were performed separately. The Mesic/Ustic bordering on Aridic and Mesic/Aridic bordering on Ustic regimes were ranked as moderate in the West-Central Semiarid Prairies in MZ I and as low in the Cold Deserts in MZ II and VII. The rankings for the Cold Deserts in MZ II and VII, and Cold Deserts in MZ III, IV, V, and VI were similar. 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.

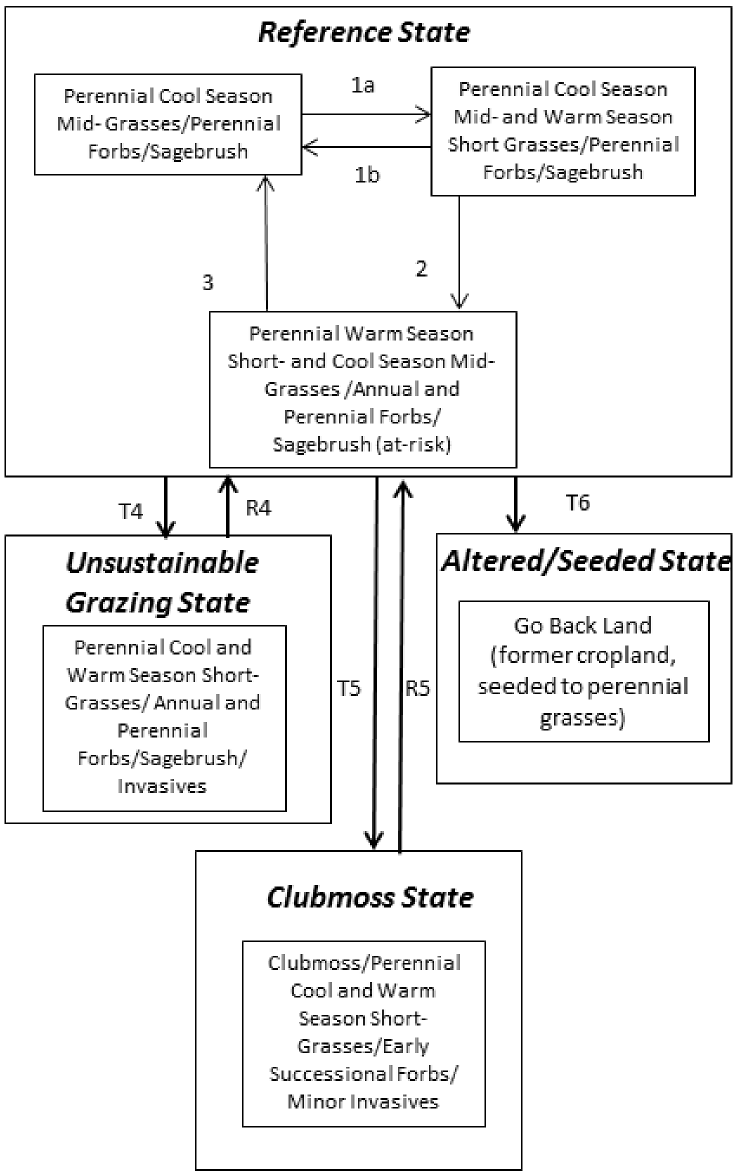
Table A2.2. Resilience and Resistance (R&R) Rating for the Soil Temperature and Moisture Regimes in the West-Central Semiarid Prairies in MZ I, Cold Deserts in MZ II and VII, and Cold Deserts in MZ III, IV, V, and VI

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

Appendix 3. State-and-Transition Models (STMs) for Predominant Sagebrush Ecological Types in the West-Central Semiarid Prairies (MZ I), and Western Cordillera and Cold Desert (MZ II, VII) (table 6; Chambers et al. *in press*). 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.

Appendix A.3.1

WEST CENTRAL SEMIARID PRAIRIES
COOL FRIGID/USTIC BORDERING ON ARIDIC
GRASS DOMINATED W/ SILVER SAGEBRUSH (10-14 IN PZ)
High Resilience and Resistance



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

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

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

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

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

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

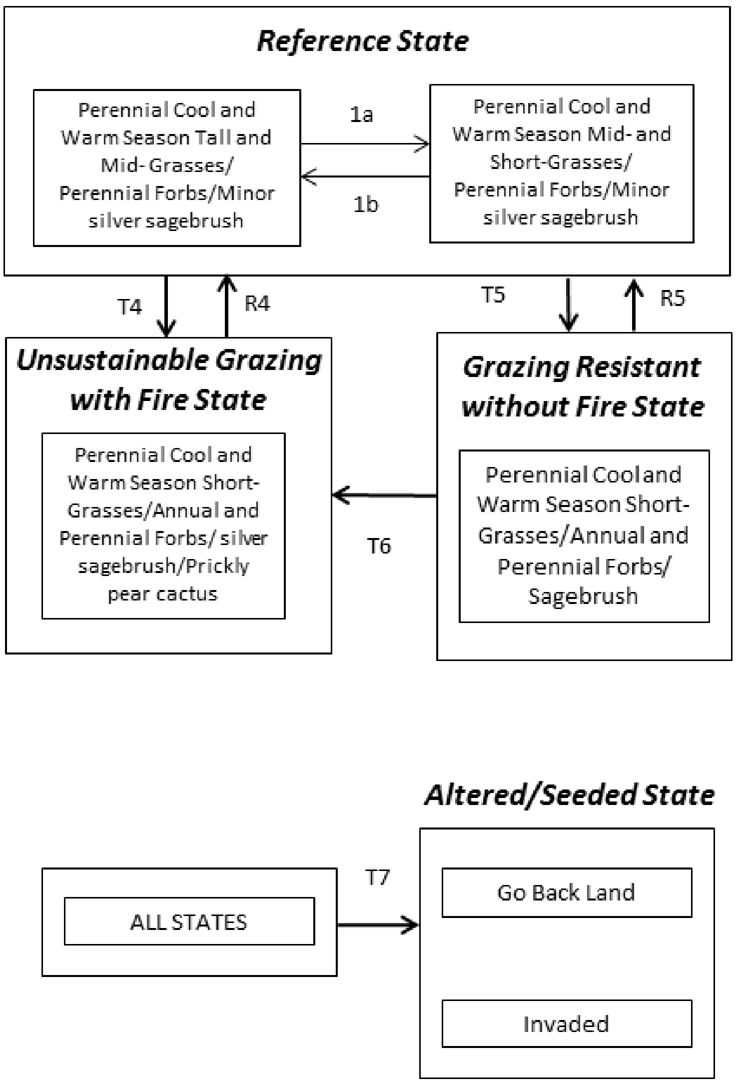
(T5) Extended drought (>7 years) may result in dense stands of clubmoss. However, no grazing, light grazing, and rotational grazing combined with drought can result in more rapid increase in clubmoss than drought alone. Lack of fire may contribute to this transition as well. Potential for invasives such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

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

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

Appendix A.3.2

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.

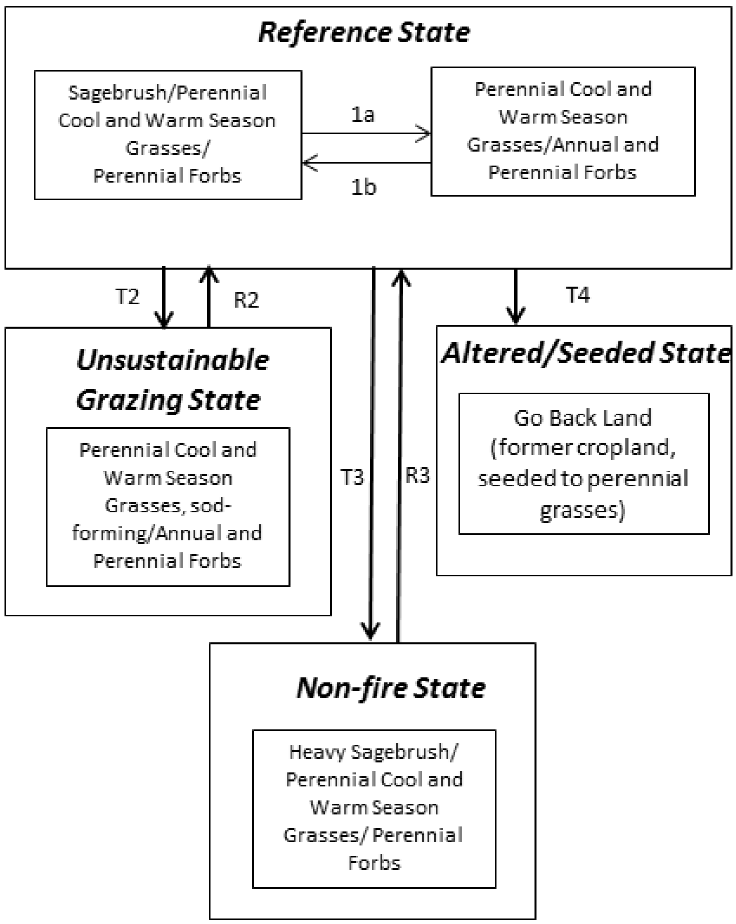
(R5) Extended periods of normal precipitation, possibly seeding (if an adequate seedbank does not exist), mechanical renovation, and reduced grazing pressure that varies season of use can return the site to one resembling the reference state.

(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.

Appendix A.3.3

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.

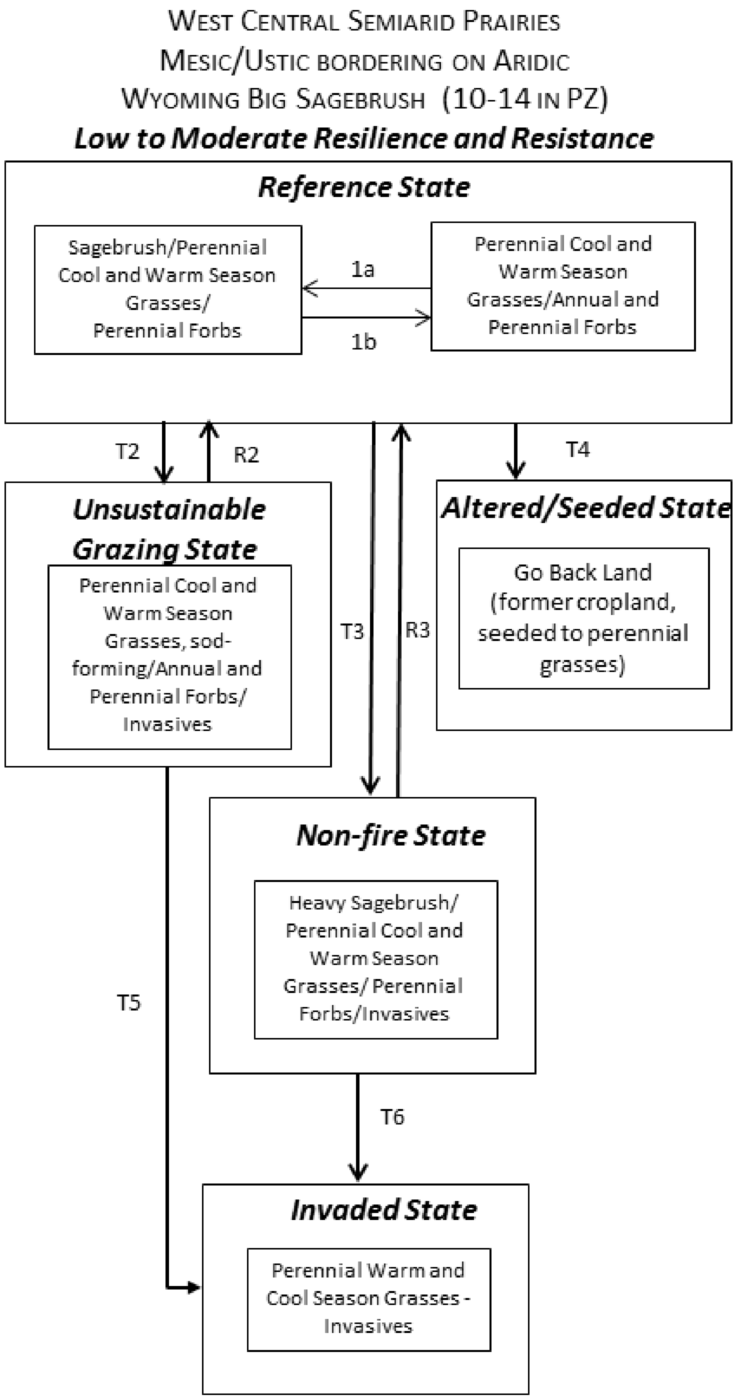
(R2) Normal precipitation patterns, reducing the frequency and severity of disturbances that kill sagebrush, and proper timing and intensity grazing regime that varies season of use can return the site to the reference state.

(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 interspaces in 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.

Appendix A.3.4



(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.

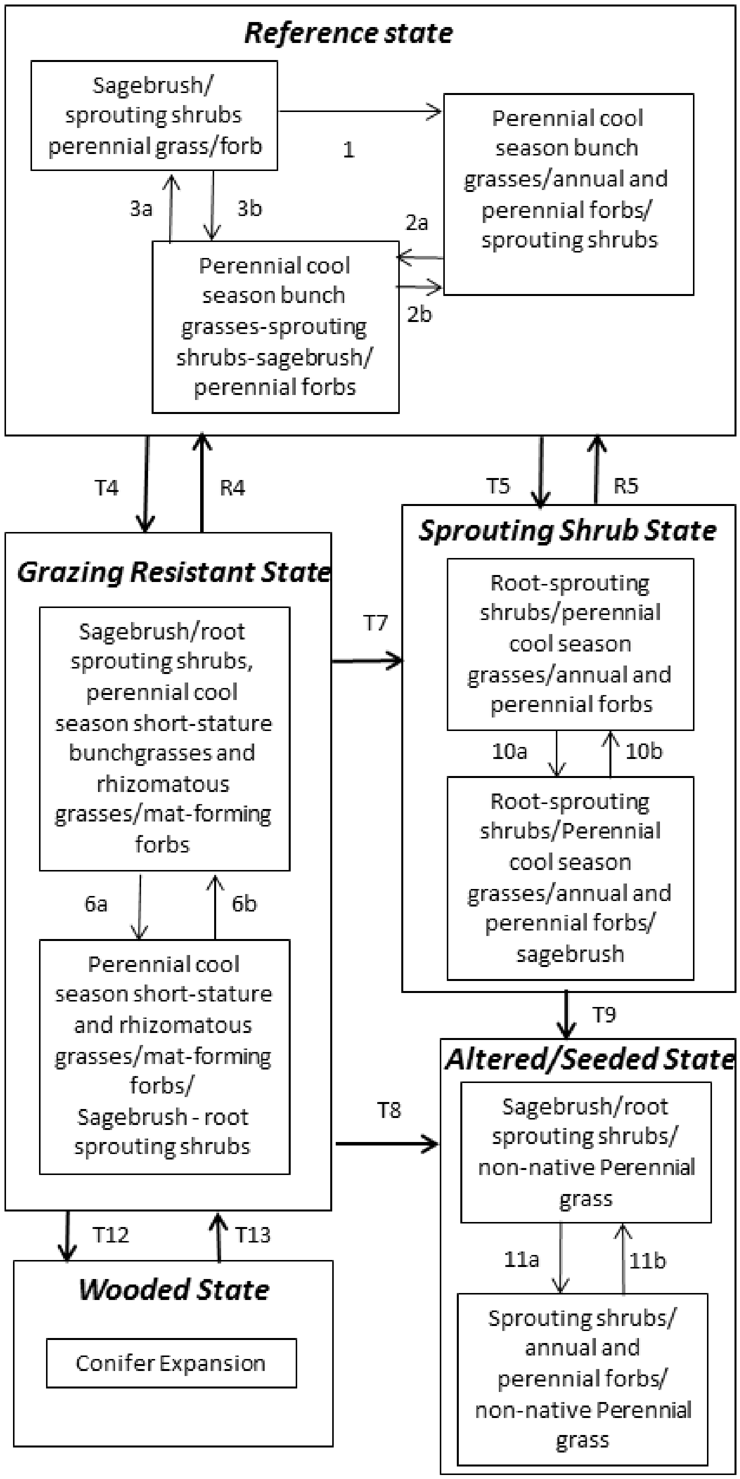
(T4) Former cropland that has been seeded to introduced and/or native perennial grasses, largely funded by government programs. In the 1960-1970s seedings were primarily introduced species such as crested wheatgrass, intermediate wheatgrass, and smooth brome. From 1985 to present seedings used both introduced 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.

Appendix A.3.5

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

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

(10a) Sagebrush and other shrubs increase.

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

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

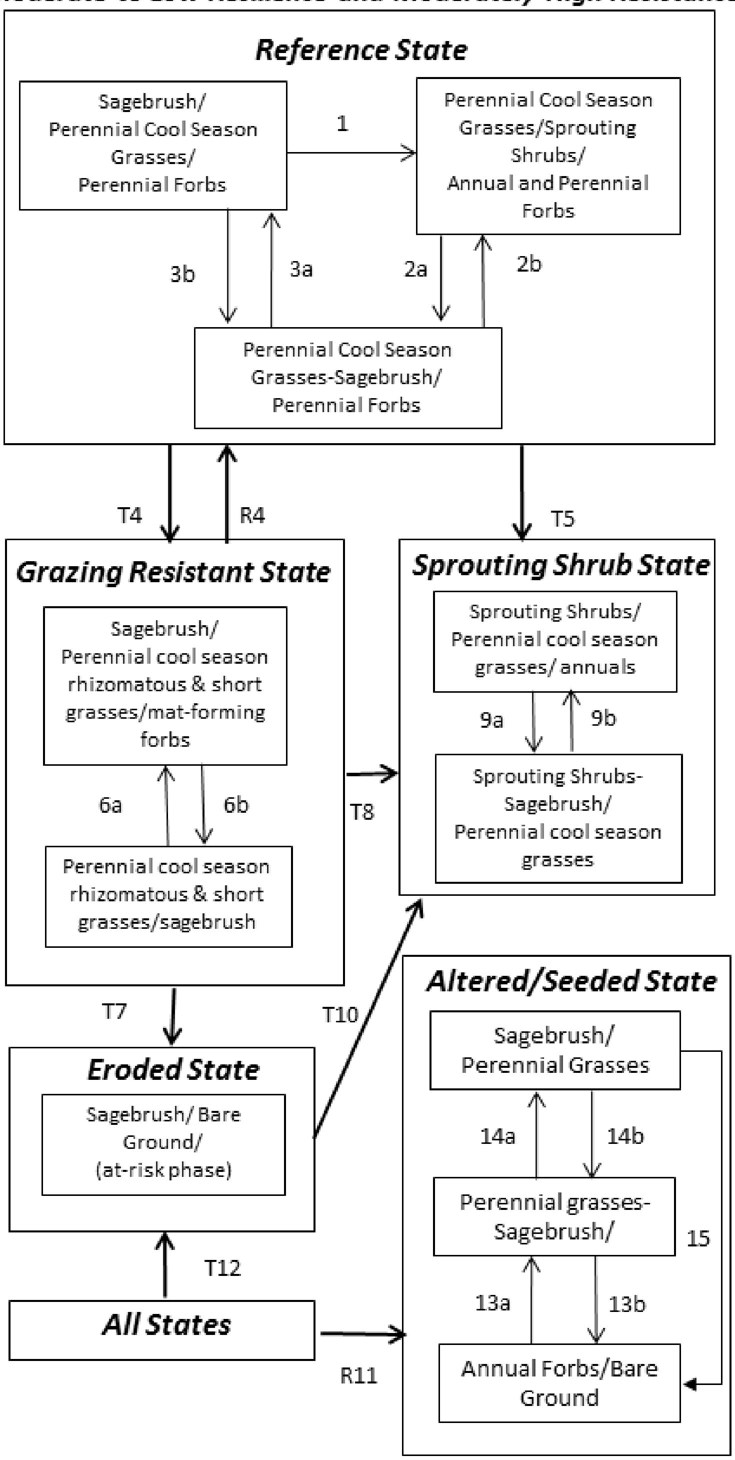
(11b) Sagebrush and other shrubs increase.

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

(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.

Appendix A.3.6

COLD DESERTS - COOL FRIGID/USTIC BORDERING ON ARIDIC
WYOMING BIG SAGEBRUSH (9-14 IN PZ)
Moderate to Low Resilience and Moderately High Resistance



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

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

(2b) Perennial grass, sprouting shrubs, and forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens.

(3a) Sagebrush increases with time until dominant.

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

(T4) Continuous spring grazing during the critical growth period of cool season grasses results in dominance of grazing tolerant species, like short-statured bunchgrasses (e.g. Sandberg bluegrass) and rhizomatous species. As 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.

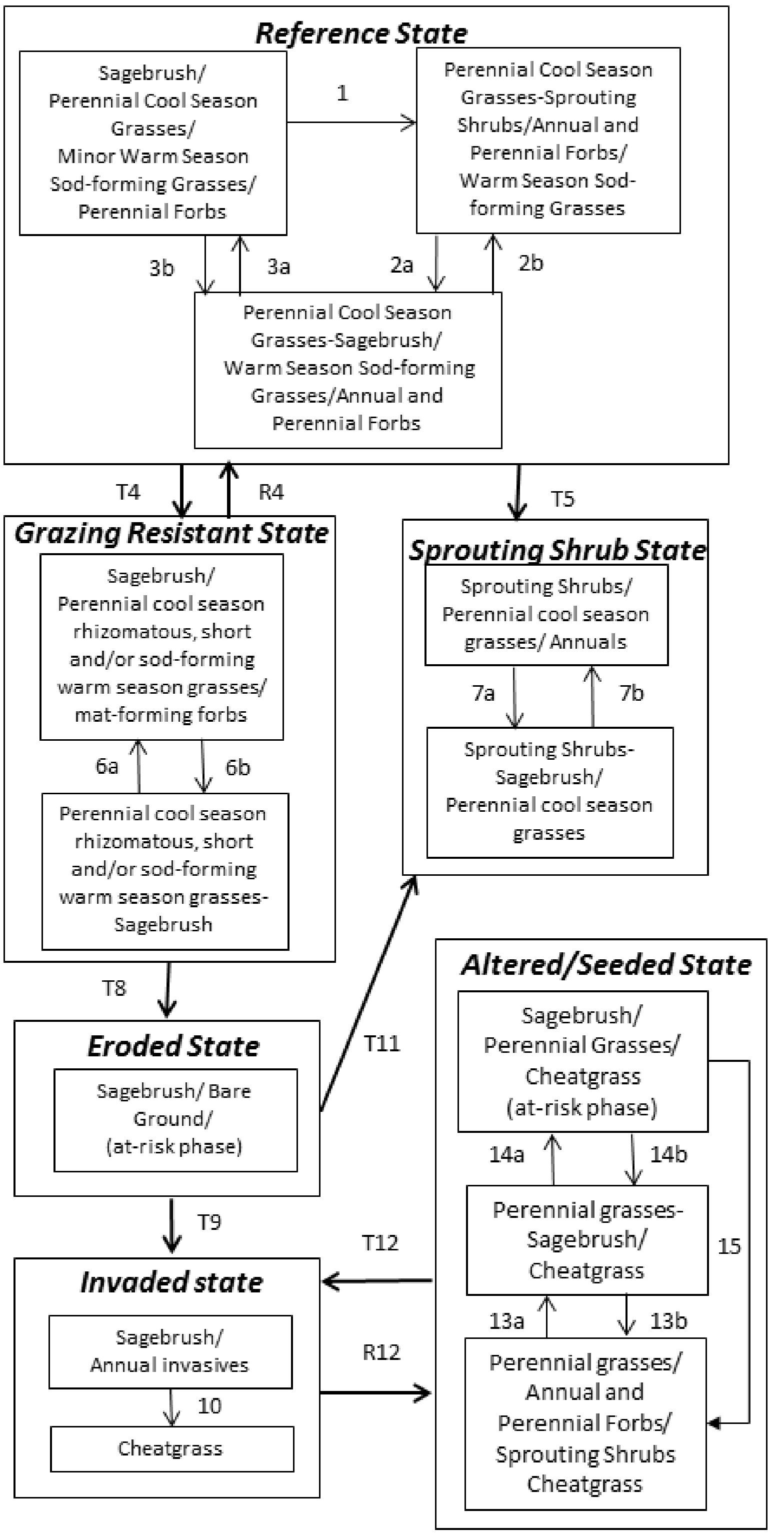
(14a) Sagebrush increases with no disturbances over time.

(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.

Appendix A.3.7

COLD DESERTS - FRIGID/USTIC BORDERING ON ARIDIC
WYOMING BIG SAGEBRUSH (10-14 IN PZ)
Moderate Resilience and Resistance

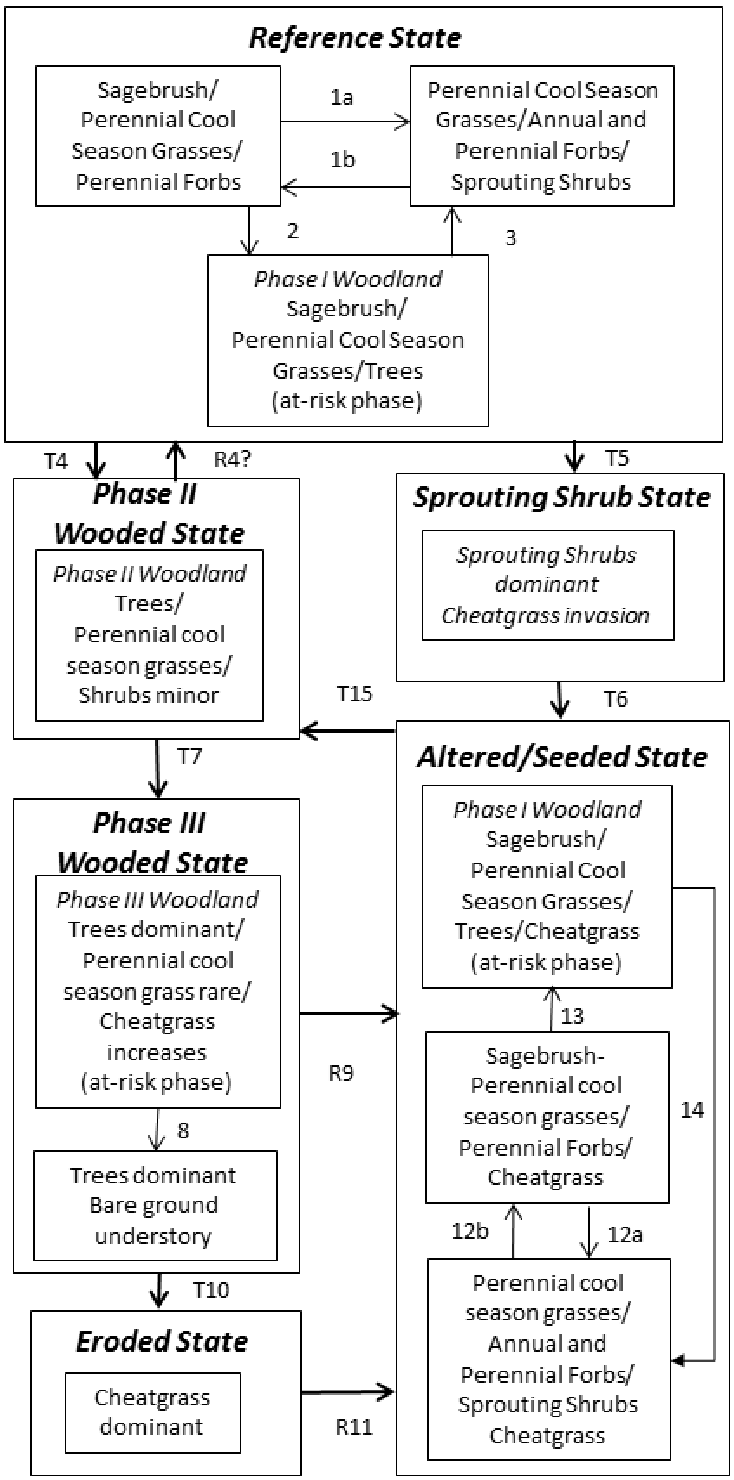


- (1) Perennial grass, sprouting shrubs, and forbs become dominant due to disturbances that decrease sagebrush like prolonged or severe drought, freezing, flooding, wildfire, insects, disease, and pathogens.
- (2a) Sagebrush increases with time until co-dominant with the herbaceous understory.
- (2b)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

Appendix A.3.8

Cold Deserts - Warm Frigid/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.

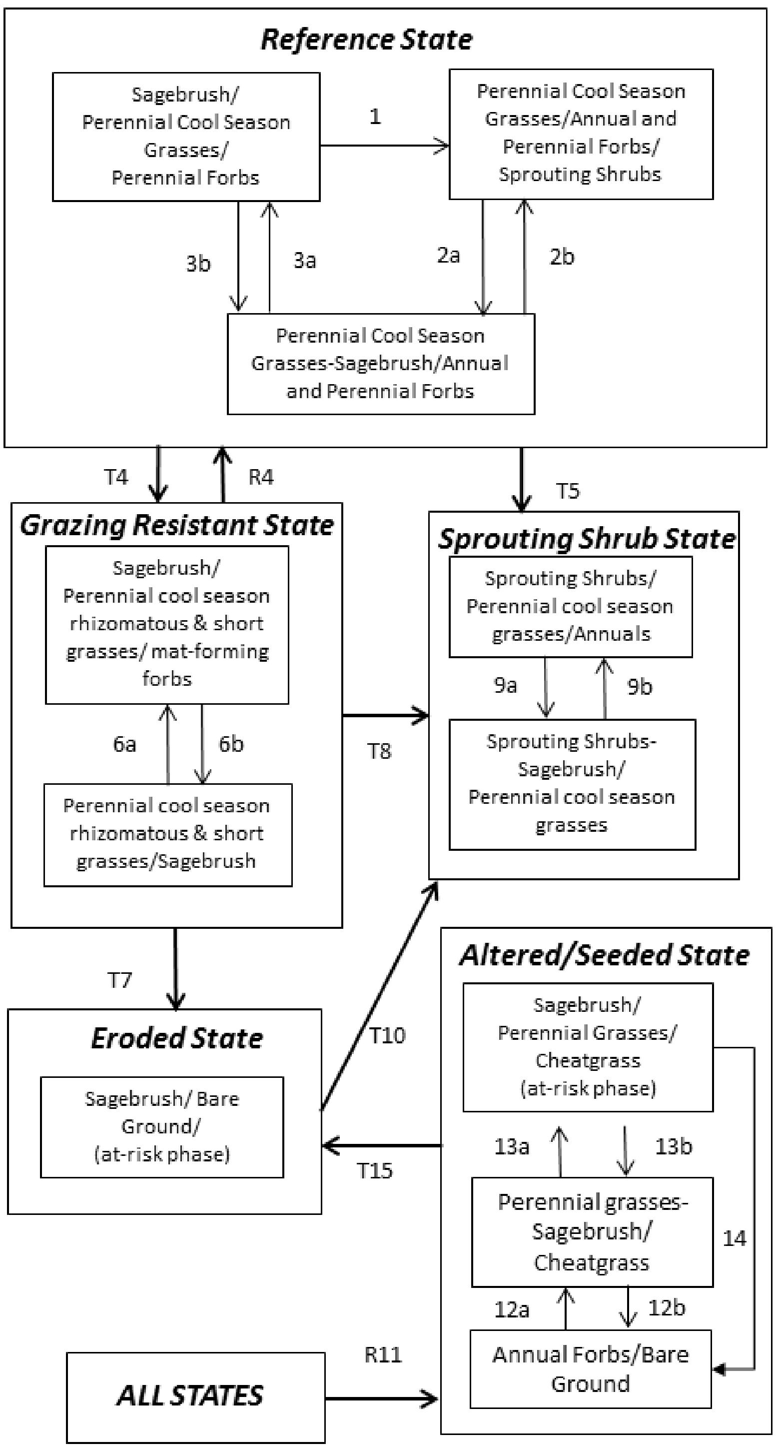
(13) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland and an at-risk phase.

(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.

Appendix A.3.9

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

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

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

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

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

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

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

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

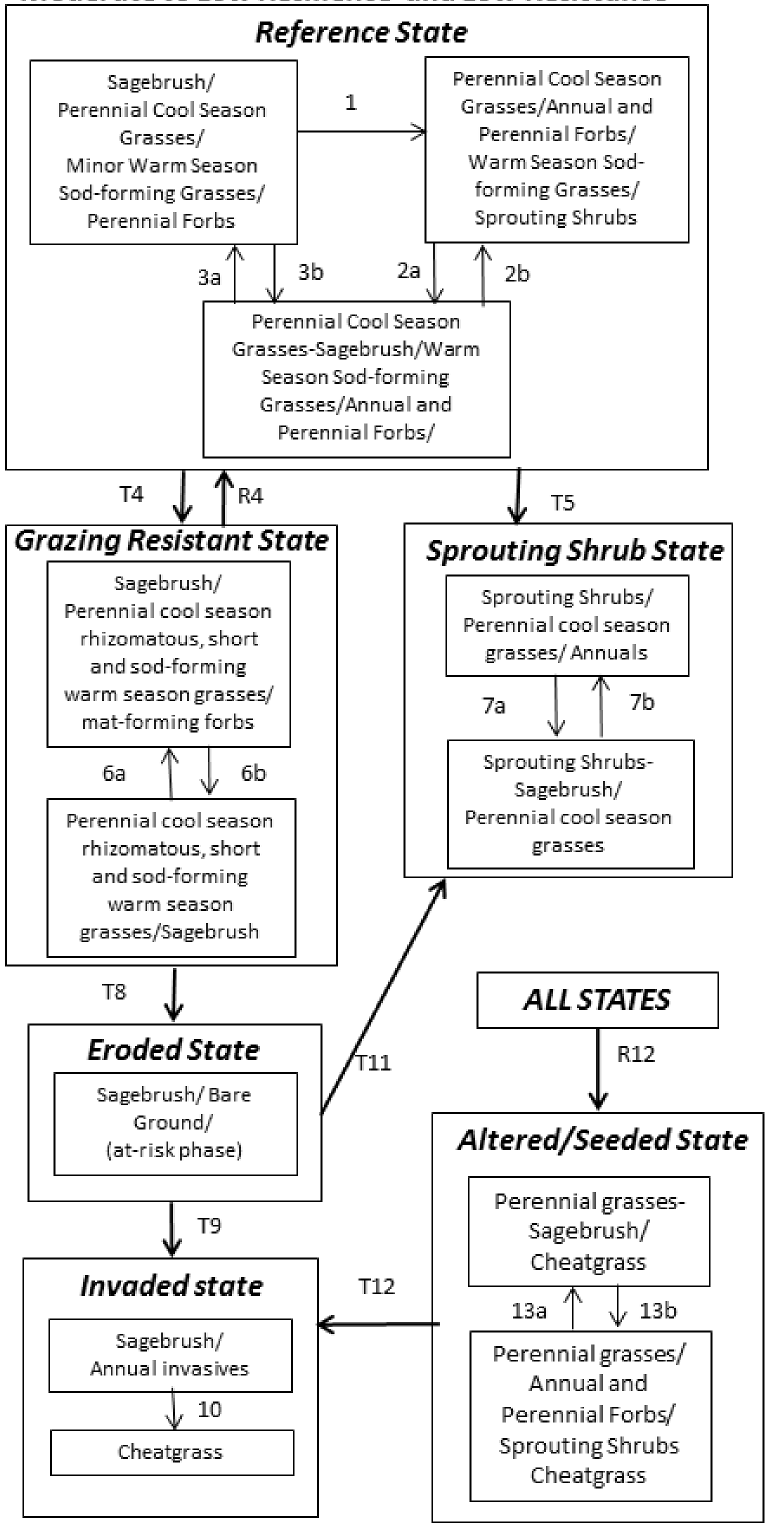
(13b) Perennial grass and forbs become dominant due to minor disturbances that decrease sagebrush. There may be a temporary flush of annuals.

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

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

Appendix A.3.10

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 removal of disturbances until co-dominant with sprouting shrubs.

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

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

(T9) If a cheatgrass seed source is introduced, and climatic conditions are conducive to establishment (warm wet spring), cheatgrass will invade.

(10) A sagebrush killing event, such as fire and fire surrogates results in conversion to cheatgrass. Some perennial species may be present, but the system dynamics will be driven by annual invasives.

(T11) Multiple treatments of chemical, mechanical, or biological disturbances to reduce sagebrush will result in a shift toward sprouting shrub dominance with potential for cheatgrass to occur.

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

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

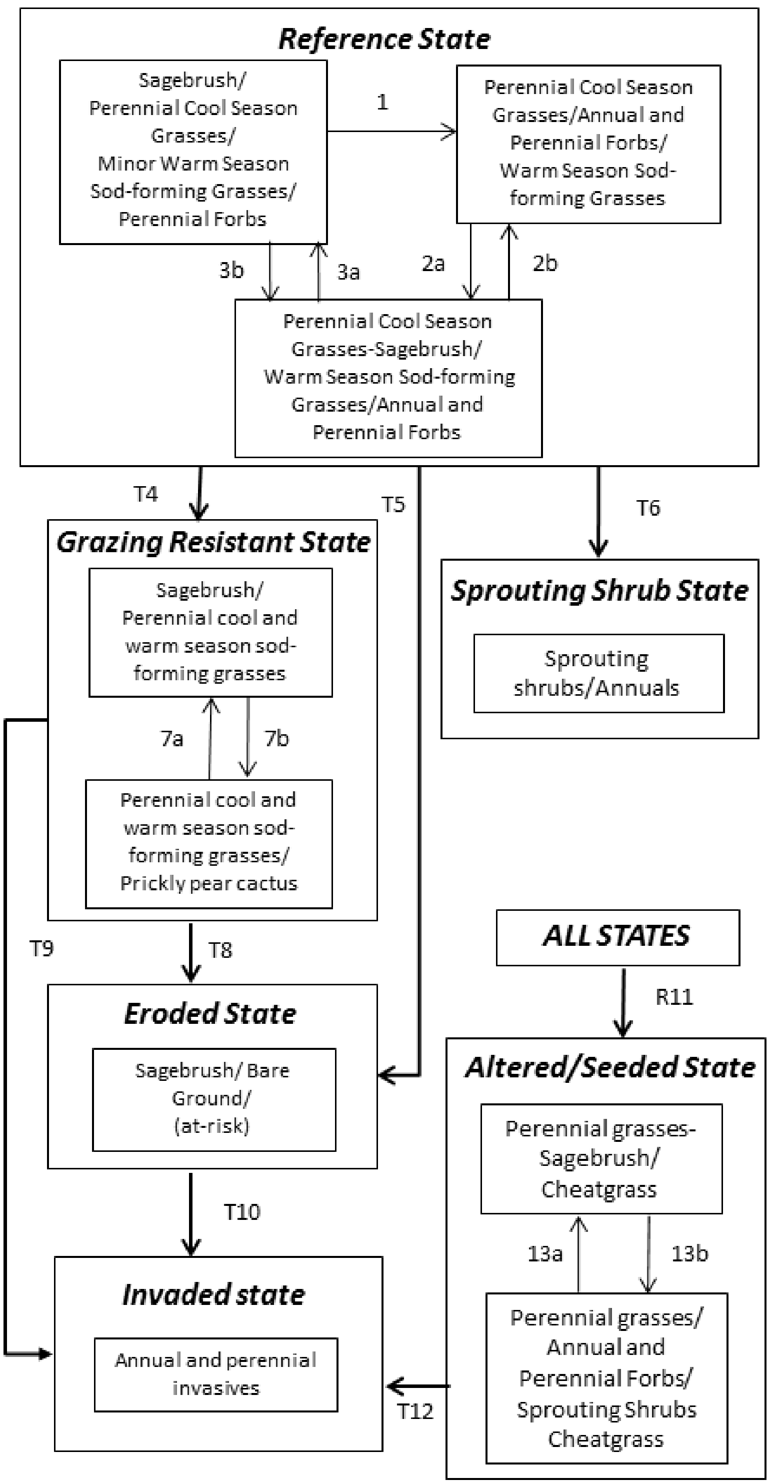
(13a) Sagebrush increases with time and no disturbances until co-dominant with the herbaceous understory, but cheatgrass will be present.

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

(T16) A restoration treatment after ground disturbing activities, including mechanical treatment, seeding with native perennials adapted to site conditions can result in a perennial grass community and eventually support an altered sagebrush community with some invaders present. Sagebrush will be slow to reestablish.

Appendix A.3.11

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 become dominant due to disturbances that decrease sagebrush. Fire is rare.

(3a) Sagebrush increases with time until dominant.

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

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

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

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

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

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

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

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

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

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

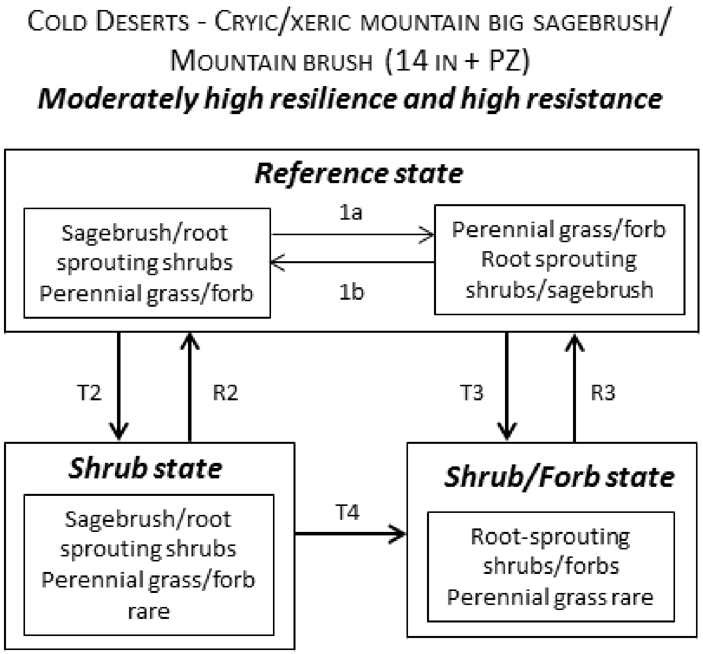
(T12) A catastrophic event such as fire or drought, followed by a wet spring can result in a system dominated by annual invasive species.

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

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

Appendix 4. State-and-Transition Models (STMs) for Predominant Sagebrush Ecological Types in the Cold Desert (MZ III, IV, V) (table 6; Chambers et al. 2014c). 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.

Appendix A.4.1



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

(1b) Sagebrush and other shrubs increase with time.

(T2) Improper grazing triggers a shrub dominated state.

(R2) Proper grazing results in a return to the reference state.

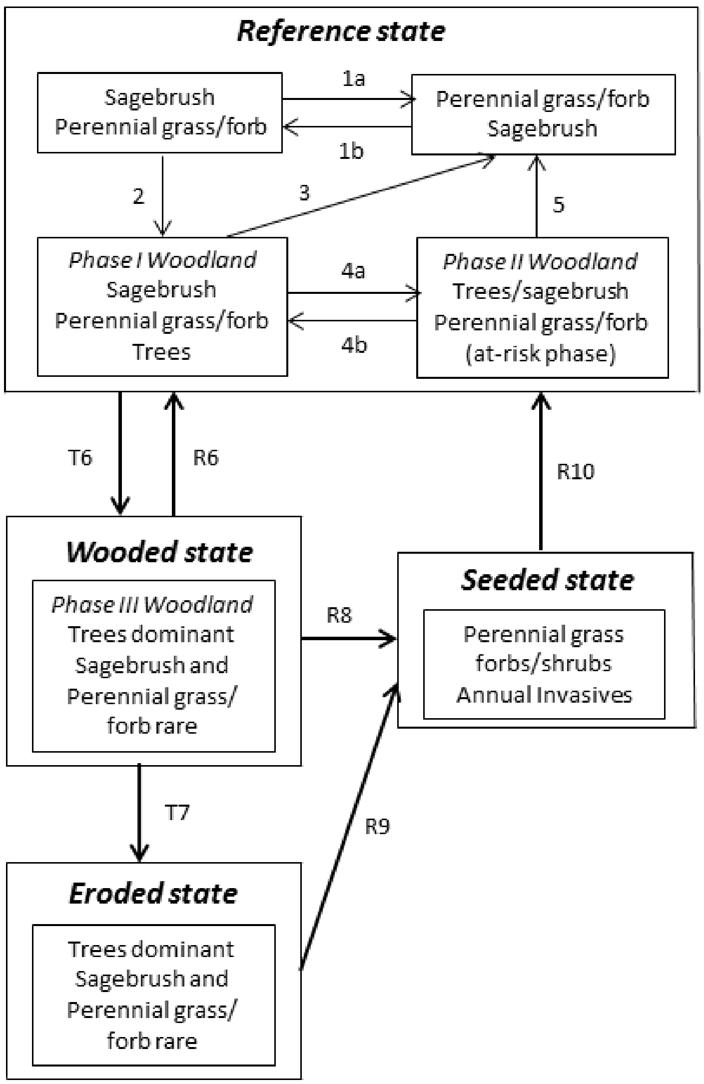
(T3 and T4) Fire or other disturbances that remove sagebrush result in dominance by root-sprouting shrubs and an increase in native forbs like lupines.

(R3) Proper grazing and time result in return to the reference state.

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

Appendix A.4.2

COLD DESERTS - COOL FRIGID/XERIC
MOUNTAIN BIG SAGEBRUSH (12 -14 IN + PZ)
Piñon pine and/or juniper potential
Moderately high resilience and resistance



(1a) Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial grass/forb.

(1b) Sagebrush increases with time.

(2) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland.

(3 and 5) Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.

(4a) Increasing tree abundance results in a Phase II woodland with depleted perennial grass/forb and shrubs and an at-risk phase.

(4b) Fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.

(T6) Infilling of trees and/or improper grazing can result in a biotic threshold crossing to a wooded state with increased risk of high severity crown fires.

(R6) Fire, herbicides and/or mechanical treatments that remove trees may restore perennial grass/forb and sagebrush dominance.

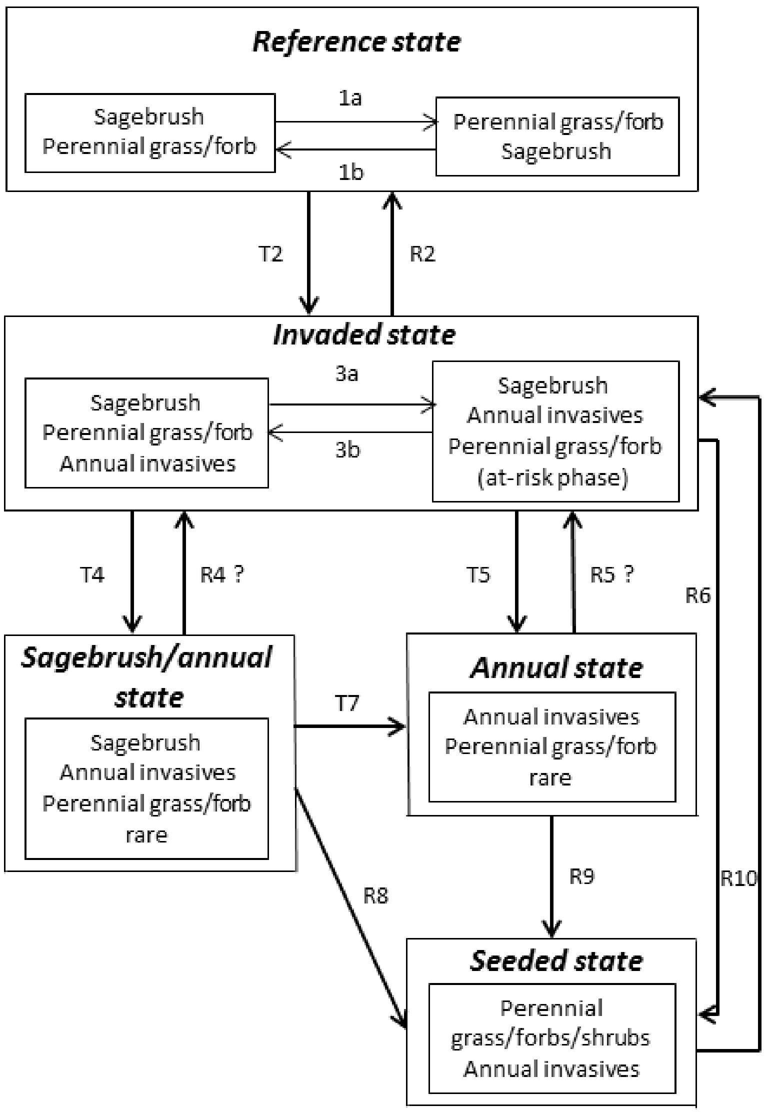
(T7) An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.

(R8 and R9) Seeding after fire may be required on sites with depleted perennial grass/forb, but seeding with aggressive introduced species can decrease native perennial grass/forb. Annual invasives are typically rare. Seeded eroded states may have lower productivity.

(R10) Depending on seed mix and grazing, return to the reference state may be possible if an irreversible threshold has not been crossed.

Appendix A.4.3

COLD DESERTS - COOL MESIC TO COOL FRIGID/XERIC
MOUNTAIN BIG SAGEBRUSH (12-14 IN PZ)
Moderate resilience and resistance



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

(1b) Sagebrush increases with time.

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

(R2) Proper grazing, fire, herbicides, and/or mechanical treatments may restore perennial grass/forb and sagebrush dominance with few invasives.

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

(3b) Proper grazing, herbicides, or mechanical treatments that reduce sagebrush may increase perennial grass/forb and decrease invasives.

(T4) Improper grazing results in a sagebrush/annual state.

(R4) Proper grazing may facilitate return to the invaded state on cooler/wetter sites if sufficient grass/forb remains.

(T5 and T7) Fire or other disturbances that remove sagebrush result in an annual state. Perennial grass/forb are rare and recovery potential is reduced. Repeated fire can result in a biotic threshold crossing to annual dominance on warmer/drier sites, and root-sprouting shrubs may increase.

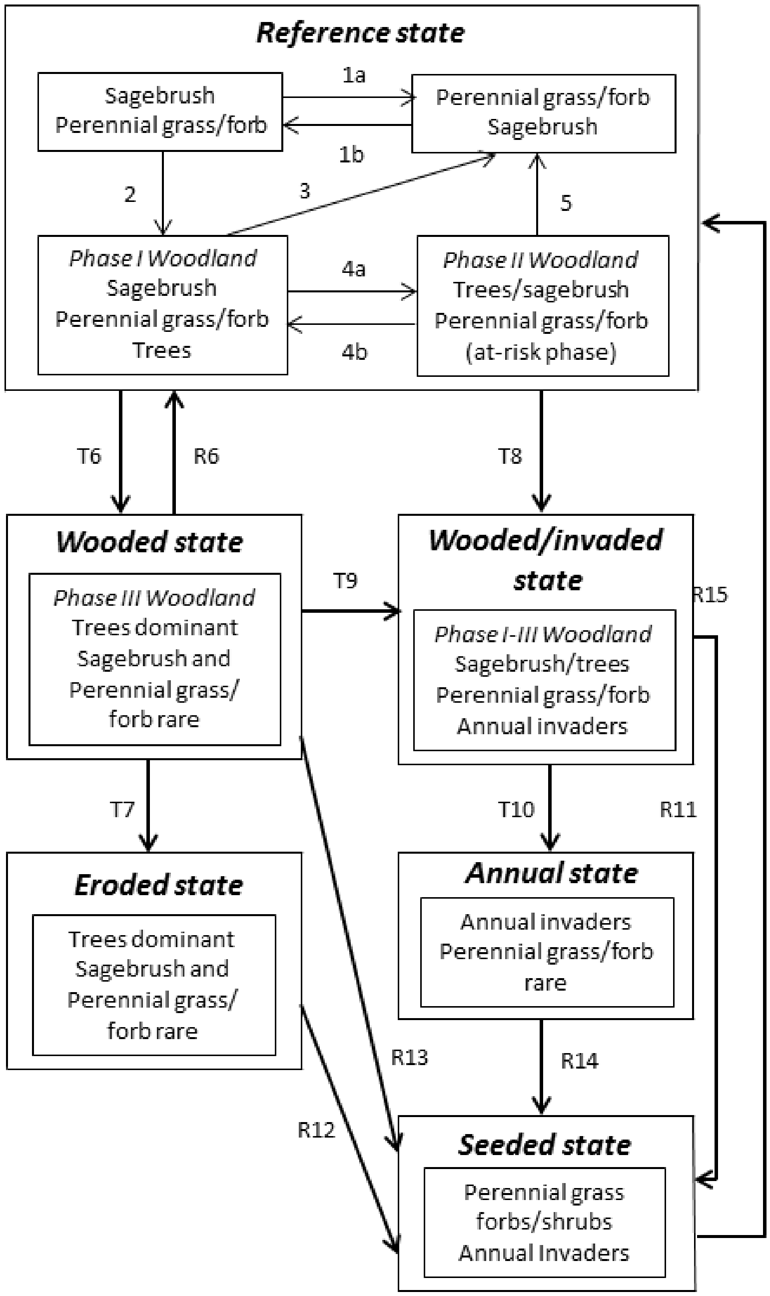
(R5) Cooler and wetter sites may return to the invaded or reference state with lack of fire, proper grazing, and favorable weather.

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

(R10) Cooler and wetter sites may return to the invaded or possibly reference state depending on seeding mix, grazing and weather.

Appendix A.4.4

COLD DESERTS - COOL MESIC TO WARM FRIGID/XERIC
BIG SAGEBRUSH (12-14 IN + PZ)
Piñon pine and/or juniper potential
Moderate resilience and moderately low resistance



(1a) Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial grass/forb.

(1b) Sagebrush increases with time.

(2) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland.

(3 and 5) Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance on cooler/wetter sites. On warmer/drier sites with low perennial grass/forb abundance resistance to invasion is moderately low.

(4a) Increasing tree abundance results in a Phase II woodland with depleted perennial grass/forb and shrubs and an at-risk phase.

(4b) Fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore sagebrush and perennial grass/forb dominance.

(T6) Infilling of trees and improper grazing can result in a biotic threshold crossing to a wooded state with increased risk of high severity crown fires.

(R6) Fire, herbicides and/or mechanical treatments that remove trees may restore perennial grass/forb and sagebrush dominance on cooler/wetter sites.

(T7) An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.

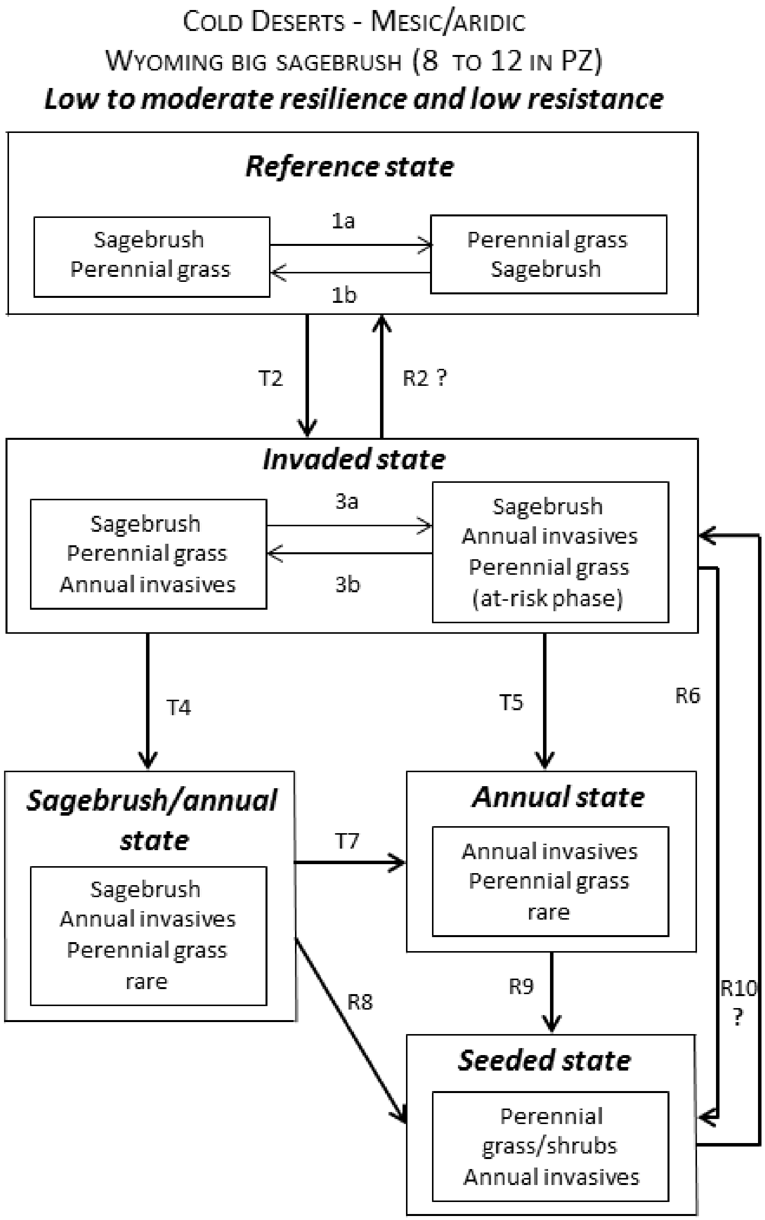
(T8 and T9) An invasive seed source and/or improper grazing can trigger a wooded/invaded state.

(T10) Fire or other disturbances that remove trees and sagebrush can result in a biotic threshold crossing to annual dominance on warmer/drier sites with low resilience.

(R11, R12, R13, and R14) Seeding after fire and/or invasive species control increases perennial grass/forb. Sagebrush may recolonize depending on seed sources, but annual invaders are still present. Seeded eroded states may have lower productivity.

(R15) Depending on seed mix, grazing, and level of erosion, return to the reference state may occur on cooler and wetter sites if an irreversible threshold has not been crossed.

Appendix A.4.5



(1a) Perennial grass increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.
(1b) Sagebrush increases with time.
(T2) An invasive seed source and/or improper grazing trigger an invaded state.
(R2) Proper grazing, fire, herbicides and/or mechanical treatments are unlikely to result in return to the reference state on all but the coolest and wettest sites.
(3a) Perennial grass decreases and both sagebrush and invasives increase with improper grazing resulting in an at-risk phase. Decreases in sagebrush due to insects, disease or pathogens can further increase invasives.
(3b) Proper grazing and herbicides or mechanical treatments that reduce sagebrush may restore perennial grass and decrease invaders on wetter sites (10-12"). Outcomes are less certain on drier sites (8-10") and/or low abundance of perennial grass.
(T4) Improper grazing triggers a largely irreversible threshold to a sagebrush/annual state.
(T 5 and T7) Fire or other disturbances that remove sagebrush result in an annual state. Perennial grass is rare and recovery potential is low due to low precipitation, mesic soil temperatures, and competition from annual invasives. Repeated fire can cause further degradation.
(R6, R8 and R9) Seeding following fire and/or invasive species control results in a seeded state. Sagebrush may recolonize depending on patch size, but annual invasives are still present.
(R10) Seeding effectiveness and return to the invaded state are related to site conditions, seeding mix, and post-treatment weather.

Appendix 5. Explanation of the Use of Landscape Measures to Describe Sagebrush Habitat

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

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

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

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

Appendix 6. Data Sources and Websites for the Maps in This Report

Data Type	Data Source	Website
Ecoregions – Levels II & III (Figure 1)	https://archive.epa.gov/wed/ecoregions/web/html/na_eco.html	
Precipitation and temperature data – 30 year normal (Figure 2, 3)	PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004. [Accessed Sept. 16, 2015]	http://prism.oregonstate.edu/normals
Soil Data (SSURGO) (Figures 6, 31, 32, 33, 37, 40, 41, 44, 46, 49)	Soil Survey Staff. 2014a. Soil Survey Geographic (SSURGO) Database. United States Department of Agriculture, Natural Resources Conservation Service. Online: http://sdmdataaccess.nrcs.usda.gov/ [Accessed Oct. 3, 2015].	http://sdmdataaccess.nrcs.usda.gov/
Soil Data (STATSGO) (Figures 6, 31, 32, 33, 37, 40, 41, 44, 46, 49)	Soil Survey Staff. 2014b. Soil Survey Geographic (STATSGO2) Database. United States Department of Agriculture, Natural Resources Conservation Service. Online: http://sdmdataaccess.nrcs.usda.gov/ [Accessed Oct. 3, 2015].	http://sdmdataaccess.nrcs.usda.gov/
Soil Temperature and Moisture Regime (Figures 6, 31, 32, 33, 37, 40, 41, 44, 46, 49)	Campbell, S.B. 2016. Soil temperature and moisture regimes across sage-grouse range. Data product. Portland, OR: USDA Natural Resources Conservation Service. Online: https://www.sciencebase.gov/catalog/item/538e5aa9e4b09202b547e56c [Accessed May 10, 2016]	https://www.sciencebase.gov/catalog/item/538e5aa9e4b09202b547e56c
Fire perimeters – GeoMAC (Figures 7, 48)	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.	http://www.geomac.gov/

	Geological Survey. 6 p. Online: https://pubs.er.usgs.gov/publication/ds612 [Accessed Feb. 1, 2016]	
Fire perimeters – MTBS (Figures 7, 48)	MTBS fire perimeters: Eidenshink, J., Schwind, B., Brewer, K., Zhu, Z., Quayle, B. and Howard, S., 2007, A project for monitoring trends in burn severity: Fire Ecology, v. 3, p. 3-21. Online: http://www.mtbs.gov/nationalregional/burnedarea.html [Accessed Sept. 15, 2015]	http://www.mtbs.gov/nationalregional/burnedarea.html
Annually tilled agriculture (cropland) (Figures 13, 39)	USDA National Agricultural Statistics Service Cropland Data Layer. 2014. Published crop-specific data layer. UDSA-NASS, Washington, DC. Online: http://nassgeodata.gmu.edu/CropScape/ [Accessed Sept. 16, 2015]	http://nassgeodata.gmu.edu/CropScape/
Cultivation Risk (Figure 39)	Lipsey, M.K., K.E. Doherty, D.E. Naugle, S. Fields, J.S. Evans, S.K. Davis and N. Koper. 2015. One step ahead of the plow: Using cropland conversion risk to guide grassland songbird conservation. Biological Conservation. 191:739–749. http://dx.doi.org/10.1016/j.biocon.2015.08.030 Smith, J. T., J. S. Evans, B. H. Martin, S. Baruch-Mordo, J. M. Kiesecker, and D. E. Naugle. 2016. Reducing cultivation risk for at-risk species: Predicting outcomes of conservation easements for sage-grouse. Biological conservation 201:10–19. http://dx.doi.org/10.1016/j.biocon.2016.06.006	http://map.sagegrouseinitiative.com/
Oil and Gas Wells	Point density analysis conducted by the Bureau of Land	https://eplanning.blm.gov/epl-front-

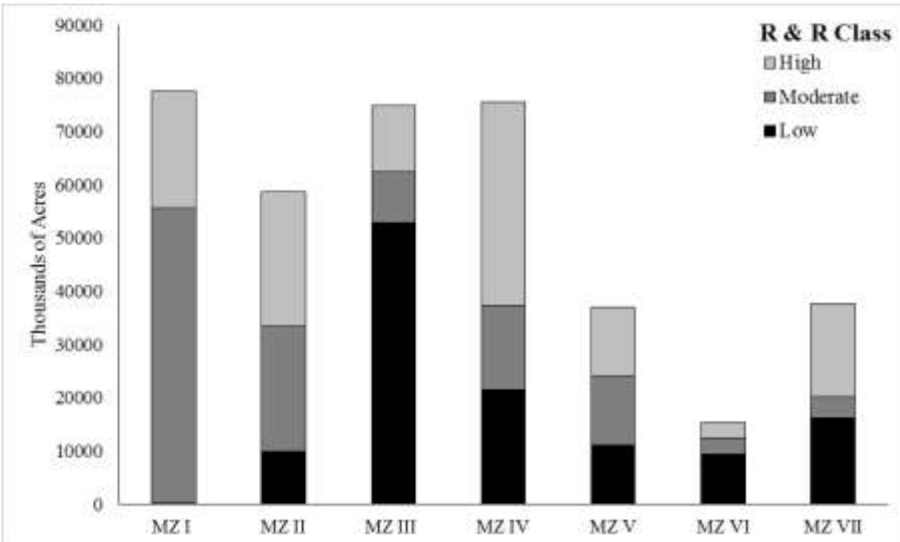
(Figures 15, 43)	Management and derived from AFMSS Currently Active Oil and Gas Well Points 2015; IHS Currently Active Oil and Gas Well Points 2015. Online: https://www.ihs.com/products/us-well-data.html [Accessed May 11, 2016]	office/projects/lup/21152/48421/52584/GRSG-FINAL-Monitoring_Framework_20140530.pdf
Human disturbance (Figure 17)	Human Disturbance Percent Developed Imperviousness: U.S. Geological Survey. 2014. NLCD 2011 Percent Developed Imperviousness (2011 Edition, amended 2014). U.S. Geological Survey, Sioux Falls, SD. Online: http://www.landfire.gov/bulk/downloadfile.php?TYPE=nlcd2011&FNAME=nlcd_2011_impervious_2011_edition_2014_10_10.zip [Accessed May 11, 2016]	http://www.mrlc.gov/nlcd11_data.php
Roads (Figure 19)	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 May 11, 2016]	https://eplanning.blm.gov/epl-front-office/projects/lup/21152/48421/52584/GRSG-FINAL-Monitoring_Framework_20140530.pdf
Land Cover – Cheatgrass (NE Nevada) (Figure 48)	Stephen P. Boyte, and Bruce K. Wylie, 2015-07-02, Near-real-time cheatgrass percent cover in the northern Great Basin, USA—2015. Online: https://www.sciencebase.gov/catalog/item/55ad3a16e4b066a2492409d5 [Accessed July 1, 2016]	https://www.sciencebase.gov/catalog/item/55ad3a16e4b066a2492409d5
Land Cover – Conifer (NE Nevada) (Figure 48)	Falkowski et al. In Review. Mapping tree canopy cover in support of proactive prairie grouse conservation in western North America. Online: http://map.sagegrouseinitiative.com/ [Accessed July 1, 2016]	http://map.sagegrouseinitiative.com/

Land Cover – Conifer (Figure 10)	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. Online: http://landfire.cr.usgs.gov/viewer/ [Accessed Aug. 26, 2015].	http://landfire.cr.usgs.gov/viewer/
Land Cover – Sagebrush (Figures 5, 27, 28)	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. Online: http://landfire.cr.usgs.gov/viewer/ [Accessed Aug. 26, 2015].	http://landfire.cr.usgs.gov/viewer/
Surface Land Management (Figures 38, 42, 47)	Bureau of Land Management. 2015. Surface Management Agency. Online: http://www.geocommunicator.gov/GeoComm/services.htm#Download [Accessed May 16, 2016]	http://www.geocommunicator.gov/GeoComm/services.htm#Download
GRSG Breeding Habitat Model (Figures 24, 32)	Breeding Habitat Model: Doherty, K.E., Evans, J.S., Coates, P.S., Juliusson, L., Fedy, B.C. 2015. Importance of regional variation in conservation planning and defining thresholds for a declining species: a range-wide example of the greater sage-grouse. Online: https://www.sciencebase.gov/catalog/folder/560ea672e4b0ba4884c5ebb7 [Accessed Oct. 6, 2015]	https://www.sciencebase.gov/catalog/folder/560ea672e4b0ba4884c5ebb7
GRSG Population Index Model (Figures 25, 33, 40, 44, 49)	Doherty, K.E., Evans, J.S., Coates, P.S., Juliusson, L., Fedy, B.C. 2015. Importance of regional variation in conservation planning and defining thresholds for a declining species: a range-wide example of the greater sage-grouse. Online: https://www.sciencebase.gov/catalog/folder/560ea65de4b0ba4884c5ebb5 [Accessed Oct. 6, 2015]	https://www.sciencebase.gov/catalog/folder/560ea65de4b0ba4884c5ebb5

Sage-grouse Management Zones (Figures 1, 2, 3, 5, 6, 7, 10, 13, 15, 17, 19, 24, 25, 27, 28, 31, 32, 33)	Stiver, S.J.; Apa, A.D.; Bohne, J.R.; Bunnell, S.D.; Deibert, P.A.; Gardner, S.C.; Hilliard, M.A.; McCarthy, C.W.; Schroeder, M.A. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, WY. 442 p. Online: http://wdfw.wa.gov/publications/01317/wdfw01317.pdf [Accessed Aug. 2, 2016]	US Fish and Wildlife Service (Wyoming Ecological Services), 2014 – Original Management Zone boundaries drawn by Tony Apa, Research Scientist, Colorado Parks and Wildlife, and the Sage-grouse Conservation Planning Framework Team. Boundaries were digitized by Lisa Langs Stoner, GIS Analyst, RS/GIS Laboratory at Utah State University. Online: https://www.sciencebase.gov/catalog/item/56f96b30e4b0a6037df06216 [Accessed Aug. 2, 2016]
Sage-grouse Priority Areas for Management (Figures 7, 24, 25, 32, 33, 36, 37, 38, 39, 40, 41, 42, 43, 45, 46, 47, 48)	U.S. Fish and Wildlife Service [USFWS]. 2013. Greater sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. Denver, CO: U.S. Fish and Wildlife Service. 91 p. https://www.fws.gov/greatersagegrouse/documents/COT-Report-with-Dear-Interested-Reader-Letter.pdf [Accessed Aug. 8, 2016].	US Fish and Wildlife Service (Wyoming Ecological Services) , 2014 – Scott Gardner, California Fish and Wildlife | BLM Eagle Lake Field Office | USGS Western Ecological Research Center | Kathy Griffin, Colorado Parks and Wildlife | Idaho Department of Fish and Game | Rick Northrup, Montana Fish, Wildlife and Parks | Aaron Robinson, North Dakota Game and Fish | State of Nevada | Oregon Fish and Wildlife | BLM, South Dakota Field Office (Belle Fourche, SD) | Utah Division of Wildlife Resources | Washington Department of Fish & Wildlife, Mike Schroeder | Wyoming Game and Fish Department | Bob Budd, State of Wyoming | USGS | BLM. Online: https://www.sciencebase.gov/catalog/item/56f96d88e4b0a6037df066a3 [Accessed Aug. 8, 2016].
GRSG Lek Data (Figure 24)	Western Association of Fish and Wildlife Agencies	

Appendix 7. Tables and maps summarizing the relative resilience and resistance, GRSG breeding habitat probabilities, and GRSG breeding populations for each management zone (MZ; Stiver et al. 2006) and the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

A



B

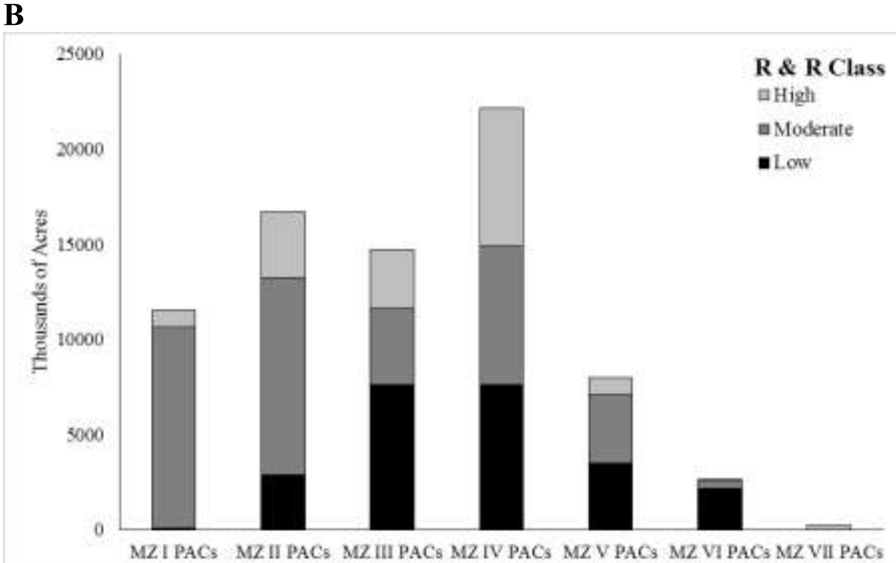


Figure A.7.1. Relative resilience and resistance in thousands of acres for (A) the management zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ. The resilience and resistance categories are explained in Appendix 2.

Table A7.1. Area and percentage of resilience and resistance classes for (A) the management zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

A.

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

B.

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

Table A.7.2. Area and percentage of breeding habitat probability category for (A) the management zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

A.

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

B.

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

Table A.7.3. Area and percentage of breeding habitat probability category by resilience and resistance class for (A) the management zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

A.

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

Unsuitable	447,209	19	29,210	1	875	0
Total	1,998,149		409,654		6,088	
MZ VII						
High	1,530	0	4,277	0	108,532	9
Moderate	236,219	20	23,873	2	125,936	11
Low	173,717	15	102,109	9	256,693	22
Unsuitable	18,368	2	48,244	4	80,532	7
Total	429,833		178,503		571,693	

B.

Breeding Habitat Probability	**Resilience & Resistance**					
	Low		**Moderate**		**High**	
	Acres	*%*	*Acres*	*%*	*Acres*	*%*
MZ I PACs						
High	17,400	0	3,507,329	30	359,745	3
Moderate	59,363	1	4,882,662	42	301,332	3
Low	20,147	0	1,919,033	17	192,156	2
Unsuitable	911	0	238,578	2	47,959	0
Total	97,822		10,547,602		901,192	
MZ II PACs						
High	673,119	4	3,547,203	21	993,466	6
Moderate	1,268,264	8	4,858,003	29	1,140,357	7
Low	799,051	5	1,734,161	10	881,707	5
Unsuitable	131,216	1	244,175	1	431,869	3
Total	2,871,650		10,383,542			
MZ III PACs						
High	2,714,174	19	1,434,391	10	839,004	6
Moderate	2,421,787	17	1,392,232	9	1,019,175	7
Low	1,667,920	11	962,210	7	738,129	5
Unsuitable	810,865	6	213,047	1	457,001	3
Total	7,614,745		4,001,880		3,053,309	
MZ IV PACs						
High	1,647,168	7	2,445,083	11	2,328,631	11
Moderate	2,588,270	12	2,503,692	11	1,943,482	9
Low	2,085,224	9	1,648,712	7	1,439,786	7
Unsuitable	1,303,025	6	657,672	3	1,455,823	7
Total	7,623,687		7,255,160		7,167,721	
MZ V PACs						
High	494,897	6	1,112,332	14	118,204	1
Moderate	1,325,037	17	1,105,710	14	219,886	3
Low	1,102,262	14	887,674	11	216,505	3

Unsuitable	569,967	7	453,059	6	343,722	4
Total	3,492,163		3,558,775		898,317	
MZ VI PACs						
High	693,992	29	160,263	7	1,146	0
Moderate	458,613	19	121,744	5	982	0
Low	371,502	16	88,104	4	3,085	0
Unsuitable	435,285	18	28,762	1	875	0
Total	1,959,392		398,873		6,088	
MZ VII PACs						
High	206	0	2,320	1	94,452	41
Moderate	1,591	1	3,512	2	63,245	27
Low	267	0	10,799	5	44,166	19
Unsuitable	25	0	3,384	1	8,156	4
Total	2,089		20,016		210,019	

Table A.7.4. Relative percentage of the GRSG population by resilience and resistance class for (A) the management zones (MZs; Stiver et al. 2006) and (B) the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

A.

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

B.

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

Appendix 8. Tables summarizing fire area by resilience and resistance class for each management zone (MZs; Stiver et al. 2006) and the Priority Areas for Conservation (PACs; USFWS 2013) within each MZ.

Table A.8.1. Area and percentage of fires >1000 acres (4 km^2) (MTBS 2014) that burned within the occupied range of GRSG from 1984-1999 and from 2000-2015 by resilience and resistance class.

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

MZ VII						
High	0	0	0	0	0	0
Moderate	0	0	0	0	0	0
Low	0	0	0	0	0	0
Total	0	0		0	0	
TOTAL						
High	1,368,908	5,540	17	2,412,217	9,762	17
Moderate	2,475,868	10,019	31	5,006,016	20,259	36
Low	4,237,237	17,148	52	6,611,679	26,757	47
Total	8,082,013	32,707		14,029,912	56,777	

Table A.8.2. Area and percentage of fires > 1000 acres (4 km^2) (MTBS 2014) that burned in the Priority Areas for Conservation (PACs; USFWS 2013) within each management zone (MZ; Stiver et al. 2006) from 1984-1999 and from 2000-2015 by resilience and resistance class.

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

TOTAL						
High	637,607	2,580	21	1,254,882	5,078	20
Moderate	1,020,536	4,130	33	2,730,910	11,052	42
Low	1,429,146	5,784	46	2,443,294	9,888	38
Total	3,087,289	12,494		6,429,086	26,018	