Chapter 7: Effects of Climate Change on Rangeland Vegetation in the Northern Rockies Region

Matt C. Reeves, Mary E. Manning, Jeff P. DiBenedetto, Kyle A. Palmquist, William K. Lauenroth, John B. Bradford, and Daniel R. Schlaepfer

Introduction

Rangelands are dominated by grass, forb, or shrub species, but are usually not modified by using agronomic improvements such as fertilization or irrigation (Lund 2007; Reeves and Mitchell 2011) as these lands would normally be considered pastures. Rangeland includes grassland, shrubland, and desert ecosystems, alpine areas, and some woodlands (box 7.1). This chapter addresses the potential effects of climate change on rangeland vegetation in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area (GYA), hereafter called the Northern Rockies region. Within the Northern Rockies region, rangelands occupy more than 65 million acres (Reeves and Mitchell 2011). Ecosystem services derived from these rangelands include forage for millions of domestic and wild ungulates, greater sage-grouse (*Centrocercus urophasianus*) habitat, and numerous recreational opportunities (see Chapter 10).

The sustainability of goods and services is threatened by land-use change, such as residential development, energy development, and invasion by nonnative plant species (see Chapter 11). These threats, expressed against the backdrop of climate change, pose unique challenges for managers in the Northern Rockies region**.** The effects of climate change on rangelands have received less attention than effects on forests, but similar to forests, past and future human land-use activities may exceed climate change effects, at least in the short term (Peilke et al. 2002). Interactions among land-use change, management, and climate change are not well understood and are difficult to forecast. Therefore, this analysis of potential climate change effects on rangelands does not explicitly include estimates of future land-use change or management, and instead focuses on estimated regeneration success, response to disturbance (especially fire), and life history traits.

Relative to forests, rangelands usually occur in more arid environments, either due to edaphic (e.g., some montane grasslands, subalpine shrublands, and fell-fields) or climatic factors. These arid conditions present challenges for studying the effects of climate change because some rangelands will be less resilient to changes in environmental

Box 7.1—Rangeland Definitions used by Different Federal Agencies

U.S. Forest Service

Land primarily composed of grasses, forbs, or shrubs. This includes lands vegetated naturally or artificially to provide a plant cover managed like native vegetation and does not meet the definition of pasture. The area must be at least 1.0 acre in size and 120.0 feet wide (USDA FS 2010).

Bureau of Land Management

Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows (Society for Range Management 1998).

Natural Resources Conservation Service

A land cover/use category that includes land on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and practices such as deferred grazing, burning, chaining, and rotational grazing, are used with little or no chemicals/fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain low forb and shrub communities, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland (USDA 2009).

influences such as fire regimes and periodicity of precipitation. Understanding resistance and resilience for rangelands is important for estimating possible effects of climate change. In broad terms, resilience refers to the capacity of ecosystems to regain structure, processes, and functioning in response to disturbance (Allen et al. 2005; Holling 1973), whereas resistance describes capacity to retain these community attributes in response to disturbance (Folke et al. 2004). These concepts are especially critical when considering establishment of nonnative plants and interactions between climate change stressors (Chambers et al. 2014). In the Northern Rockies region, areas with higher precipitation and cooler temperatures generally result in greater resources and more favorable conditions for plant growth and reproduction (Alexander et al. 1993; Dahlgren et al. 1997). These concepts are demonstrated in fig. 7.1, which indicates that management for ecosystem services derived from rangelands will be relatively more effective in more mesic rangelands.

In this chapter we explore potential effects of climate change on selected rangeland habitats. The evaluation of risk was qualitatively and synthetically determined by using a combination of workshop output, literature (where available), and the judgment of the authors and two reviewers. It is meant to represent our best guess as to the relative vulnerability of each system to estimated perturbations brought forth by expected changes in climate across the Northern Rockies region.

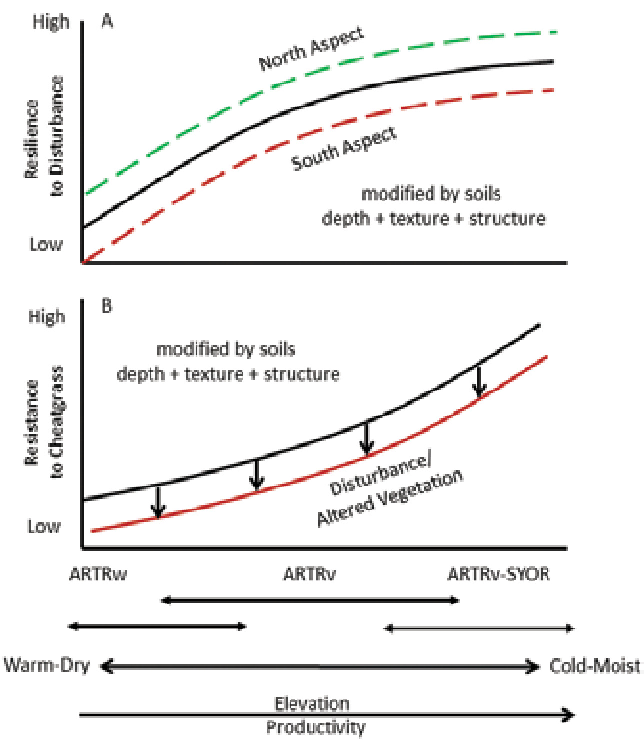

Figure 7.1—Resilience to disturbance (a) and resistance to cheatgrass (b) over a typical temperature/precipitation gradient in the cold desert. Dominant ecological sites occur along a continuum that includes Wyoming big sagebrush on warm and dry sites, to mountain big sagebrush on cool and moist sites, to mountain big sagebrush and root-sprouting shrubs on cold and moist sites. Resilience increases along the temperature/precipitation gradient and is influenced by site characteristics like aspect. Resistance also increases along the temperature/precipitation gradient and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. ARTRw = Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis); ARTRv = mountain big sagebrush (A. tridentata ssp. vaseyana); SYOR = mountain snowberry (Symphoricarpos oreophilus) (modified from Chambers et al. 2014).

Vegetation Classes

The rangeland assessment focuses largely on groupings of vegetation types but also references individual species where information and data suggest inferences can be made for species. We identified rangeland vegetation to be included in the vulnerability assessment by first reviewing the extent of rangelands within the conterminous United States (Reeves and Mitchell 2011). The National Resources Inventory definition (box 7.1) of rangelands was used to identify rangelands within the Northern Rockies region. The list of U.S. Ecological Systems designated as rangelands that were retained for evaluation is found in table 7.1. The great complexity of rangeland vegetation combined with a paucity of studies on climate change effects suggests that a grouping of individual vegetation types into classes would be useful. The resulting groups to be analyzed are the northern Great Plains, montane shrubs, montane grasslands (referred to as “western grasslands”), and sagebrush systems. It is important for the reader to understand that multiple vegetation types make up each of the four broad classes of vegetation. In the case of sagebrush systems, however, four groups (big sagebrushes, short sagebrushes, sprouting sagebrushes, and mountain sagebrush) were subsequently further permuted by individual types (table 7.1).

The northern Great Plains has a broad geographic expanse and mixture of both cool-season (C3) and warm-season (C4) species. Montane shrubs are species important for browsing by native ungulates. The relatively rare montane grasslands have a unique position on the landscape, dominance of cool-season species, and specific types of habitats they provide in juxtaposition to forest vegetation.

Sagebrush systems (dominated by species in the genus *Artemisia*) provide critical wildlife habitat, including for the imperiled greater sage-grouse, and are a ubiquitous and iconic species in much of the western United States. In addition, sagebrush systems, especially those dominated by big sagebrushes, have been more widely studied, at least partially as a result of recent research on sage-grouse habitat. Therefore, the vulnerability of some sagebrush species is supported by a richer body of information than for other vegetation. But this does not mean that all sagebrush types have been studied equally in the context of climate change.

Table 7.1—Aproximate area of U.S. Ecological Systems identified as rangelands within the NRAP assessment region. Sagebrush systems were further subdivided into mountain, low, and big or sprouters. These distinct species were grouped into the "big or sprouters" category only for developing map legends because, using the mid-level Ecological Systems mapping approach, without external data, it would be difficult to differentiate each unique cover type dominated by the various *Artemisia* spp. across the landscape.

Rangeland vegetation types	Ecological system	Area	Sagebrush grouping
		Acres	
Northern Great Plains (C3/C4 mix)	Central Tallgrass Prairie	479,899	NA
	Northwestern Great Plains Mixedgrass Prairie	37,818,629	NA
	Western Great Plains Sand Prairie	2,285,234	NA
	Western Great Plains Shortgrass Prairie	39,543	NA
	Western Great Plains Tallgrass Prairie	7,763	NA
	North-Central Interior Sand and Gravel Tallgrass Prairie	209,599	NA
	Northern Tallgrass Prairie	367,864	NA
	Great Plains Prairie Pothole	262,813	NA
Total		**41,471,344**	**NA**
Montane shrubs	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	1,257,671	NA
	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	175,887	NA
	Rocky Mountain Lower Montane-Foothill Shrubland	4,602	NA
Total		**1,438,160**	**NA**
			NA
Montane grasslands (C3)	Columbia Plateau Steppe and Grassland	1,257,642	NA
	Columbia Basin Palouse Prairie	2,692,161	NA
	Columbia Basin Foothill and Canyon Dry Grassland	58,773	NA
	Inter-Mountain Basins Semi-Desert Grassland	42,311	NA
	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	14,419	NA
	Northern Rocky Mountain Subalpine-Upper Montane Grassland	5,957	NA
Total		**4,071,263**	**NA**
Sagebrush systems	*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance	2,931,640	Mountain
	Inter-Mountain Basins Big Sagebrush Steppe	9,656,339	Big or sprouter
	Inter-Mountain Basins Big Sagebrush Shrubland	2,451,624	Big or sprouter
	Inter-Mountain Basins Montane Sagebrush Steppe	1,993,178	Big or sprouter
	Columbia Plateau Low Sagebrush Steppe	156,012	Low
	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	49,723	Low
	Inter-Mountain Basins Semi-Desert Shrub-Steppe	41,572	Big or sprouter
	Great Basin Xeric Mixed Sagebrush Shrubland	17,970	Low
	Columbia Plateau Scabland Shrubland	14,529	Big or sprouter
Total		**17,312,587**	
All rangelands total		**64,293,354**	

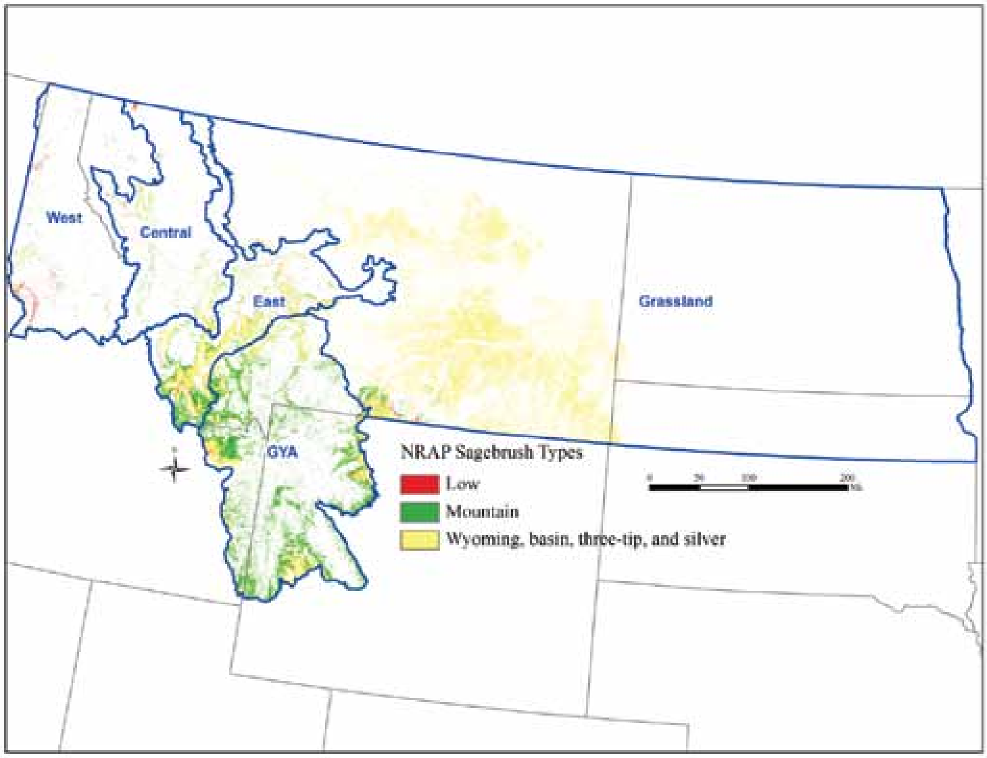

Figure 7.2—Estimated distribution of various sagebrush vegetation classes in the Northern Rockies.

To reflect the disparate amount of study on climate change effects on sagebrush species, four sagebrush types were delineated for the Northern Rockies for this study (fig. 7.2, sagebrush types):

- Big sagebrushes: Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*) and basin big sagebush (*A. tridentata* ssp*. tridentata*)
- Low sagebrushes: low sagebrush (*A. arbuscula*) and black sagebrush (*A. nova*)
- Sprouting sagebrushes: silver sagebrush (*A. cana*) and threetip sagebrush (*A. tripartita*)
- Mountain big sagebrush (*A. tridentata* ssp*. vaseyana*)

Figure 7.2 does not represent an exact accounting of these four vegetation classes but suggests an estimated distribution where each grouping is usually found. In addition, when Ecological Systems are mapped at this level, it is not possible to differentiate the distribution of silver and threetip sagebrush as they are often disjunctively commingled with other types. As a result, only three categories are mapped; within the largest category, the big sagebrushes and sprouting sagebrushes are all represented in one estimated distribution.

The Wyoming and basin big sagebrush types were aggregated because they have similar life histories, stature, and areal coverage in the Northern Rockies region, and represent critical habitats for many species of birds and wild and domestic ungulates. Despite similar life history traits, basin big sagebrush occupies sites with deeper soils (often on alluvial fans). These conditions tend to increase available moisture with higher coverage by perennial bunchgrasses, suggesting these sites may be more resilient and resistant to various threats (Chambers et al. 2007). Similarly, the low sagebrushes were chosen for the unique habitats they represent (especially black sagebrush) and similar life histories. Both silver sagebrush and threetip sagebrush can resprout after fire, making them unique in that regard among the sagebrush species, with the exception of periodic sprouting by some variants of mountain big sagebrush.

Finally, mountain big sagebrush was chosen for its (usually) distinct positioning on the landscape, in addition to being the most mesic of sagebrush communities in the Northern Rockies region. Communities dominated by Wyoming big sagebrush are by far the most common and occupy the greatest area (table 7.2), whereas the low sagebrush type occupies the least. However, although basin and Wyoming big sagebrush are common throughout the Northern Region, mountain big sagebrush communities occupy the greatest extent on lands managed by the USFS. Although the communities dominated by the *Artemisia* species listed here were subdivided for evaluating possible effects of climate change, four species (basin big, Wyoming big, threetip, and silver) were grouped for mapping purposes as the “big or sprouter” category (table 7.1) because differentiating them across the landscape was impractical.

Vegetation Productivity in Response to Climate Change

Although the current extent of rangeland in the Northern Rockies region can be accurately described, uncertainty in

Table 7.2—Area of rangeland vegetation classes evaluated in each NRAP subregion.

Subregion	Rangeland vegetation classes	Area	Proportion
		Acres	*Percent*
Western Rockies	Montane grasslands	596,837	34.4
	Montane shrubs	298,153	35.7
	Sagebrush systems	358,086	29.9
Total		**1,253,076**	
Central Rockies	Montane grasslands	845,539	43.6
	Montane shrubs	173,980	18.6
	Sagebrush systems	507,391	37.8
Total		**1,526,909**	
Eastern Rockies	Montane grasslands	735,758	13.5
	Montane shrubs	328,306	12.5
	Northern Great Plains (C3/C4 mix)	221,193	5.9
	Sagebrush systems	2,572,138	68.2
Total		**3,857,395**	
Grassland	Montane grasslands	1,343,858	1.8
	Montane shrubs	266,233	0.7
	Northern Great Plains (C3/C4 mix)	41,204,297	80.6
	Sagebrush systems	8,586,897	16.8
Total		**51,401,285**	
Greater Yellowstone Area	Montane grasslands	549,271	6.1
	Montane shrubs	371,488	8.5
	Northern Great Plains (C3/C4 mix)	45,848	0.7
	Sagebrush systems	5,288,075	84.7
Total		**6,254,682**	
All subregions total		**128,586,695**	

the underlying global climate models (GCMs) used to estimate climate change effects (see Chapter 3), and uncertainty in models of physiological response, make it difficult to confidently project the effects of climate change on rangelands. Our understanding of the potential effects of climate change in the region can be improved if comparisons of impacts are made with other areas.

The primary inference about climate change effects on rangeland vegetation nationally is one of increasing temperature, lower soil moisture, changing phenology, and decreasing annual production. However, projected temperatures exhibit far less variability among scenarios and GCMs than precipitation. Therefore, areas where projections suggest that temperature rather than precipitation is a dominant driver may be more reliable. Figure 7.3 suggests that, relative to much of the rest of the United States, the Northern Rockies region could experience an increase in annual net primary productivity (NPP). In addition, the modeled overall increases in productivity appear to be more consistent in the region compared with other areas because there is less disagreement among the three emissions scenarios evaluated (Nakićenović et al. 2000; Reeves et al. 2014).

Changing climate regimes will also influence phenology in unexpected ways. For example, in tallgrass prairie (a rare type in the Northern Rockies region), a 7.2 °F increase in ambient temperature caused earlier anthesis among spring-blooming species and later anthesis in fall-blooming species (Sherry et al. 2007), implying that climate change will influence vegetation in complex ways (Suttle et al. 2007; Walther 2010). In addition, effects of climate change may be greater at higher elevations (Beniston et al. 1997) (fig. 7.3), a logical projection for the Northern Rockies region, where

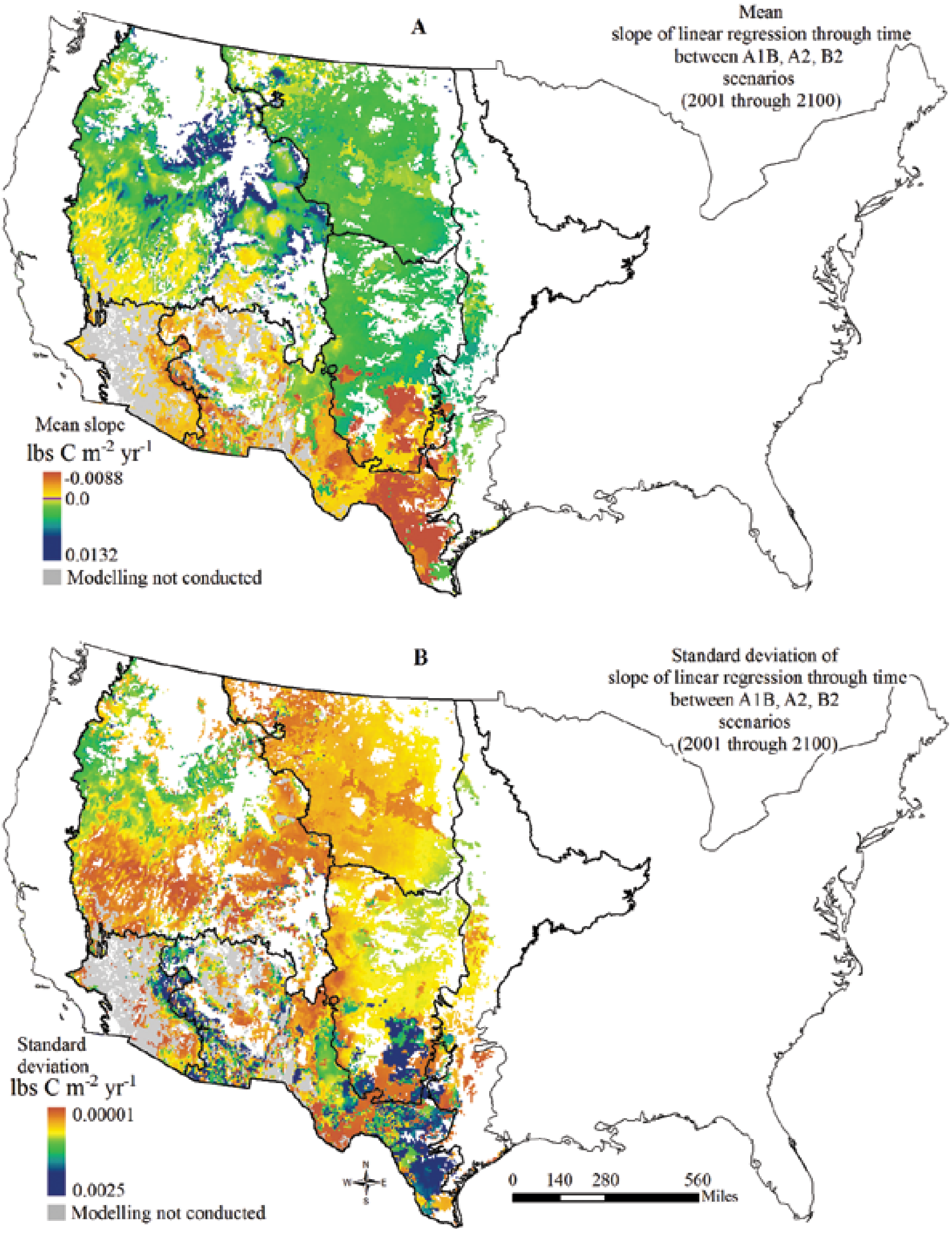

Figure 7.3—Mean slope of linear regression of the net primary productivity trend for the B2, A1B, and A2 emission scenarios (models averaged here include: GCGM2, HadCM3, CSIRO, MK2, MIROC3.2) (a) and standard deviation of the mean slope of linear regression of the net primary productivity trend for the same scenarios (b) (from Reeves et al. 2014).

the primary factor limiting plant growth at high elevations is growing season length and cold temperatures.

The modeled overall effect of projected climate change in the Northern Rockies region is apparently increased growing season length and increased NPP, which may be especially pronounced at higher elevations. Removal of growth limitations could result in significant changes in vegetation at higher elevations, such as the Greater Yellowstone Area subregion. Higher NPP may seem counterintuitive because increased temperatures suggest greater moisture stress and therefore potentially less favorable growing conditions. Indeed, if all other factors besides temperature remained constant in the future, then vegetation might undergo significant reductions in productivity from increased evaporative demand and reduced soil moisture. Conversely, some high-elevation areas may experience increased production with increasing temperatures (Reeves et al. 2014), especially relatively mesic areas supporting mountain sagebrush.

Increased atmospheric carbon dioxide (CO_2) concentrations may modify ecophysiological growth processes in rangeland vegetation. Carbon dioxide enrichment can enhance water use efficiency through reduced water lost through stomata (see Chapter 6), but the response is not consistent across all vegetation. For example, in tallgrass prairie, Owensby et al. (1999) found that elevated CO_2 could increase productivity of aboveground and below-ground biomass, but response depended on water stress. These findings are consistent with results from Reeves et al. (2014) and suggest that desiccation effects of increased temperature can be offset to some extent by CO_2 enrichment via reduced transpirational demand (Leakey 2009; Morgan et al. 2004b, 2011; Woodward and Kelly 2008) and higher water use efficiency (Bachelet et al. 2001; Christensen et al. 2004; Morgan et al. 2008, 2011; Polley et al. 2003).

Recent experimental research on the northern Great Plains is particularly relevant to the managers in the Grassland subregion where northern mixed-grass prairie dominates. The Prairie Heating and CO_2 Enrichment (PHACE) study reported an increase of aboveground productivity by an average of 33 percent over 3 years (Morgan et al. 2011), which substantiates estimates by Reeves et al. (2014) of a 28-percent increase in productivity for the northern Great Plains by 2100.

As a footnote to the preceding discussion, it is important to note that all models are a simplification of reality, and interpretation of model results needs to consider uncertainty, inputs, and model assumptions. Models cited here have increasing disparity as time progresses, especially in more arid regions where changing precipitation amounts and patterns may be the primary driver of change.

Management Concerns

The primary management and ecological concerns identified as affecting rangelands in the Northern Rockies region include uncharacteristic fire regimes, improper grazing, and invasive species. Uncharacteristic fire regimes, which are based on the historical fire regime, threaten some rangeland habitats, especially sagebrush steppe, across much of the western United States, including the Northern Rockies region. The overall concern over uncharacteristic fire regimes is perhaps smaller than for other regions such as the Great Basin. On one end of the spectrum, the shortened fire return intervals of many sagebrush habitats suggest that "too much" fire currently affects the landscape relative to historical fire regimes. It is widely documented that increasing dominance of invasive annual grasses has created a positive feedback cycle characterized by frequent fire followed by increased dominance of annual grasses, which further create fuel conditions that facilitate combustion (Chambers et al. 2007). These conditions are exacerbated by wetter and warmer winters, which are projected throughout the region in the future.

On the other end of the spectrum, fire exclusion has led to decreased fire return intervals, which may be responsible for Douglas-fir (*Pseudotsuga menziesii*) encroachment into montane grasslands (Arno and Gruell 1986), and into higher elevation sagebrush habitats, especially those dominated by mountain big sagebrush (Heyerdahl et al. 2006) (fig. 7.4). Overall, the invasive species of greatest concern in sagebrush communities throughout Northern Rockies rangelands is cheatgrass (*Bromus tectorum*), although Japanese brome (*B. japonicus*) and leafy spurge (*Eurphorbia esula*) are also concerns in the northern Great Plains. Recent range expansion of cheatgrass is particularly prominent in the western half of the Northern Rockies region and can be somewhat explained by genetic variation leading to increased survival and persistence in otherwise marginal habitats (Merrill et al. 2012; Ramakrishnan et al. 2006). This rapid range

Figure 7.4—Conifer encroachment, predominantly ponderosa pine into a montane grassland, including the ubiquitous graminoid rough fescue (photo: Mary Manning, USDA Forest Service).

expansion may be enhanced by elevated atmospheric CO_2 concentrations and increased soil disturbance (Chambers et al. 2014). Improper grazing, a term referring to the mismanagement of grazing that produces detrimental effects on vegetation or soil resources, can exacerbate these conditions (see chapter 6). Generally, however, U.S. rangelands are not improperly grazed (Reeves and Bagget 2014; Reeves and Mitchell 2011) to the point of degradation; improper grazing is not the normal condition across rangelands in the Northern Region. Where improper grazing does occur, it can accelerate the annual grass invasion/fire cycle, especially in some sagebrush types, the northern Great Plains, and montane grasslands.

Broad-Scale Vulnerability of Rangelands to Climate Change

Determining the vulnerability of rangeland vegetation is a difficult task. Uncertainty exists in the projections of future climatic conditions as well as in expected effects of vegetation. Given the lack of studies focused on manipulated climate on vegetation performance, we are limited to past observations, some published scientific studies, and our collective best judgment. Despite the paucity of relevant studies and the uncertainty of projected climates, a few elements of climate change are increasingly recognized as potential outcomes. In this section, we briefly discuss some overarching expected climatic conditions against which we estimate likely outcomes for vegetation in each of the four identified vegetation classes.

Projected temperature increases (Intergovernmental Panel on Climate Change [IPCC] 2014; see also Capter 3) are expected to increase evaporative demand (e.g., potential evapotranspiration) (Klos et al. 2014) and pose the greatest overall temperature stress of all the estimated future climate outcomes (Polley et al. 2013). Projected changes in precipitation patterns and increasing potential evapotranspiration could encourage more frequent and intense fires from the effects of early-season plant growth combined with the desiccating effects of warmer, drier summers (Morgan et al. 2008). Collectively, these changes may result in considerably drier soils, particularly in the summer months when plants are phenologically active (Bradford et al. 2014; Polley et al. 2013). However, winter precipitation is projected to increase by 10 to 20 percent in the Northern Rockies region (IPCC 2014; Shafer et al. 2014; see also Chapter 3), which may compensate for increasing severity and frequency of droughts. In addition, rising CO_2 levels may offset water loss due to higher evaporative demand by increasing stomatal closure and water use efficiency.

Warmer winters and decreasing snowpack may also be significant factors affecting rangeland vegetation classes (discussed next). Minimum temperatures are expected to increase more than maximum temperatures, providing longer frost-free periods. Warmer, wetter winters would favor early-season plant species and tap-rooted species that are able to reach accumulated early growing season soil water (Polley et al. 2013). These conditions are projected to significantly increase annual area burned and fire intensity (Westerling et al. 2006).

Northern Great Plains, Dominated by Mixtures of Cool-Season and Warm-Season Grasses

Eastern grasslands are expansive across the northern Great Plains, extending from the foothill grasslands along the east slope of the northern and central Rocky Mountains in Montana to the Red River basin in eastern North Dakota. Annual precipitation increases from west to east and ecological provinces change from dry temperate steppe to humid temperate prairie parkland along this gradient (Cleland et al. 2007). Grasslands are the predominant potential vegetation type, occupying about 80 percent of the northern Great Plains landscape. Küchler (1975) divides the potential natural vegetation of this area into shortgrass prairie, northern mixed grass prairie, and tallgrass prairie, reflecting the changing precipitation regime. The shortgrass prairie borders the foothill grasslands and extends to eastern Montana. The typical grassland vegetation types are characterized by grama (*Bouteloua* spp.)/needlegrass (*Stipa* spp.)/wheatgrass (*Pseudoroegneria* spp.) and a mix of C3 and C4 plant species. The northern mixed grass prairie borders the shortgrass prairie in eastern Montana and extends to eastern North Dakota. Typical grassland vegetation types are characterized by wheatgrass/needlegrass in the west and wheatgrass/bluestem (*Andropogon* spp.)/needlegrass to the east, including a mix of C3 and C4 plant species. The tallgrass prairie borders the northern mixed grass prairie in eastern North Dakota and South Dakota and borders the eastern hardwood forest to the east. The typical grassland vegetation types are characterized by bluestem and a dominance of C4 grasses, although C3 grass species are present.

Frequent fire was a major factor in maintaining grassland dominance, particularly in the eastern Great Plains. Settlement in the late 19th and early 20th centuries altered fire regimes by reducing fire frequency and changing the seasonality of fire. The predominant land use and land cover changed from grasslands to crop agriculture and domestic livestock production, affecting the continuity of fuels and fire spread. Reduced fire coupled with increased CO_2 has encouraged woody plant encroachment, primarily in the eastern Great Plains (Morgan et al. 2008).

Other stressors include increased presence and abundance of competitive invasive grass and forb species. These species reduce plant diversity of native grasslands and alter grassland structure. Noxious weeds such as leafy spurge (*Euphorbia esula*) are abundant in places, and other invasive nonnative species include Kentucky bluegrass (*Poa pratensis*), Japanese brome, and cheatgrass. In addition, energy development and the associated infrastructure fragments local grassland patterns where it occurs. Roads and traffic increase opportunities for introduction and spread of invasive species.

Soil water availability and water stress are principal driving factors in semiarid grasslands, influencing plant species distribution, plant community composition and structure, productivity, and associated social and economic systems of the northern Great Plains. Soil water availability is influenced by complex interactions among temperature, precipitation, topography, soil properties, and ambient CO_2 (Ghannoum 2009; Morgan et al. 2011). These physical factors interacting with plant species physiological mechanisms, particularly those of C3 and C4 plants, will influence how grasslands will respond to climate change and elevated atmospheric CO_2 levels (Bachman et al. 2010; Chen et al. 1996; Ghannoum 2009; Morgan et al. 2011).

Available soil water is unevenly distributed across landscapes and is a function of landform, topography, and soil properties. Soil moisture loss through evapotranspiration is influenced by slope, aspect, and solar loading at the ground surface, and water holding capacity is influenced by soil properties. These characteristics in the northern plains may modify the effects of climate change and enhanced CO_2 locally. Landscape patterns of available soil water may result in uneven patterns of vegetation change and productivity under changing temperature and moisture regimes and elevated CO_2 levels. The desiccating effect of higher temperature and increased evaporative demand (Morgan et al. 2011) is expected to offset the benefit of higher precipitation, resulting in lower soil water content and increased drought throughout most of the Great Plains (Morgan et al. 2008). Elevated CO_2 may counter the effects of higher temperatures and evaporative demand by improving water use efficiency of plants (Morgan et al. 2011).

Rising CO_2 and temperature combined with increased winter precipitation may favor some herbaceous forbs, legumes, and woody plants (Morgan et al. 2008). Plant productivity is expected to increase with projected changes in temperature and moisture combined with elevated CO_2 (Morgan et al. 2008). Forage quality may decline as a result of less available forms of soil nitrogen and changes in plant species and functional groups (Morgan et al. 2008). A major shift in functional groups from C3 to C4 plants is possible but uncertain; warmer temperature and longer growing seasons favor C4 grasses, but the effects of higher CO_2 on water-use efficiency may benefit C3 grasses. Most invasive species are C3 plants, so they may become more problematic with the benefits of increased CO_2 (Morgan et al. 2008).

The adaptive capacity of Great Plains grasslands during the drought of the 1930s and 1950s was documented for the central plains (Weaver 1968). There was a shift in C4 grasses, in which big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*) were replaced by the shortgrass species blue grama (*Bouteloua gracili*) and buffalograss (*B. dactyloides*). Shifts from tallgrass prairie to mixed grass prairie were also documented with an increase in the C3 plants western wheatgrass and needlegrass. This shift was later reversed during the higher precipitation period of the 1940s, indicating historical adaptive capacity of Great Plains grasslands to the effects of long-term drought. These shifts were also affected by grazing condition of the grasslands before the drought.

Risk Assessment

Magnitude of effects: Moderate magnitude for change from temperate grassland to subtropical grassland by 2050 under no fire suppression. Change toward increased woody vegetation by 2050 with fire suppression. High magnitude for change from temperate grassland to subtropical grassland by 2100. Moderate magnitude for change toward woody vegetation by 2100.

Likelihood of effects: Moderate likelihood for change from temperate grassland to subtropical grassland by 2050 with no fire suppression, and moderate likelihood for change to increased woody vegetation by 2050 with fire suppression. The response of C3 and C4 species to the combined effects of higher temperature and elevated CO_2 is uncertain.

Communities Dominated by Montane Shrubs

Montane shrubs are typically associated with montane and subalpine forests, and occur as large patches within forested landscapes. Species such as Rocky Mountain maple (*Acer glabrum*), oceanspray (*Holidiscus discolor*), tobacco brush (*Ceanothus velutintis* var. *velutinus*), Sitka alder (*Alnus viridus* subsp. *sinuata*), thimbleberry (*Rubus parviflorus*), chokecherry *(Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), currant (*Ribes* spp.), snowberry (*Symphoricarpos albus*), Scouler willow (*Salix scouleriana*), and mountain ash (*Sorbus scopulina*) are common.

Montane shrubs persist on sites where regular disturbance kills the top of plants. This, along with full sunlight and adequate soil moisture, stimulates regrowth from the root crown, rhizomes, and roots. Stressors include fire exclusion and conifer establishment, browsing by both native and domestic wildlife, and insects and disease. Loss of topsoil following frequent, hot fires, can lead to loss of these species over time (Larsen 1925; Wellner 1970). Mesic shrubs are well adapted to frequent fire, and under the right conditions can expand and outcompete regenerating conifers. However, with declining snowpack and warmer temperatures, fires may be hotter and sites may be drier, causing variable amounts of mortality, depending on site conditions.

Mesic shrubs are well adapted to frequent fire (Smith and Fisher 1997) and sprout vigorously after fire, enabling them to quickly regain dominance on the site. As sites become drier and fires become more frequent and severe, however, there may be a shift away from mesic species to more xeric species such as rubber rabbitbrush (*Ericameria nauseosa*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and spineless horsebrush (*Tetradymia canescens*). Nonnative invasive plant species may also expand into these communities, particularly following fire (Bradley 2008;

D'Antonio and Vitousek 1992). With warmer temperatures and drier soils, some mesic shrub species (e.g., Sitka alder and Rocky Mountain maple) may shift their distribution up in elevation or to cooler, moister sites (e.g., northeast-facing depressions).

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: High

Montane Grasslands

Montane grasslands are associated with mountainous portions of the Northern Rockies region including the Palouse prairie and canyon grasslands of northern and central Idaho. Montane grasslands occur in intermountain valleys, foothills, and mountain slopes from low to relatively high elevation. They are dominated by C3 grasses, along with a large number of forbs and upland sedges. Shrubs and trees may occur with low cover. Dominant species include bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), Idaho fescue (*F. idahoensis*), Sandberg bluegrass (*Poa secunda*), needle-and-thread (*Hesperostipa comata*), western wheatgrass (*Pascopyrum smithii*), prairie junegrass (*Koeleria macrantha*), western needlegrass (*Achnatherum nelsonii*), and Richardson's needlegrass *(A. richardsonii*).

Many low-elevation grasslands have been converted to agricultural use or are grazed by domestic livestock. They have also been subjected to extensive human use and land use conversion. Those grasslands that remain, particularly at lower elevations, are typically highly disturbed, fragmented, and frequently occupied by many nonnative invasive plant species. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors in these grasslands (Finch 2012). Loss of topsoil can occur if vegetation cover and density decline and bare ground increases. Lack of fire is also a chronic stressor because conifers from lower montane forests can become established in some areas, and can increase in density and cover with fire exclusion (Arno and Gruell 1986; Heyerdahl et al. 2006). As conifer density and cover increase with fire exclusion, grass cover declines because most grassland species are shade-intolerant (Arno and Gruell 1983). If fires become hotter and more frequent, however, there is an increased risk of mortality of native species and invasion by nonnative plant species. But invasive plants may not always establish and dominate a site (Ortega et al. 2012; Pearson et al., in review) under these conditions. If spring and winter precipitation increase, some expect exotic annual grasses, particularly cheatgrass, which germinates in the winter/early spring, to establish and set seed earlier than native perennial grasses (Finch 2012). This would create an uncharacteristic, continuous fine fuel load that is combustible by early summer and capable of burning native perennial grasses often before they have matured and set seed (Bradley 2008; Chambers et al. 2007). Other nonnative species, such as spotted knapweed (*Centaurea melitensis*), Dalmatian toadflax (*Linaria dalmatica*), butter-and-eggs (*Linaria vulgaris*), and sulphur cinquefoil (*Potentilla recta*) respond favorably after fire and can increase in cover and density.

Nonnative invasive plant species will probably expand, particularly in the lower elevation grassland communities, because resistance to invasion may decrease as these communities become warmer and drier (Chambers et al. 2014). Greater disturbance is likely to increase the rate and magnitude of infestation (Bradley 2008). In addition, drier site conditions coupled with ungulate effects (grazing, browsing, hoof damage) and the associated increases in surface soil erosion may increase bare ground (Washington-Allen et al. 2010). Low-elevation grasslands may shift in dominance towards more drought-tolerant species. Some model output, such as MC2 (Bachelet et al. 2001) (see Chapter 6), suggests that C3 grasslands will decline and C4 grasslands will expand based solely on temperature trends. However, elevated CO_2 favors C3 grasses and enhances biomass production, whereas warming favors C4 grasses due to increased water use efficiency (Morgan et al. 2004a, 2007). Although C3 grasses dominate western montane grasslands, a warmer and drier climate may allow C4 grasses (primarily northern Great Plains species) to expand westward into montane grasslands. In general, it is likely that with increased warming and more frequent fires, grasslands will become a more dominant landscape component as shrublands and lower montane conifer forests are burned more frequently and unable to regenerate. Increasing fire would also lead to the expansion of invasive species into grasslands (Bradley 2008; D'Antonio and Vitousek 1992).

Risk Assessment

Magnitude of effects: High
Likelihood of effects: High

Sagebrush Systems

Communities Dominated by Wyoming Big Sagebrush and Basin Big Sagebrush

The current distribution of Wyoming big sagebrush ecosystems in the Northern Rockies region is generally patchy throughout most of Montana with more spatially consistent cover in the Eastern Rockies and Grassland subregions (Comer et al. 2002). As previously mentioned, the distribution of basin big sagebrush habitats is generally restricted to deeper soils, often including alluvial fans. Stressors to both Wyoming and basin big sagebrush communities include prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage). In contrast with mountain and basin big sagebrush habitats, Wyoming big sagebrush habitats spatially coincide with oil and gas development, which is prominent on the eastern edge of its distribution. The Grassland and Greater Yellowstone Area subregions contain the largest extent of these two big sagebrushes, although the Western Rockies subregion may contain the largest amount of basin big sagebrush.

Big sagebrush ecosystems have decreased in spatial extent in the 20th century (Bradley 2010; Knick et al. 2003; Manier et al. 2013; Noss et al. 1995) because of oil and gas development (Doherty et al. 2008; Walston et al. 2009), removal of big sagebrushes to increase livestock forage (Shane et al. 1983), plant pathogens and insect pests (Haws et al. 1990; Nelson et al. 1990), improper grazing (Davies et al. 2011), invasive species (D'Antonio and Vitousek 1992; Davies 2011), and changes in disturbance regimes (Baker 2011; Balch et al. 2013). Oil and gas development, along with urbanization and land conversion for agriculture and livestock grazing, lead not only to habitat loss, but to fragmented habitat patches (Naugle et al. 2011), resulting in barriers to plant dispersal, avoidance by greater sage-grouse, and loss of obligate and facultative wildlife species (Rowland et al. 2006). In addition to habitat destruction of big sagebrush ecosystems, several stressors can cause big sagebrush dieback and reduce its biomass and density, including insect pests (Haws et al. 1990), plant pathogens (Cárdenas et al. 1997; Nelson et al. 1990), and frost damage (Hanson et al. 1982). Improper use by domestic livestock alters the structure and composition of big sagebrush ecosystems through the loss of palatable components of the plant community (i.e., perennial grasses and forbs), along with reducing or increasing big sagebrush cover (Anderson and Holte 1981; Brotherson and Brotherson 1981), and increasing the probability of nonnative annual grass invasion (Cooper et al. 2007; Davies et al. 2011; Knapp and Soulé 1996). Cheatgrass has reduced the spatial distribution and habitat quality of sagebrush ecosystems throughout much of the western United States (Balch et al. 2013; Brooks et al. 2004).

Invasion by cheatgrass will pose an even greater threat to big sagebrush ecosystems in the future because of projected increases in its biomass production and in fire frequency due to rising temperature and CO_2 levels (Westerling et al. 2006; Ziska et al. 2005). Although less studied, field brome (*Bromus arvensis*) can also negatively affect big sagebrush plant communities because it can colonize readily after stand-replacing fires that eliminate big sagebrushes (Cooper et al. 2007).

Several life history traits of big sagebrushes make them sensitive to direct and indirect effects of climate change. Amount and timing of precipitation control seeding establishment at low elevation, whereas minimum temperature and snow depth control germination and survival at high elevations (Nelson et al. 2014; Poore et al. 2009; Schlaepfer et al. 2014a). Drought events are projected to increase in the western United States in the future (IPCC 2014), although the likelihood of increased drought in the Northern Rockies Region is uncertain (see Chapter 3). Big sagebrush ecosystems remain vulnerable to drought, which may affect germination and survival of seedlings because soil water content primarily controls seedling survival (Schlaepfer et al. 2014a). Big sagebrush seedling survival may be highest in intermediate temperature and precipitation regimes (Schlaepfer et al. 2014b). Even after seedling establishment, drought and increased summer temperature can affect survival and growth of adult plants because growth is positively correlated with winter precipitation and winter snow depth (Poore et al. 2009). Thus, if drought events increase in frequency and severity in the Northern Rockies region, big sagebrush biomass and the abundance and diversity of perennial grasses and forbs may decrease.

It is uncertain if big sagebrush species can move in concert with shifting temperature and precipitation regimes and disperse to available habitat patches and colonize them. Most big sagebrush seeds (50–60 percent) are not viable in the seedbank after 2 years, with few viable seed in the upper soil (Wijayratne and Pyke 2009, 2012). Furthermore, big sagebrushes are poor dispersers (Schlaepfer et al. 2014a; Young and Evans 1989) and seed production is episodic (Young et al. 1989). Even if big sagebrush seeds successfully disperse and germinate in response to a changing climate, probabilities of seedling establishment and adult survivorship are uncertain because big sagebrushes are poor competitors relative to associated herbaceous species (Schlaepfer et al. 2014a).

Big sagebrushes are sensitive to fire and cannot resprout (Shultz 2006). Recovery from seed dispersal can take 50 to 150 years (Baker 2006, 2011), so postfire recovery may become a problem in the future, if the frequency and intensity of fires increase as projected (Abatzoglou and Kolden 2011; Westerling et al. 2006). Regeneration of big sagebrushes postfire is strongly linked to winter precipitation (Nelson et al. 2014), which is expected to increase by 10 to 20 percent in the Northern Rockies region by 2100 (IPCC 2014; Shafer et al. 2014). Although more frequent fire may result in larger losses of big sagebrush habitat in the future, recovery of big sagebrushes may be less impeded. It is also possible that much of this increased precipitation will come as rainfall (Klos et al. 2014), which could, in turn, promote herbaceous growth that might suppress sagebrush recovery in some instances.

Climate change will result in shifts in the distribution of conditions suitable to support big sagebrushes and hence the spatial configuration of big sagebrush habitat, with direct and indirect effects on sagebrush-dependent species (e.g., greater sage-grouse). Several studies using species distribution modeling (SDM) have projected that big sagebrushes will move northward and up in elevation in response to increased winter temperatures and summer drought associated with climate change (Schlaepfer et al. 2012; Shafer et al. 2001). Although big sagebrush species may expand northward and upslope, their habitat is predicted to contract significantly due to increased soil moisture stress, primarily at southern latitudes and lower elevations (fig. 7.5).

The probability of big sagebrush regeneration has been projected to increase at the leading edge of their range (i.e., northern range limit) under future climatic conditions, suggesting potential northward range expansion with climate

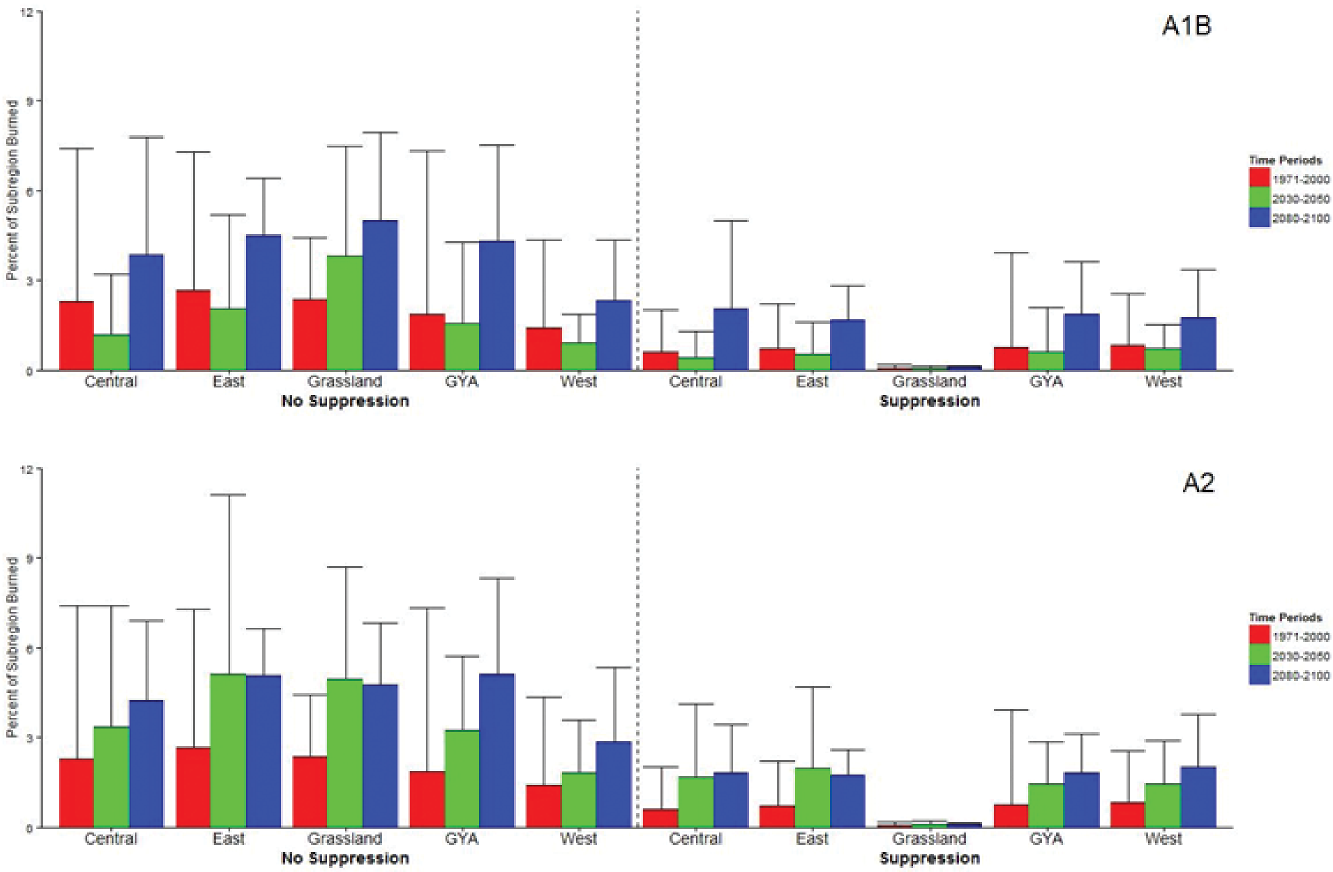

Figure 7.5—Mean and standard deviation of percent of subregions burned across three time spans (historic, 2030–2050, 2080–2100) and without/with fire suppression.

change (Schlaepfer et al. 2015). This is in part due to changes in habitat suitability because soil water conditions at the leading edge will be similar to current soil water patterns in big sagebrush systems. Habitat suitability for big sagebrush species is predicted to increase primarily in northeastern and north-central Montana (Schlaepfer et al. 2015; Schrag et al. 2011) (fig. 7.5). In contrast, habitat suitability is predicted to decrease in parts of the Western Rockies and northwestern Greater Yellowstone Area subregions (fig. 7.5), primarily from summer drought (Schlaepfer et al. 2012; Schlaepfer et al, in review). However, expansion of big sagebrush species out of unsuitable habitat and into suitable habitat is contingent on the ability of the species to disperse to available habitat patches and compete with other species.

In addition to changes in big sagebrush distribution, shifts in community composition and productivity are expected with climate change. Because of the uncertainty about length and severity of drought events in the future, the projected shifts in community composition and productivity in big sagebrush ecosystems in response to climate change remain uncertain. If drought events do increase in the Northern Rockies region, native herbaceous plant diversity and cover may be reduced. In contrast, in nondrought years, warming temperatures and increased levels of CO_2 may lead to increased biomass production (Reeves et al. 2014), more frequent fires, and increases in herbaceous biomass at the expense of fire-intolerant shrubs, such as big sagebrush species.

Paleoecological studies have shown that species move individualistically and at different rates in response to climate change, resulting in novel combinations of species (Delcourt and Delcourt 1981). Even species in the same functional group (e.g., grasses) may respond differentially to climate change (Anderson and Inouye 2001). Thus, big sagebrush plant communities are unlikely to migrate as a unit in response to altered temperature and precipitation. The response of individual species to climate change will depend on both physiological tolerances and competitive ability.

Shifts in disturbance regimes (e.g., fire, insects, pathogens) associated with climate change may affect big sagebrush ecosystems in the future. Disturbances affect vegetation directly by killing individuals and removing aboveground biomass, and indirectly by altering soil conditions. Climate change and disturbance may have additive effects on soil water balance in big sagebrush ecosystems, decreasing soil water content (Bradford et al. 2014) and resulting in diminished growth and regeneration (Poore et al. 2009). Increased disturbance frequency could reduce the spatial extent of big sagebrush in the future, despite increased habitat suitability and regeneration potential, because big sagebrush is incapable of resprouting after disturbance (Shultz 2006). As with other vegetation types, there is great uncertainty and variability regarding estimates of fire return intervals of stands dominated by big sagebrush species. For example, in the Northern Rockies, Lesica et al. (2007) suggest that fire return intervals for Wyoming big sagebrush are longer than for basin big sagebrush and mountain big sagebrush, and range from 50 to 150 years, whereas Baker (2011, 2013) and Bukowski and Baker (2013) estimate ranges of 200 to about 350 years.

The long fire return intervals to which Wyoming big sagebrush is adapted are related to its very slow postfire recovery, as low as 2 percent recovery 23 years after fire (Lesica et al. 2007). The slow recovery of these systems is partly due to slow growth rates and harsher environmental conditions in many sites in the Northern Rockies region. Basin big sagebrush canopy cover development and growth are faster than for Wyoming big sagebrush (Booth et al. 1990; Lesica et al. 2007; McArthur and Welch 1982). Invasive annual grasses such as cheatgrass may exacerbate slow growth.

Big sagebrush ecosystems have some capacity to adapt to climate change. Big sagebrush species occur over a large geographic area with high diversity in topography, soils, and climate, suggesting that these species can withstand a relatively broad range of ecological conditions and may tolerate shifting climates. Various subspecies of big sagebrush often hybridize and have a high level of polyploidy, providing them with the capacity to undergo selection and adapt to shifting climatic regimes relatively quickly (e.g., Poore et al. 2009).

Although lower soil water availability may pose a threat to big sagebrush ecosystems, long periods of sustained drought would be needed to cause mortality (Kolb and Sperry 1999). Even though big sagebrush habitat suitability is projected to change across space (e.g., decreasing suitability in northwestern Wyoming and across much of western Montana), big sagebrush species may still persist in relatively “unsuitable” habitat for some time, perhaps in a degraded state.

Risk Assessment

Magnitude of effects: Highly variable. In northwestern Wyoming and western Montana, the effects of climate change are likely to be low to moderate. Lower water availability may cause declines in big sagebrush growth and regeneration, facilitating some habitat contraction. However, big sagebrush species may expand northward into northern and eastern Montana, as habitat suitability increases in future decades. Despite this generalization, it is also possible that an increase in fire activity will decrease the extent of big sagebrush communities in many locations.

Likelihood of effects: Variable. Some contraction in big sagebrush habitat may occur in northwestern Wyoming and western Montana, particularly at lower elevations, because of increased temperature and evapotranspiration. However, if big sagebrush can successfully exploit changing climatic conditions, the total area covered by big sagebrush species in the Northern Rockies region may increase by the end of the 21st century. Potential expansion may be tempered by faster rates of loss if the cheatgrass-fire cycle tracks new habitats in the northeastern part of the region. It is conceivable that drier sites, such as those with sandy soils, may lose the ability to regenerate sagebrush, whereas more mesic sites might still be able to regenerate.

Communities Dominated by Low Sagebrushes (Black and Low Sagebrush)

The current distribution of low sagebrush ecosystems in the Northern Rockies region is restricted to about 1 percent of the total sagebrush habitat as indicated in the LANDFIRE existing vegetation type (EVT) database. The western portion of the Northern Rockies region contains 50 percent of the low sagebrush habitat, but limited patches are also found in the Eastern Rockies subregion and in the Greater Yellowstone Area subregion, especially on the western edge. Most of these sites support low sagebrush but not black sagebrush. Low sagebrush sites are characterized as relatively low-production areas over shallow, claypan soils that restrict drainage and root growth. Low sagebrush is found on altitudinal gradients from 2,300 feet to more than 11,500 feet (Beetle and Johnson 1982), and it is generally found between 6,000 and 9,000 feet in Montana and Idaho. In contrast, black sagebrush is considerably more restricted in ecological amplitude and is found on shallow, dry, infertile soils. Current stressors are predominantly improper use by livestock and invasion by nonnative species.

Despite growing across a broad range of elevations, low and black sagebrush are less common than other sagebrush species. Thus, it is reasonable to assume that as climates change, ranges could be further restricted, resulting in small islands being isolated, although this is more likely for black sagebrush because of its poor competitive ability (West and Mooney 1972). Both species depend heavily on seeding for reproduction (Wright et al. 1979) and recovery from disturbance. In addition, several traits make low sagebrush species sensitive to climate change. There is high mortality in the first year of growth (Shaw and Monsen 1990). Establishment is probably greatest when a thin layer of soil covers the seeds, and if erosion increases from drought-induced reductions of plant cover, the already thin soils may not provide suitable seedbeds for germination. Seed development and establishment are best in years with ample precipitation, and if unfavorable conditions for seeding persist following disturbance, it is reasonable to assume that low sagebrush species may disappear from some stands, especially if annual grass invasion occurs concomitantly with unfavorable growth conditions.

Climate change will result in shifts in the distribution of conditions suitable to support low sagebrush species and hence the spatial configuration of low sagebrush habitats. Both low and black sagebrush are intolerant of fire and do not resprout. Therefore, increased fire activity will have negative consequences for both species. Fire return intervals vary considerably among communities dominated by low sagebrush species. Estimates of fire return intervals for xeric sagebrush communities of the Great Basin range from 35 to more than 100 years (Brown 2000; Riegel et al. 2006), but intervals of 100 to 200 years for low-productivity black sagebrush communities have been reported. Especially for black sagebrush, which usually occupies quite unproductive sites with small buildup of fuels, these fire return intervals may be overestimated (Baker 2013). Within the boundaries and on the periphery of the Greater Yellowstone Area subregion, MC2 results indicate that the proportion of landscape burned will increase substantially in the future (fig. 7.6), allowing a higher likelihood of ignition and flaming fronts to reach some low sagebrush communities. The extent to which these sites will carry fire depends on herbaceous production and probably on magnitude of invasion by annual grasses (especially cheatgrass). In summary, climate change may influence low sagebrush systems by reducing seedling establishment in unfavorable years. In addition, projected increased fire activity will decrease the abundance of low sagebrush relative to other species, especially if nonnative annual grasses, such as medusahead (*Taeniatherum caput-medusae*) and cheatgrass, become more prevalent.

Relative to other sagebrush species, low and black sagebrush have limited adaptive capacity. Black sagebrush hybridizes with silver sagebrush, and sprouting is thought to be a heritable trait in crosses between nonsprouting and sprouting sagebrushes (McArthur 1994). In the Northern Rockies region, however, it is unlikely that silver sagebrush will exhibit a significant presence in areas that support low sagebrush; the distribution of these species is usually disjunctive, so the possibility of inheriting sprouting traits is unlikely. In addition, the relatively low productivity characterizing low sagebrush sites may also limit adaptive capacity, especially if other risk factors are present.

Risk Assessment

Magnitude of effects: High. The resilience of many of these areas is low given the thin and argillic soil properties characterizing these sites. The magnitude of effects is likely to increase if other perturbations such as improper recreational or grazing schemes are present. The low adaptive capacity of this sagebrush type, intolerance of fires, and low rate of reproduction act in concert to increase the magnitude of effects.

Likelihood of effects: Moderate to high. Models suggest increased production at higher elevations (Reeves et al. 2014), increasing the likelihood of fires carrying through otherwise relatively unburnable landscapes. The problem of increased flammability will increase, especially if invasive

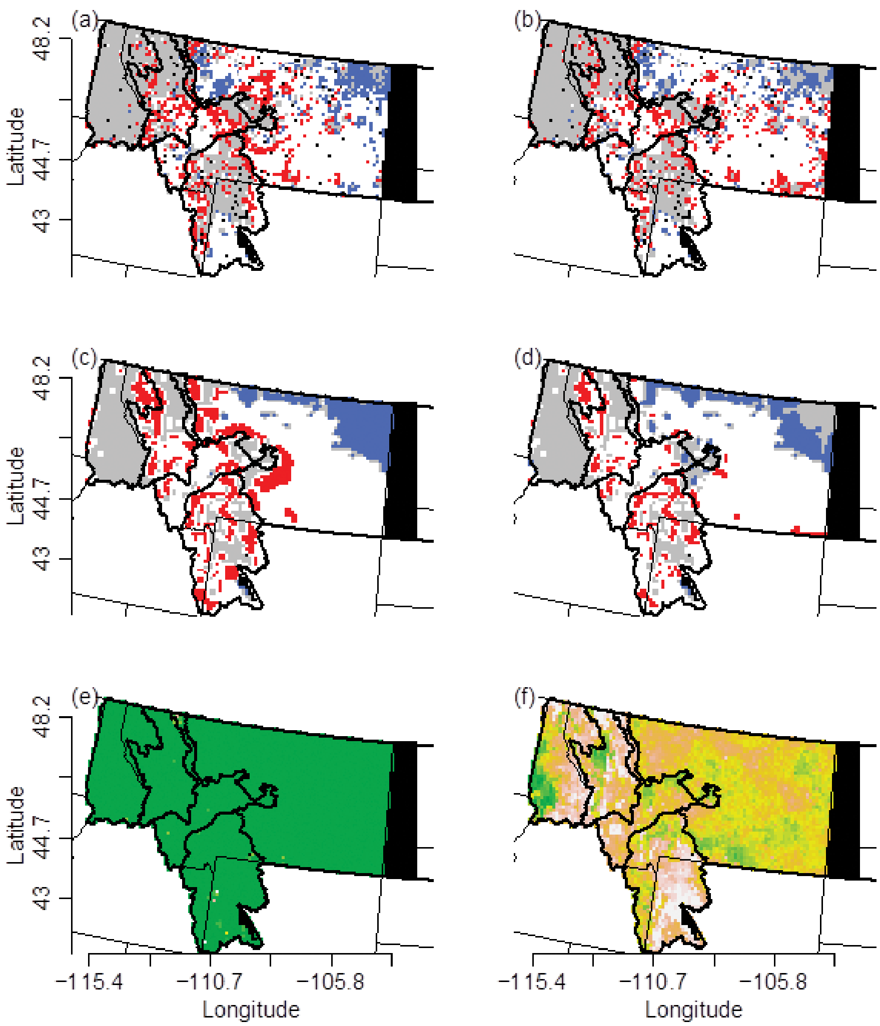

Figure 7.6—Change in big sagebrush habitat suitability (a–d) based on species distribution models using climate (c)-(d) or ecohydrology (a)-(b), along with germination (e) and seedling survival potential (f) for NR (outlined in bold). Projected change in big sagebrush habitat suitability is between 1970–1999 climate and future A2 scenario (a)-(c) and B1 scenario (b)-(d) 2070–2099 emission scenarios. Red cells indicate areas of decrease in big sagebrush habitat suitability, blue cells indicate areas of increase, white cells indicate stable areas, and gray cells indicate absence of big sagebrush. Maps of germination (e) and seedling survival (f) represent current conditions and are summarized as fraction of years with successes: red (0, no years with success), tan (>0), green (1, every year with success). Black cells indicate data not available (data source: Schlaepfer et al. 2012).

annual grasses exhibit a significant presence on short sagebrush sites in the future.

Shrublands Dominated by Sprouting Sagebrush Species (Threetip and Silver Sagebrush)

Significant areas of threetip and silver sagebrush shrublands have been converted to agricultural lands. Those that remain are often used for domestic livestock grazing because of the palatable herbaceous undergrowth in this sagebrush type. Those that have had chronic improper grazing typically have a large amount of bare ground, low vigor of native herbaceous species, and as a result, nonnative plant species present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage) (Sheatch and Carlson 1998; Washington-Allen et al. 2010).

Both species can sprout from the root crown following top kill (primarily from fire) (Bunting et al. 1987), but this trait depends on site conditions and fire severity. Silver sagebrush is a vigorous sprouter (Rupp et al. 1997), whereas threetip sagebrush is less successful as a sprouter, and its response varies with site characteristics (Akinsoji 1988; Bunting et al. 1987). Both species occur on mesic sites; threetip sagebrush is often associated with mountain big sagebrush communities, and silver sagebrush typically occupies moist riparian benches or moist toe slopes. Although these species will sprout, increased fire frequency and severity (particularly in threetip communities) may cause a shift in community composition to dominance by fire-adapted herbaceous species or nonnative species. Other fire-adapted shrub species may increase, particularly following fire. In addition, if spring and winter precipitation increase, exotic annual grasses may establish and set seed earlier than the native perennial grasses, particularly in lower elevation communities (Bradley 2008; D'Antonio and Vitousek 1992). This creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native grasses often before they have matured and set seed (Chambers and Pellant 2008). Other nonnative invasive species respond favorably after fire, and, if present, will increase in cover and density.

Historical fire return intervals for both species are relatively short and research shows that threetip sagebrush cover can return to preburn levels 30 to 40 years after fire (Barrington et al. 1988; Neuenschwander n.d.). Lesica et al. (2007) found that after a fire in southwestern Montana, threetip sagebrush cover did not increase by resprouting, but instead established from seed. These generalizations will vary considerably depending on site conditions and postfire management. All three subspecies of silver sagebrush sprout after fire, and along with threetip, also typically occur on more mesic sites. With a warmer and drier climate, not only may frequent high-severity burns cause initial mortality, but sites may not be as favorable for postfire vegetation regeneration (from sprouting, regrowth, or seed). Invasive species are likely either to expand into these communities after fire or to increase in abundance in altered conditions that are less favorable to the native plant community.

Understory composition in both communities may possibly shift to more-xeric grassland species (e.g., bluebunch wheatgrass, needle-and-thread grass [*Hesperostipa comata*]), which are better adapted to warmer and drier conditions. Both of these sagebrush species may shift landscape position to sites with more moisture and cooler temperature (e.g., higher elevation, lower landscape position, and northeast aspects).

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: High

Mountain Big Sagebrush Shrublands

Some areas of mountain big sagebrush shrublands have been converted to agricultural lands, and those that remain are used for domestic livestock grazing, primarily because of the palatable herbaceous undergrowth. Those that have had chronic improper grazing typically have high bare ground and low vigor of native herbaceous species; as a result, nonnative plant species are present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and invasive nonnative plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases due to improper grazing and other impacts, primarily caused by ungulates (e.g., grazing and mechanical/hoof damage). Lack of fire is also a chronic stressor, facilitating establishment of conifers, which increase in density and cover over time (Arno and Gruell 1986; Heyerdahl et al. 2006) while grass cover declines (Arno and Gruell 1983).

Mountain big sagebrush is killed by fire. If fire severity and frequency increase, there will be a shift in community composition to dominance by fire-adapted shrub and herbaceous species and possibly nonnative species. Fire-adapted shrub species may increase in abundance following fire (Fischer and Clayton 1983; Smith and Fischer 1997). In addition, if spring and winter precipitation increase, establishment of nonnative annual grasses (particularly cheatgrass, which germinates in winter/early spring) may be facilitated, although this is less likely in cooler, moister mountain big sagebrush communities than in lower elevation Wyoming and basin big sagebrush communities. With a warmer, drier climate, however, the conditions may be conducive to cheatgrass establishment. An abundance of cheatgrass creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native perennial grasses often before they have matured and set seed (Chambers et al. 2007; Pellant 1990; Whisenant 1990), especially in the

Great Basin. However, other research in the northern edge of the Great Basin indicates that some sagebrush communities may be less susceptible to cheatgrass invasion following fire, at least under the current climate (Lavin et al. 2013; Seefeldt et al. 2007). Other nonnative species respond favorably after fire and, if present, will increase in cover and density.

Historically, the fire return intervals were relatively short but variable—a few decades (Lesica et al. 2007) to more than 100 years (Baker 2013)—compared to Wyoming big sagebrush habitat (more than 100 years) (Heyerdahl et al. 2006; Lesica et al. 2005, 2007). Mountain big sagebrush regenerates from seeds shed from nearby unburned plants. It will fully recover between 15 and 40 years after fire (Bunting et al. 1987), depending on site characteristics and fire severity. In a warmer and drier climate, frequent high-severity burns (facilitated by cheatgrass) may not cause initial mortality and create unfavorable conditions for postfire regeneration (from sprouting, regrowth, or seed). There is no viable sagebrush seedbank; if fires burn large areas and there are no live, seed-bearing sagebrush nearby, there may be a type conversion to grassland. In addition, invasive nonnative species are likely either to expand into these areas after fire, or to increase in abundance due to altered conditions that no longer favor the native plant community (Bradley 2008; D'Antonio and Vitousek 1992).

Mountain big sagebrush is not fire adapted, and may decline in cover and density or be extirpated in response to warmer temperatures and increased fire frequency and severity. Over time, especially if fine fuels such as senesced cheatgrass are present, more frequent fires may eliminate mountain big sagebrush from a community (Chambers and Pellant 2008; D'Antonio and Vitousek 1992; Whisenant 1990). However, because mountain big sagebrush occurs at higher elevations, typically on more productive cooler, mesic sites, these communities are typically less invaded by nonnative species. If these sites become warmer and drier, however, herbaceous understory composition could shift to more xeric species that are better adapted, and bare ground may increase (Chambers et al. 2014). As a result, invasive species, particularly cheatgrass, could expand into and establish dominance in these altered communities.

The distribution of mountain big sagebrush possibly may shift to cooler and moister sites (e.g., higher elevation, northeast-facing snow-filled depressions). With climate change, it may be able to persist only in sites with higher moisture and deeper soils than the surrounding landscape. Understory composition may shift to more-xeric grassland species, that are more tolerant of warmer, drier conditions.

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: Moderate

Adapting Rangeland Vegetation Management to Climate Change in the Northern Rockies Region

Rangeland vegetation in the Northern Rockies Region is likely to be affected by changing fire regimes, increased drought, and increased establishment of invasive species in a changing climate. Effects of climate change will also compound existing stressors on rangeland ecosystems caused by human activities. Thus, adaptation strategies and tactics for rangeland vegetation focused on increasing the resilience of rangeland ecosystems, primarily through invasive species control and prevention (table 7.3).

To control invasive species in rangelands, managers stressed the importance of using ecologically based invasive plant management (EBIPM) (Krueger-Mangold et al. 2006; Sheley et al. 2006). The EBIPM framework focuses on strategies to repair damaged ecological processes that facilitate invasion (James et al. 2010). For example, prescribed fire treatments can be used where fire regimes have been altered, and seeding of desired natives can be done where seed availability and dispersal of natives is low.

Another adaptation strategy is to increase proactive management actions to prevent establishment of invasive species. Early detection, rapid response (EDRR) for new invasions was the most frequently suggested tactic to prevent invasive species establishment. Other tactics include implementing weed-free policies, conducting outreach to educate employees and the public about invasive species (e.g., teach people to clean their boots), and developing weed management areas that are collaboratively managed by multiple agencies, nongovernmental organizations, and the public.

In addition to invasive species control and prevention, grazing management will be important in maintaining and increasing resilience of rangelands to climate change. Climate changes will lead to altered availability of forage, requiring some reconsideration of grazing strategies. For example, reducing grazing in July and August may encourage growth of desired perennials in degraded systems. Livestock grazing can also be managed through the development of site-specific within-season triggers and end point indicators that would inform livestock movement guides and allow for the maintenance and enhancement of plant health.

A changing climate has led to a decline of pollinators in some communities (Potts et al. 2010) and may lead to phenological mismatches between pollinators and host plants (Forrest 2015). Pollinator declines may negatively affect the health of grasslands in the Northern Rockies, and encouraging native pollinators may be key to sustaining these ecosystems. Tools to promote native pollinators include revegetation with native species, appropriate herbicide and insecticide use, and education. Implementing long-term monitoring of pollinators can help to identify where treatments can be prioritized.

Table 7.3—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species.			
Adaptation strategy/approach: Increase proactive management actions in order to prevent invasive species.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct ecologically based invasive plant management; implement prescriptive grazing, fire, herbicide and re-seeding.	Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and the public.	Apply early detection rapid response (EDRR) and inventory and mapping.
Where can tactics be applied?	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas.	Recreation high use areas (roads); administrative areas	All lands
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	Remove conifers with mechanical treatments, prescribed fire, and harvest.	Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, targeted grazing).
Where can tactics be applied?	Forest/grassland/region level	Encroached communities	Recreation high-use areas (roads), administrative areas

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.			
Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Inventory intact areas with high native cover (i.e., weed-free areas).	Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	Manage priority invasive species on priority acres.
Where can tactics be applied?	On all land	Areas that are currently weed free	In priority areas
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Restore to minimize or reverse adverse effects.	Manage fire for resource benefits.	Promote the occurrence and growth of native species.
Where can tactics be applied?	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and nonnatives are not dominant
	Specific tactic – G	**Specific tactic – H**	**Specific tactic – I**
Tactic	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices; reduce grazing in July and August to encourage perennial growth.	Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive nonnative and noxious weeds and undesirable species, and reduce fire risk).
Where can tactics be applied?	On all grazed lands	On all grazed lands	Priority areas based on current condition and potential response to treatment

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.			
Adaptation strategy/approach: Maintain and restore natural grassland habitat to ensure pollination.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover).	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long-term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Where can tactics be applied?	Throughout current range of grasslands	Use ecological site descriptions to identify priority areas for restoration or enhancement.	Look at native and nonnative ecosystems, overlap in these ecosystems, and the types of pollinators present.
Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds in montane shrublands.			
Adaptation strategy/approach: Maintain and increase montane shrublands.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion), and targeted grazing.
Where can tactics be applied?	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries

In montane shrublands, existing stressors include fire exclusion and conifer establishment, browsing by both native and domestic ungulates, and insects and disease. Characteristic species can be lost in these systems with loss of topsoil following frequent, hot fires. Warmer temperatures and drier conditions with climate change may lead to an increase in high-severity fires. Adaptation tactics include implementing fuel reduction projects such as brush cutting, slashing, mastication, and targeted browsing; reestablishing appropriate fire regimes may prove beneficial in maintaining these shrublands and increasing their resilience. To control invasive vegetation, EDRR and EBIPM can be applied, along with maintenance of adequate shrub cover, vigor, and species richness. Educating specialists on ecology and disturbances affecting shrublands, effects of repeated burns, reforestation needs, and reporting on weeds will also help to maintain these systems.

More specific details on adaptation strategies and tactics that address climate change effects on rangeland vegetation in each Northern Rockies Adaptation Partnership subregion are in Appendix 7A.

References

Abatzoglou, J.T.; Kolden, C.A. 2011. Climate change in western US deserts: Potential for increased wildfire and invasive annual grasses. Rangeland Ecology and Management. 64: 471–478.

Akinsoji, A. 1988. Postfire vegetation dynamics in a sagebrush steppe in southeastern Idaho, USA. Vegetation. 78: 151–155.

Alexander, E.B.; Mallory, J.I.; Colwell, W.L. 1993. Soil-elevation relationships on a volcanic plateau in the southern Cascade Range, northern California, USA. Catena. 20: 113–128.

Allen, C.R.; Gunderson, L.; Johnson, A.R. 2005. The use of discontinuities and functional groups to assess relative resilience in complex systems. Ecosystems. 8: 958–966.

Anderson, J.E.; Holte, K.E. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. Journal of Range Management. 34: 25–29.

Anderson, J.E.; Inouye, R.S. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs. 71: 531–556.

Arno, S.; Gruell, G. 1983. Fire history at the forest-grassland ecotone in southwestern Montana. Journal of Range Management. 36: 332–336.

Arno, S.; Gruell, G. 1986. Douglas-fir encroachment into mountain grasslands in southwestern Montana. Journal of Range Management. 39: 272–276.

Bachelet, D.; Neilson, R.P.; Lenihan, J.M.; [et al.]. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems. 4: 164–185.

Bachman, S.; Heisler-White, J.L.; Pendall, E.; [et al.]. 2010. Elevated carbon dioxide alters impacts of precipitation pulses on ecosystem photosynthesis and respiration in a semi-arid grassland. Oecologia. 162: 791–802.

Baker, W.L. 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin. 34: 177–185.

Baker, W.L. 2011. Pre-EuroAmerican and recent fire in sagebrush ecosystems. In: Knick, S.T.; Connelly, J.W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Berkely, CA: University of California Press: 185–201.

Baker, W.L. 2013. Is wildland fire increasing in sagebrush landscapes of the western United States? Annals of the Association of American Geographers. 103: 5–19.

Balch, J.K.; Bradley, B.A.; D'Antonio, C.M.; [et al.]. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). Global Change Biology. 19: 173–183.

Barrington, M.; Bunting, S.; Wright, G. 1988. A fire management plan for Craters of the Moon National Monument. Cooperative Agreement CA-9000-8-0005. Moscow, ID: University of Idaho, Range Resources Department. 52 p.

Beetle, A.A.; Johnson, K.L. 1982. Sagebrush in Wyoming. Laramie, WY: University of Wyoming, Agricultural Experiment Station. 68 p.

Beniston, M., Diaz, H.F., Bradley, R.S. 1997. Climatic change at high elevations: An overview. Climatic Change. 36: 233–251.

Booth, G.D.; Welch, B.L.; Jacobson, T.L.C. 1990. Seedling growth rate of 3 subspecies of big sagebrush. Journal of Range Management. 43: 432–436.

Bradford, J.; Schlaepfer, D.; Lauenroth, W. 2014. Ecohydrology of adjacent sagebrush and lodgepole pine ecosystems: The consequences of climate change and disturbance. Ecosystems. 17: 590–605.

Bradley, B.A. 2008. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Global Change Biology: 14: 1–13.

Bradley, B.A. 2010. Assessing ecosystem threats from global and regional change: Hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography. 33: 198–208.

Brooks, M. L.; D'Antonio, C.M.; Richardson, D.M.; [et al.]. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54: 677–688.

Brotherson, J.D.; Brotherson, W.T. 1981. Grazing impacts on sagebrush communities of central Utah. Western North American Naturalist. 41: 335–340.

Brown, J. K. 2000. Chapter 1: Introduction and fire regimes.In: Brown, J.K.; Smith, J.K., eds. Wildland fire in ecosystems: Effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1–8.

Bukowski, B.E., Baker, W.L. 2013. Historical fire in sagebrush landscapes of the Gunnison sage-grouse range from land-survey records. Journal of the Arid Environment. 98: 1–9.

Bunting, S. C.; Kilgore, B.M.; Bushey, C.L. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. Gen. Tech. Rep. INT-231. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 33 p.

Cárdenas, A.; Lewinsohn, J.; Auger, C.; [et al.]. 1997. Characterization of a sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) die-off on the Handford Site. Richland, WA: Pacific Northwest National Laboratory.

Chambers, J.C.; Pellant, M. 2008. Climate change impacts on northwestern and intermountain United States rangelands. Rangelands. 30: 29–33.

Chambers, J.C.; Bradley, B.A.; Brown, C.A.; [et al.]. 2014. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. Ecosystems. 17: 360–375.

Chambers, J.C.; Roundy, B.A.; Blank, R.R.; [et al.]. 2007. What makes Great Basin sagebrush ecosystems invasible to *Bromus tectorum*? Ecological Monographs. 77: 117–145.

Chen, D., Hunt, H. W.; Morgan, J.A. 1996. Responses of a C3 and C4 perennial grass to CO_2 enrichment and climate change: Comparison between model predictions and experimental data. Ecological Modelling. 87: 11–27.

Christensen, L.; Coughenour, M.B.; Ellis, J.E.; [et al.]. 2004. Vulnerability of the Asian typical steppe to grazing and climate change. Climatic Change. 63: 351–368.

Cleland, D.T.; Freeouf, J.A.; Keys, J.E.; [et al.]. 2007. Ecological Subregions: Sections and Subsections for the conterminous United States. Gen. Tech. Report WO-76D [Map on CD-ROM] (A.M. Sloan, cartographer). Washington, DC: U.S. Department of Agriculture, Forest Service, presentation scale 1:3,500,000; colored.

Comer, P.; Kagan, J.; Heiner, M.; [et al.]. 2002. Current distribution of sagebrush and associated vegetation in the western United States (excluding NM and AZ). Interagency Sagebrush Working Group. http://sagemap.wr.usgs.gov [Accessed July 1, 2014].

Cooper, S.V.; Lesica, P.; Kudray, G. M. 2007. Postfire recovery of Wyoming big sagebrush shrub-steppe in central and southeast Montana. Helena, MT: U.S. Department of the Interior, Bureau of Land Management, State Office, Montana Natural Heritage Program. 16 p.

D'Antonio, C.M.; Vitousek, P.M. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics. 23: 63–87.

Dahlgren, R.A.; Boettinger, J. L.; Huntington, G.L.; [et al.]. 1997. Soil development along an elevational transect in the western Sierra Nevada. Geoderma. 78: 207–236.

Davies, K. 2011. Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass. Oecologia. 167: 481–491.

Davies, K.W.; Boyd, C.S.; Beck, J. L.; [et al.]. 2011. Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. Biological Conservation. 144: 2573–2584.

Delcourt, P.A.; Delcourt, H.R. 1981. Vegetation maps for eastern North America: 40,000 yr B.P. to the present. Geobotany. 2: 123–165.

Doherty, K.E.; Naugle, D.E.; Walker, B.L.; [et al.]. 2008. Greater sage-grouse winter habitat selection and energy development. The Journal of Wildlife Management. 72:187–195.

Finch, D.M. 2012. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 139 p.

Fischer, W.C.; Clayton, B.D. 1983. Fire ecology of Montana forest habitat types east of the continental divide. Gen. Tech. Rep. INT-GTR-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

Folke, C.; Carpenter, S.; Walker, B.; [et al.]. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics. 33: 557–581.

Forrest, J.R. 2015. Plant-pollinator interactions and phonological change: What can we learn about climate impacts from experiments and observations? Oikos. 124: 4–13.

Ghannoum, O. 2009. C4 photosynthesis and water stress. Annals of Botany. 103: 635–644.

Hanson, C.L.; Johnson, C.W.; Wight, J.R. 1982. Foliage mortality of mountain big sagebrush [*Artemisia tridentata* subsp. *vaseyana*] in southwestern Idaho during the winter of 1976–77. Journal of Range Management 35: 142–145.

Haws, B.A.; Bohart, G.E.; Nelson, C.R.; [et al.]. 1990. Insects and shrub die-off in western states: 1986–89 survey results. In: McArthur, E.D.; Romney, E.M.; Smith, S.D.; [et al.], eds. Proceedings symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5–7; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 127–151.

Heyerdahl, E.K.; Miller, R.F.; Parson, R.A. 2006. History of fire and Douglas-fir establishment in a savanna and sagebrush-grassland mosaic, southwestern Montana, USA. Forest Ecology and Management. 230: 107–118.

Holling, C.S. 1973. Resilience and stability in ecological systems. Annual Review of Ecology and Systematics. 4: 1–23.

Intergovernmental Panel on Climate Change [IPCC]. 2014. Climate Change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

James, J.J.; Smith, B.S.; Vasquez, E.A.; [et al.]. 2010. Principles for ecologically based invasive plant management. Invasive Plant Science and Management. 3: 229–239.

Klos, P.Z.; Link, T.E.; Abatzoglou, J.T. 2014. Extent of the rain-snow transition zone in the western U.S. under historic and projected climate. Geophysical Research Letters. 2014GL060500.

Knapp, P.A.; Soulé, P.T. 1996. Vegetation change and the role of atmospheric CO_2 enrichment on a relict site in central Oregon: 1960–1994. Annals of the Association of American Geographers. 86: 387–411.

Kolb, K.J.; Sperry, J.S. 1999. Differences in drought adaptation between subspecies of sagebrush (*Artemisia tridentata*). Ecology. 80: 2373–2384.

Krueger-Mangold, J.M.; Sheley, R.L.; Svejcar, T.J. 2006. Toward ecologically-based invasive plant management on rangeland. Weed Science. 54: 597–605.

Küchler, A.W. 1975. Potential natural vegetation of the conterminous United States. 2nd ed. Map 1:3,168,000. Washington, DC: American Geographical Society.

Larsen, J.A. 1925. Natural reproduction after forest fires in northern Idaho. Journal of Agricultural Research. 30: 1177–1197.

Lavin, M.; Brummer, T.; Quire, J.; [et al.]. 2013. Physical disturbance shapes vascular plant diversity more profoundly than fire in the sagebrush steppe of southeastern Idaho, U.S.A. Ecology and Evolution. 3: 1626–1641.

Leakey, A.D.B. 2009. Rising atmospheric carbon dioxide concentration and the future of C4 crops for food and fuel. Proceedings of the Royal Society B: Biological Sciences. 276: 2333–2343.

Lesica, P.; Cooper, S.V.; Kudray, G. 2005. Big sagebrush shrub-steppe postfire succession in southwest Montana. Report to the Montana Heritage Program. Unpublished report on file with: U.S. Department of the Interior, Bureau of Land Management, Dillon Field Office, Helena, MT. 29 p. plus appendices.

Lesica, P.; Cooper, S.V.; Kudray, G. 2007. Recovery of big sagebrush following fire in southwest Montana. Rangeland Ecology and Management. 60: 261–269.

Lund, G.H. 2007. Accounting for the world's rangelands. Rangelands. 29: 3–10.

Manier, D.J.; Wood, D.J.A.; Bowen, Z.H.; [et al.]. 2013. Summary of science, activities, programs, and policies that influence the rangewide conservation of greater sage-grouse (*Centrocercus urophasianus*). Open-File Rep. 2013-1098. Reston, VA: U.S. Geological Survey.

McArthur, E.D. 1994. Ecology, distribution, and values of sagebrush within the Intermountain region. In: Monsen, S.B.; Kitchen, S.G., compilers. Proceedings—Ecology and management of annual rangelands; 1992 May 18–22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 347–351.

McArthur, E.D.; Welch, B.L. 1982. Growth rate differences among big sagebrush (*Artemisia tridentata*) accessions and subspecies. Journal of Range Management. 35: 396–401.

Merrill, K.R.; Meyer, S.E.; Coleman, C.E. 2012. Population genetic analysis of *Bromus tectorum* (Poaceae) indicates recent range expansion may be facilitated by specialist genotypes. American Journal of Botany. 99: 529–537.

Morgan, J.A.; Derner, J. D.; Milchunas, D. G.; [et al.]. 2008. Management implications of global change for Great Plains rangelands. Rangelands. 30: 18–22.

Morgan, J.A.; LeCain, D.R.; Pendall, E.; [et al.]. 2011. C4 grasses prosper as carbon dioxide eliminates desiccation in warmed semi-arid grassland. Nature. 476: 202–206.

Morgan, J.A.; Milchunas, D.G.; LeCain, D.R.; [et al.]. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the short grass steppe. Proceedings of the National Academy of Sciences, USA. 104: 14724–14729.

Morgan, J.A.; Mosier, A.R.; Milchunas, D.G.; [et al.]. 2004a. CO_2 enhances productivity, alters species composition, and reduces digestibility of short grass steppe vegetation. Ecological Applications. 14: 208–219.

Morgan, J.A.; Pataki, D.E.; Körner, C.; [et al.]. 2004b. Water relations in grassland and desert ecosystems exposed to elevated atmospheric CO_2. Oecologia. 140: 11–25.

Nakićenović, N.; Davidson, O.; Davis, G.; [et al.]. 2000. Special report on emissions scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 599 p.

Nelson, D.L.; Weber, D.J.; Garvin, S.C. 1990. The possible role of plant disease in the recent wildland shrub dieoff in Utah. In: McArthur, E.D.; Romney, E.M.; Smith, S.D.; Tueller, P.T., eds. Proceedings symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5–7; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 84–90.

Nelson, Z.J.; Weisberg, P.J.; Kitchen, S.G. 2014. Influence of climate and environment on postfire recovery of mountain big sagebrush. International Journal of Wildland Fire. 23: 131–142.

Neuenschwander, L.F. [n.d.]. The fire induced autecology of selected shrubs of the cold desert and surrounding forests: A state-of-the-art review. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. Unpublished manuscript on file at: U.S. Department of Agriculture, Forest Service, Intermountain Fire Sciences Laboratory, Missoula, MT. 30 p.

Noss, R.F.; LaRoe, E.T., III; Scott, J.M. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. Washington, DC: National Biological Service.

Ortega, Y.; Pearson, D.E.; Waller, L.P.; [et al.]. 2012. Population-level compensation impedes biological control of an invasive forb and indirect release of a native grass. Ecology. 93: 783–792.

Owensby, C.E.; Ham, J.M.; Knapp, A.K.; [et al.]. 1999. Biomass production and species composition change in a tallgrass prairie ecosystem after long-term exposure to elevated atmospheric CO_2. Global Change Biology. 5: 497–506.

Pearson, D.E.; Ortega, Y.K.; Eren, O.; [et al.]. [In review]. Quantifying "apparent" impact and distinguishing impact from invasiveness in multispecies plant invasions. Ecological Applications.

Pellant, M. 1990. The cheatgrass-wildfire cycle—Are there any solutions? In: McArthur, E.D.; Romney, E.M.; Smith, S.D.; [et al.], eds. Proceedings symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5–7; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 11–18.

Pielke, R.A.; Marland, G.; Betts, R.A; [et al.]. 2002. The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases. Philosophical Transactions: Mathematical, Physical and Engineering Sciences. 360: 1705–1719.

Polley, H.W.; Briske, D.D.; Morgan, J.A.; [et al.]. 2013. Climate change and North American rangelands: Trends, projections, and implications. Rangeland Ecology and Management. 66: 493–511.

Polley, H.W.; Johnson, H.B.; Derner, J.D. 2003. Increasing CO_2 from subambient to superambient concentrations alters species composition and increases above-ground biomass in C3/C4 grasslands. New Phytologist. 160: 319–327.

Poore, R.E., Lamanna, C.A.; Ebersole, J.J.; [et al.]. 2009. Controls on radial growth of mountain big sagebrush and implications for climate change. Western North American Naturalist. 69: 556–562.

Potts, S.G.; Biesmeijer, J.C.; Kremen, C.; [et al.]. 2010. Global pollinator declines: Trends, impacts and drivers. Trends in Ecology & Evolution. 25: 345–353.

Ramakrishnan, A.P.; Meyer, S.E.; Fairbanks, D.J.; [et al.]. 2006. Ecological significance of microsatellite variation in western North American populations of *Bromus tectorum*. Plant Species Biology. 21: 61–73.

Reeves, M.; Moreno, A.; Bagne, K.; [et al.]. 2014. Estimating the effects of climate change on net primary production of US rangelands. Climatic Change. 126: 429–442.

Reeves, M. C.; Mitchell, J. E. 2011. Extent of coterminous U.S. rangelands: Quantifying implications of differing agency perspectives. Rangeland Ecology and Management. 64: 1–12.

Riegel, G.M.; Miller, R.F.; Smith, S.E.; [et al.]. 2006. Northeastern Plateaus bioregion. In: Sugihara, N.G; van Wagtendonk, J.W.; Shaffer, K.E.; [et al.], eds. Fire in California's ecosystems. Berkeley, CA: University of California Press: 225–263.

Rowland, M.M.; Wisdom, M.J.; Spring, L.H.; Meinke, C.W. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation. 129: 323–335.

Rupp, L.; Roger, K.; Jerrian, E.; William, V. 1997. Shearing and growth of five Intermountain native shrub species. Journal of Environmental Horticulture. 15: 123–125.

Schlaepfer, D.R.; Lauenroth, W.K.; Bradford, J.B. 2012. Effects of ecohydrological variables on current and future ranges, local suitability patterns, and model accuracy in big sagebrush. Ecography. 35: 374–384.

Schlaepfer, D.R.; Lauenroth, W.K.; Bradford, J.B. 2014a. Modeling regeneration responses of big sagebrush (*Artemisia tridentata*) to abiotic conditions. Ecological Modeling. 286: 66–77.

Schlaepfer, D.R., Lauenroth, W.K.; Bradford, J.B. 2014b. Natural regeneration processes in big sagebrush (*Artemisia tridentata*). Rangeland Ecology and Management. 67: 344–357.

Schlaepfer, D.R.; Taylor, K.A.; Pennington, V.E.; [et al.]. 2015. Future regeneration of big sagebrush support predicted changes in habitat suitability at the trailing and leading edges. Ecosphere. 6: 3.

Schrag, A.; Konrad, S.; Miller, B.; [et al.]. 2011. Climate-change impacts on sagebrush habitat and West Nile virus transmission risk and conservation implications for greater sage-grouse. GeoJournal. 76: 561–575.

Seefeldt, S.; Germino, M.J.; DiChristina, K.M. 2007. Prescribed fires have minor and transient effects on herbaceous vegetation cover and composition. Applied Vegetation Science. 10: 249–256.

Shafer, M.; Ojima, D.; Antle, J.M.; [et al.]. 2014. Chapter 19: Great Plains. In: Melillo, J.M.; Richmond, T.C.; Yohe, G.W., eds. Climate change impacts in the United States: The third National Climate Assessment. Washington, DC: U.S. Global Change Research Program: 441–461.

Shafer, S.L.; Bartlein, P.J.; Thompson, R.S. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems. 4: 200–215.

Shane, R.L.; Garrett, J.R.; Lucier, G.S. 1983. Relationship between selected factors and internal rate of return from sagebrush removal and seeding crested wheatgrass. Journal of Range Management. 36: 782–786.

Shaw, N.L.; Monsen, S.B. 1990. Use of sagebrush for improvement of wildlife habitat. In: Fisser, H.G., ed. Wyoming shrublands: Aspen, sagebrush and wildlife management. Proceedings, 17th Wyoming shrub ecology workshop; 1988 June 21-22; Jackson, WY. Laramie, WY: University of Wyoming, Department of Range Management: 19–35.

Sheatch, G.W.; Carlson, W.T. 1998. Impact of cattle treading on hill land. 1. Soil damage patterns and pasture status. New Zealand Journal of Agricultural Research. 41: 271–278.

Sheley, R.L.; Mangold, J.M.; Anderson, J.L. 2006. Potential for successional theory to guide restoration of invasive-plant-dominated rangeland. Ecological Monographs. 76: 365–379.

Sherry, R.A.; Zhou, Z.; Gu, S.; [et al.]. 2007. Divergence of reproductive phenology under climate warming. Proceedings of the National Academy of Sciences, USA. 104: 198–202.

Shultz, L.M. 2006. The genus *Artemisia* (Asteraceae: Anthemideae). In: Editorial Committee, eds. Flora of North America: Flora of North America North of Mexico. New York, NY: Oxford University Press. 503–534.

Smith, J.K.; Fischer, W.C. 1997. Fire ecology of the forest habitat types of northern Idaho. Gen. Tech. Rep. INT-GTR-363. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 142 p.

Society for Range Management. 1998. Glossary of terms used in range management. 4th ed. Denver, CO: Society for Range Management, Glossary Update Task Group. 32 p.

Suttle, K.B.; Thomsen, M.A.; Power, M.E. 2007. Species interactions reverse grassland responses to changing climate. Science. 315: 640–642.

U.S. Department of Agriculture [USDA]. 2009. Summary report: 2007 national resources inventory. Washington, DC: Natural Resources Conservation Service and Center for Survey Statistics and Methodology; Ames, IA: Iowa State University. 123 p.

USDA Forest Service [USDA FS]. 2010. Interior West Forest Inventory & Analysis P2 field procedures. Washington, DC: U.S. Department of Agriculture, Forest Service. 370 p.

Walston, L.J.; Cantwell, B.L.; Krummel, J.R. 2009. Quantifying spatiotemporal changes in a sagebrush ecosystem in relation to energy development. Ecography. 32: 943–952.

Walther, G.R. 2010. Community and ecosystem responses to recent climate change. Philosophical Transactions of the Royal Society B: Biological Sciences. 365: 2019–2024.

Washington-Allen, R.A.; Briske, D.D.; Shugart, H.H.; [et al.]. 2010. Introduction to special feature on catastrophic thresholds, perspectives, definitions, and applications. Ecology and Society. 15: 38.

Weaver, J.E. 1968. Prairie plants and their environment: A fifty-year study in the Midwest. Lincoln, NE: University of Nebraska Press. 276 p.

Wellner, C.A. 1970. Fire history in the Northern Rocky Mountains. In: The role of fire in the Intermountain West: Intermountain Fire Research Council combined business meeting and symposium; 1970 October 27–29; Missoula, MT. University of Montana, School of Forestry: 42–64.

West, M.; Mooney, H.A., 1972. Photosynthetic characteristics of three species of sagebrush as related to their distribution patterns in the White Mountains of California. American Midland Naturalist. 88: 479–484.

Westerling, A.L.; Hidalgo, H.G.; Cayan, D.R.; [et al.]. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science. 318: 940–943.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plain: Ecological and management implications. In: McArthur, E.D.; Romney, E.M.; Smith, S.D.; [et al.], eds. Proceedings symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5–7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: Department of Agriculture, Forest Service, Intermountain Research Station: 5–7.

Wijayratne, U.C.; Pyke, D.A. 2009. Investigating seed longevity of big sagebrush (*Artemisia tridentata*). Open-File Rep. 2009-1146. Reston, VA: U.S. Geological Survey.

Wijayratne, U.C.; Pyke, D.A. 2012. Burial increases seed longevity of two *Artemisia tridentata* (Asteraceae) subspecies. American Journal of Botany. 99: 438–447.

Woodward, F.I.; Kelly, C.K. 2008. Responses of global plant diversity capacity to changes in carbon dioxide concentration and climate. Ecological Letters. 11: 1229–1237.

Wright, H.A.; Neuenschwander, L.F.; Britton, C.M. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: A state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Young, J.A.; Evans, R.A. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Science. 37: 201–206.

Young, J.A.; Evans, R.A.; Palmquist, D.E. 1989. Big sagebrush (*Artemisia tridentata*) seed production. Weed Science. 37: 47–53.

Ziska, L.H.; Reeves, J.B.; Blank, B. 2005. The impact of recent increases in atmospheric CO_2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): Implications for fire disturbance. Global Change Biology. 11: 1325–1332.

Appendix 7A—Adaptation Options for Nonforest Vegetation in the Northern Rockies.

The following tables describe climate change sensitivities and adaptation strategies and tactics for nonforest vegetation, developed in a series of workshops as a part of the Northern Rockies Adaptation Partnership. Tables are organized by sub-region within the Northern Rockies. See Chapter 7 for summary tables and discussion of adaptation options for nonforest vegetation.

Table 7A.1—Adaptation options that address climate change effects on nonforest vegetation in the Central Rockies subregion.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species. Effects of climate change on grasslands will be amplified by management actions.

Adaptation strategy/approach: Increase proactive management actions in order to prevent invasive species

Strategy objective: Reduce stressors/threats, engage coordination, increase knowledge

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, education, targeted grazing).	Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and public.	Apply early detection rapid response (EDRR) and inventory and mapping.	Update weed risk assessment (WRA) to enhance integrated weed management.
Tactic effectiveness (risks)	High	High (if properly implemented)	High	Moderate
Implementation urgency	Near term	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Recreation high use areas (roads), administrative areas; Lolo Creek (Missoula District for sheep/goat grazing)	Recreation high use areas (roads); administrative areas	Wilderness protected areas	Multi-scale effort
Opportunities for implementation	Coordinate with multiple agencies, non-governmental organizations, public; opportunity to graze in newly acquired lands (sheep/goats)	Coordinate with multiple agencies, non-governmental organizations, public	Coordinate with multiple agencies, non-governmental organizations, public, employees	Coordinate with Federal and State agencies
Cost	Expensive	Inexpensive/moderately expensive (depends on implementation scale)	Inexpensive/moderately expensive	Moderately expensive
Barriers to implementation	Management support; conflict between bighorn sheep and domestic	Community support; social economic barriers (e.g., education, trust, holdouts)	Lack of acceptance that it is a priority	Time, lack of prioritization

Table 7A.2—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Inventory intact/high native cover/weed free areas.	Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	Survey for new invasive species.	Manage priority invasive species on priority acres.
Tactic effectiveness (risks)	High	Moderate to high	High	Moderate
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	On all lands (where access can be granted)	Areas that are currently weed free	On all lands (where access can be granted)	On priority acres
Opportunities for implementation	Work with agencies, counties, State, non-profit and private land owners to share and incorporate current and future inventory data	Work with agencies, counties, State, non-profit and private land owners to partner in weed prevention strategies and practices	Work with agencies, counties, State, non-profit and private land owners to share and incorporate current and future survey data, technology	Work with agencies, counties, State, non-profit and private land owners to collaborate on invasive species management activities
Cost	Moderately expensive	Inexpensive to moderately expensive	Moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Some to major barriers: staff capacity; budgets; priorities	Some to major barriers: public and internal awareness and perception; funding	Some to major barriers: staff capacity; budgets; priorities	Some to major barriers: budget; plant identification and phenology; capacity

Table 7A.2 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and nonnative species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems.

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – E	**Specific tactic – F**	**Specific tactic – G**	**Specific tactic – H**
Tactic	Restore to minimize or reverse adverse effects.	Manage conifer encroachment.	Manage fire for resource benefits.	Promote the occurrence and growth of early-season natives.
Tactic effectiveness (risks)	Moderate to high	Low to high	Moderate to high	Moderate
Implementation urgency	Near term	Near term	Near term	Short term
Where can tactics be applied? (geographic)	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to treatment	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and non-natives are not dominant
Opportunities for implementation	Collaborate with partners on the design and implementation of restoration activities	Collaborate with partners on conifer encroachment management activities	Collaborate with agencies, counties, state, non-profit and private land owners on fire management	Coordinate with range permittees
Cost	Inexpensive to expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Moderately expensive, depending on work needed
Barriers to implementation	Some to major barriers: awareness and recognition of need	Some to major barriers: litigation; burn windows; awareness and recognition of need	Some to major barriers: Recognition of need; public and internal perception and risk aversion	Some barriers: Some public opposition

Table 7A.2 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and nonnative species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems.

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – I	Specific tactic – J	Specific tactic – K	Specific tactic – L
Tactic	Reduce grazing in July and August to encourage perennial growth.	Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive exotic and noxious weeds and undesirable species, reduce fire risk).	Identify and manage (e.g., close, obliterate, re-route) non-system/user created routes (roads and trails).
Tactic effectiveness (risks)	Moderate	Low to moderate	Low to moderate	Low to high
Implementation urgency	Mid term	Near term	Near to mid term	Near term
Where can tactics be applied? (geographic)	Areas with high probability of recovery, primarily moist sites	On all grazed lands	Priority areas based on current condition and potential response to treatment	On priority areas
Opportunities for implementation	Coordinate with range permittees	Livestock managers	Livestock managers	Partner with National Forest Foundation, NGOs
Cost	Inexpensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Opposition by some permittees	Commitment by managers; compliance by livestock managers; staff capacity	Public perception, National Environmental Policy Act; litigation; logistics and access	Awareness; detection; budget; perception of need (internal and external);

Table 7A.3—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.		
Adaptation strategy/approach: Maintain and restore natural habitat to ensure pollination.		
Strategy objective: Promote resilience, reduce stressors/threat.		
	Specific tactic – A	**Specific tactic – B**
Tactic	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Tactic effectiveness (risks)	Depends on the combination of tools	Not applicable
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Use ecological site descriptions to identify priority areas for restoration or enhancement	Look at native and non-native ecosystems, overlap in these ecosystems and the types of pollinators present
Opportunities for implementation	Take advantage of other restoration activities; public involvement	Search for existing information; engage with Natural Resources Conservation Service, Agricultural Research Service, state extensions, North Dakota Department of Agriculture for education on pollinators and agricultural practices; opportunity for citizen science projects to detect broad trends
Cost	Cost varies by tool; shared cost with other restoration projects	Inexpensive with partnerships (i.e., citizen science projects)
Barriers to implementation	Some of the restoration tools may adversely impact the habitat.	

Table 7A.4—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Encroachment of native species into grasslands (i.e., willow [*Salix*], sumac [*Rhus*], juniper [*Juniperus*], snowberries [*Gaultheria*], ponderosa pine [*Pinus ponderosa*]).

Adaptation strategy/approach: Restore natural disturbance regimes in grasslands.

Strategy objective: Promote resilience, reduce stressors/threats

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Conduct prescribed fires.	Conduct mechanical treatments (chainsaws, mowing, mastication, logging, lop and scatter, haying, grazing).	Use herbicide (use appropriate delivery method).
Tactic effectiveness (risks)	Moderate	Moderate/high	High
Implementation urgency			
Where can tactics be applied? (geographic)	Use ecological site descriptions to determine where to apply prescribed fire		
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 7A.5—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Encroachment of nonnative species into grasslands (i.e., leafy spurge [*Euphorbia esula*], knapweed [*Centaurea*], sulphur cinquefoil [*Potentilla recta*], Canada thistle [*Cirsium arvense*], Russian olive [*Elaeagnus angustifolia*], hounds tongue [*Cynoglossum officinale*], redtop [*Agrostis stolonifera*], cattail [*Typha*], reed canary grass [*Phalaris arundinacea*], paleyellow iris [*Iris pseudacorus*], Japanese brome [*Bromus japonicus*], Kentucky bluegrass [*Poa pratensis*], smooth brome [*Bromus inermis*], crested wheatgrass [*Agropyron cristatum*], cheatgrass [*Bromus tectorum*], sweet clover [*Melilotus*], absinth wormwood [*Artemisia absinthium*], black henbane [*Hyoscyamus niger*], buckthorn [*Rhamnus*]).

Adaptation strategy/approach: Maintain and increase resilience of native grassland communities.

Strategy objective: Promote resilience.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Use ecological site descriptions to prioritize areas for treatment *(would not apply to all the species listed above)*.	Apply biological control.	Implement prescriptive grazing, fire, herbicide and re-seeding (timing, duration, frequency, kind and class of livestock).
Tactic effectiveness (risks)	Moderate/high	Low-high	Moderate/high
Implementation urgency	Near term	Dependent on research	Near term
Where can tactics be applied? (geographic)	Forest/grassland/subregion level	Where it is likely to be effective and not have unintended consequences	Forest/grassland/sub region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups	Interagency weed working groups; US Fish and Wildlife Service; interagency fire program; ranchers
Cost	Varies	Varies by agent	Moderately expensive/ expensive
Barriers to implementation	Lack of knowledge; funding and training	Uncertainty and unintended consequences of using biological control in a changing climate	Social perceptions (e.g., grazing, fire, herbicide use)

Table 7A.5 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Grasslands subregion.

Sensitivity to climatic variability and change: Encroachment of non-native species into grasslands.

Adaptation strategy/approach: Maintain and increase resilience of native grassland communities.

Strategy objective: Promote resilience.

	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**	**Specific tactic – G**
Tactic	Apply early detection rapid response.	Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	Conduct internal and external education and outreach.	Maintain and increase agency, State and county cooperation on invasive weeds.
Tactic effectiveness (risks)	High	High	High	High
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Wherever new invasions are	Forest/grassland/region level	Forest/grassland/region level	Forest/grassland/region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups; field technicians	Interagency weed working groups; field technicians	Interagency weed working groups
Cost	Inexpensive	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Plant identification skills	Plant identification skills; turnover of local population	Plant identification skills; turnover of local population	Coordinated action (need mechanism to ensure continued coordination)

Table 7A.6—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire frequency and intervals, invasive species, herbivory, and species shift (C4)

Adaptation strategy/approach: Increase resilience of C3 grassland communities to the above sensitivities, and maintain C3 grassland communities on the landscape.

Strategy objective: Promote resilience, reduce stressors/threats.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Allow natural and prescribed fire.	Conduct ecologically based invasive plant management; use herbivory (goats), biocontrol, wildfire, and seeding (e.g., smooth brome).	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	Moderate	Moderate	High	High
Implementation urgency	Mid term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings	Encroached communities
Opportunities for implementation	Implement projects per forest management plan	Effective at local levels; not at landscape scale	Effective at local levels; not at landscape scale	Small watershed or landscape of 1000–1500 acres
Cost	Cost varies by project size and complexity	Moderately expensive	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Community acceptance; litigation; risk aversion; lack of non-WUI funding	Major barriers: Community acceptance; capacity; need to scale up to be effective; perceived lack of urgency	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Staffing; litigation; availability of burn windows; fiscal year limitations; risk aversion

Table 7A.7—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation strategy/approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.

Strategy objective: Maintain current trend. Promote resilience. Reduce stressors/threats.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Strategically place fuels treatments (thinning, mulching, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.
Tactic effectiveness (risks)	Moderate	Moderate	High
Implementation urgency	Near term/mid term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with existing healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends group).
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive	Inexpensive
Barriers to implementation	Some barriers: political; community acceptance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: community acceptance; availability of workforce; need to scale up to be effective; perceived lack of urgency	Some barriers: lack of champions; workforce availability; perceived lack of urgency

Table 7A.7 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.		
Adaptation strategy/approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.		
Strategy objective: Maintain current trend. Promote resilience. Reduce stressors/threats.		
	Specific tactic – D	**Specific tactic – E**
Tactic	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	High	High
Implementation urgency	Moderate	Near term
Where can tactics be applied? (geographic)	Everywhere	Encroached communities
Opportunities for implementation	Coordinate with range permittees; cultivate management support.	Coordinate with fuels and habitat objectives for interagency and partnership work and funding; commercial harvest
Cost	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency	Some barriers: Staffing levels; litigation; uncertain availability of burn windows due to climate change; fiscal year limitations; challenges with interagency and/or non-Federal implementation and coordinated planning efforts; risk aversion

Table 7A.8—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation strategy/approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.

Strategy objective: Maintain sagebrush communities on the landscape; create and maintain a healthy and diverse plant community.

	Specific tactic – A	**Specific tactic – B**
Tactic	Strategically place fuels treatments (thinning, mulch, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.
Tactic effectiveness (risks)	Moderate	Moderate (unless strict adherence to EBIPM, then high)
Implementation urgency	Near term/Mid term	Near term
Where can tactics be applied? (geographic)	Anywhere we can; expand beyond wildland urban interface; apply tactic in areas with existing healthy intact vegetation; avoid degraded areas	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas in non-wilderness.
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive
Barriers to implementation	Some barriers: Political; community acceptance; management and community tolerance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: Community acceptance; availability of workforce; methodology; public perception; technology; need to scale up to be effective; perceived lack of urgency

Table 7A.8 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.		
Adaptation strategy/approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.		
Strategy objective: Maintain sagebrush communities on the landscape; **c**reate and maintain a healthy and diverse plant community.		
	Specific tactic – C	**Specific tactic – D**
Tactic	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.
Tactic effectiveness (risks)	High	High
Implementation urgency	Near term	Moderate
Where can tactics be applied? (geographic)	EDRR for all new findings	Everywhere
Opportunities for implementation	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)	Coordinate with range permittees; cultivate management support.
Cost	Inexpensive	Inexpensive
Barriers to implementation	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency

Table 7A.9—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation strategy/approach: Maintain healthy and intact grasslands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific tactic – A	Specific tactic – B
Tactic	Maintain or restore adequate native plant cover, vigor, and species richness; ensure ecologically significant remnant populations of endemics are maintained; tools include appropriate grazing management, focused herbicide use, re-vegetation (with locally adapted and site specific species, forbs and graminoids), appropriate fire management, appropriate travel management, maintaining public land management of ecologically significant remnant plant communities (e.g., rough fescue, Palouse prairie), and conservation easements.	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover); tools include re-vegetation (with native species), appropriate herbicide and insecticide use, and education for public and within agency.
Tactic effectiveness (risks)	Low/moderate/high	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout current range of grasslands; management activities are species specific	Throughout
Opportunities for implementation	Acquiring remnant populations (partners: The Nature Conservancy (TNC), working with tribes, private landowners, land trusts); conservation easements (TNC, local land trusts)	Xerces Society; native plant societies; local garden clubs; local conservation groups; Idaho Master Naturalists; youth organizations (high schools, 4H)
Cost	Inexpensive/moderately expensive	Inexpensive/ moderately expensive
Barriers to implementation	Multiple land ownership and fragmentation; lack of scientific knowledge; reduced budgets for inventory and monitoring	Farm Bill language; introduction of nonnative pollinators; use of insecticides; multiple ownerships

Table 7A.9 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation strategy/approach: Maintain healthy and intact grasslands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific tactic – C	**Specific tactic - D**
Tactic	Step 1 - Identify and map soil types (locate molisols); Step 2 - Prioritize restoration based on Step 1; sites that were historically maintained have now shifted to conifer savannas; identify sites that were fire maintained versus snow maintained.	Step 1 - Map risk areas for severe drought, and conduct snow melt risk analysis; Step 2 - Establish targeted areas for monitoring based on step 1 (re-visit and monitor established plots); Step 3 - Work with geneticists to isolate frost and drought hardiness, early emergence; Step 4 - Use seed sources with those traits (Step 3) to help vegetate specific sites that were identified in Step 1.
Tactic effectiveness (risks)	Step 1/2 moderate	High
Implementation urgency	Near term	Step 1 – near term; Step 2 – ongoing dependent on prioritization of areas
Where can tactics be applied? (geographic)	In identified and mapped areas	In identified risk areas
Opportunities for implementation	Partnerships with Natural Resources Conservation Service (NRCS)	Heritage Program (for monitoring); partner with NRCS, National Oceanic and Atmospheric Administration (snow melt data), Rocky Mountain Research Station; local cooperators to help with seed accessions and Forest Service nursery
Cost	Moderately expensive	Moderately expensive
Barriers to implementation	Funding; time and personnel intensive; Requires finer-scale knowledge to be effective; higher priorities (mindset)	Funding; time and personnel intensive; higher priorities? (mindset); sequential process

Table 7A.10—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.

Adaptation strategy/approach: Maintain and increase montane shrublands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.

	Specific tactic – A	**Specific tactic – B**
Tactic	Implement fuel reduction projects (i.e., reduce conifer encroachment, brush cutting, slashing/ mastication without burning, targeted browsing); if burning is used, design prescriptions according to requirements of desired shrub species (soil moisture requirements, desired end result conditions).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.
Tactic effectiveness (risks)	Moderate (unintended consequences, higher priorities)	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout; critical areas for restoration	Throughout and across jurisdictional boundaries
Opportunities for implementation	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, Bureau of Land Management, Idaho Forest Landowner association; forest harvests open up new shrublands	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, BLM, Idaho Forest Landowner association, Turkey Federation
Cost	Inexpensive/moderately expensive (depends on scale)	Inexpensive/moderately expensive (depends on scale)
Barriers to implementation	Current forest management policies about allowing shrubfields to be maintained rather than reforestation; mindset of current land managers (tradition)	Mindset of current land managers (tradition); lack of equipment; availability of target livestock; road access; inaccessibility (slope); multi-resource objectives

Table 7A.10 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.		
Adaptation strategy/approach: Maintain and increase montane shrublands.		
Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.		
	Specific Tactic – C	**Specific tactic - D**
Tactic	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion, and targeted grazing.	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).
Tactic effectiveness (risks)	Low/moderate	Moderate
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout and across jurisdictional boundaries	Throughout and across land management jurisdictions
Opportunities for implementation	Coordinate with private landowners; cooperative weed management areas; partner with Bonneville Power, tribes, private groups such as backcountry horsemen, National Forest Foundation; use volunteer cooperators (for surveys and monitoring)	Revise Forest Service manual; brownbag lunch – weed webinar; educational products such as flyers, posters; ross training and/or internal training for line officers
Cost	Inexpensive/moderately expensive (depends on scale)	Moderately expensive
Barriers to implementation	Multiple jurisdictions; National Environmental Policy Act – not being able to adapt to new chemicals; logistically inaccessible (backpack or on horse); public mindset of using chemicals; budgets are prohibitive.	Tie implementation to performance for achieving objectives (misuse of herbicides, treating non-target native plants); need line officer support; mindset of current land managers (tradition); public mindset of using chemicals