Chapter 8

Rangeland Resources

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Rangelands are areas where the natural vegetation is comprised principally of grasses, forbs, grass-like plants, and shrubs that are suitable for browsing or grazing, but the presence of herbivory is not a prerequisite for rangeland classification. In this chapter, we evaluate the nature of rangeland resources across the conterminous United States and provide projections of future rangeland resources. One of the main changes since the 2010 Resources Planning Act (RPA) Assessment has been the dramatic increase in computational power and remotely sensed data describing the biophysical properties of the Earth's surface, allowing us to characterize trends in rangeland vegetation not previously possible (Reeves et al. 2014b). Increased computational capacity also offers an improved ability to evaluate the role and effect of climate change on the potential future of rangelands. We begin this chapter by evaluating recent trends in rangeland extent, health, vegetation ground cover, aboveground net primary productivity (NPP), and livestock numbers. We then examine the potential impacts of climate change on U.S. rangelands by using the RPA scenarios and climate models to project future changes in rangeland phenology, vegetation productivity, and land use.

Key Findings

- ❖ Rangeland health is relatively unchanged since the 2010 RPA Assessment. The greatest overall impacts to rangeland health have been observed in the RPA Pacific Coast Region and in the southwestern part of the United States due to increases in invasive annual grasses and drought.
- ❖ Rangeland production is increasing in the northern parts of the rangeland extent and decreasing in the South, with corresponding changes in bare ground. Interannual variability in productivity is increasing in most areas at the same time, with the largest changes since 2000 having occurred in the Southwestern United States. Current production trends are projected to intensify in the future and become more variable on an interannual basis.
- ❖ Rangelands have been steadily converted to developed and agricultural land uses. Urbanization is projected to be responsible for most of the future reduction in rangeland extent, especially in the Pacific Coast Region.

Rangeland Extent

- The non-Federal rangeland base declined by 6 million hectares (ha; 3.6 percent) from 1982 to 2017, primarily driven by net movement of 2.3 million ha to developed uses (urban and rural transportation infrastructure) and 1.2 million ha to cropland.
- Land area enrolled in the Conservation Reserve Program (CRP) reached a national peak in 2007 of about 14.7 million ha, followed by a steady decline to 9.1 million ha in 2018, representing a loss of 38 percent.

Most of the rangeland area in the conterminous United States exists west of the 97th meridian (Reeves and Mitchell 2011). Although not part of the conterminous United States and not discussed in this report, rangelands also occur in Alaska, Hawaii, and several of the U.S. protectorates and territories. The composition and distribution of rangelands are described in Reeves and Mitchell (2011, 2012), while rangeland transitions to and from other land uses are described in the Land Resources Chapter of this Assessment. Highlights from those sources are provided here, as well as significant trends in rangeland area since 2010.

The National Resources Inventory (NRI), administered by the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS), estimated 169 million ha of non-Federal rangelands in 1982 (USDA NRCS 2018). By 2017, the estimated area of non-Federal rangelands was 163 million ha, representing a loss of 6 million ha or 3.6 percent of the non-Federal rangeland base (168,571 ha average loss per year from 1982 to 2017). More than half of the net loss in rangeland area (3.6 million ha, 2.1 percent) occurred between 1982 and 1992. The decline in rangeland area was driven by net movement of 2.3 million ha to developed uses (urban and rural transportation infrastructure) and 1.2 million ha to cropland. Smaller net losses were observed in shifts to forest and other rural land including farmsteads.

The Rocky Mountain Region has the most non-Federal rangeland area in the United States (about 106 million ha in 2017), followed by the South, Pacific Coast, and North Regions (table 8-1). While all regions lost rangelands from 1982 to 2017, the Rocky Mountain Region lost the greatest total amount of rangeland and the North Region lost the highest percentage of rangeland over this period. Missouri is the only State in the North Region for which the NRI has recorded rangeland data, and it has lost 39 percent of its rangeland base since 1982. In all regions, the largest rangeland conversions were transitions to crop and urban land cover.

Federally managed rangelands generally do not undergo land use transitions and are therefore assumed to stay constant. The rare exception is when public lands are transferred to, or purchased by, non-Federal ownership. For example, the U.S. Bureau of Land Management (BLM) had a net disposal of 56,376 ha from all 50 States in 2020, approximately 0.00057 percent of the BLM land base (BLM 2020). Similarly, the 2020 U.S. Department of Agriculture (USDA), Forest Service land base was 67,275 ha larger than the average area from 2013 to 2019 (94,093,141 ha), an increase of 0.00072 percent (USDA Forest Service 2020). These examples support the validity of the stationarity assumption from a national perspective. Non-Federal rangelands lost about 168,571 ha per year from 2010 to 2017 for a total loss of about 1.7 million ha. Given that Federal rangeland area remains essentially constant over time and that Reeves and Mitchell (2011) estimated a total rangeland area in the conterminous United States of about 268 million ha, it follows that the total rangeland area in the conterminous United States in 2017 was about 266.3 million ha.

Table 8-1. Non-Federal rangeland area by RPA region.

	1982	2017	Change (1982 to 2017)	Proportion of non-Federal rangeland area (2017)
Region	thousand ha		thousand ha (%)	%
North	51	31	-20 (-38.9)	0.02
South	45,290	43,429	-1,861 (-4.1)	26.64
Rocky Mountain	108,762	105,654	-3,108 (-2.9)	64.81
Pacific Coast	14,841	13,906	-935 (-6.3)	8.53
National	168,948	163,020	-5,928 (-3.5)	

ha = hectares.

Source: USDA NRCS 2018.

Table 8-2 shows the proportional ownership of rangelands across the conterminous United States. Private rangelands cover a larger area than all other rangeland ownerships combined. Of the non-private rangelands, the BLM manages

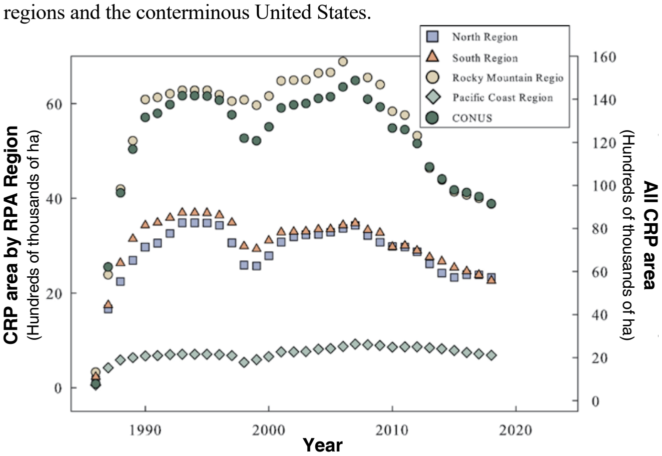
Table 8-2. Approximate proportion of rangeland under management in the conterminous United States.

Ownership	Proportion of all rangeland	Proportion of publicly owned rangeland
	percent	percent
U.S. Bureau of Land Management	21	47
U.S. Department of Defense	2	5
U.S. National Park Service	2	4
Privately owned	55	0
State government	6	13
Tribal	5	12
U.S. Fish and Wildlife Service	1	2
USDA Forest Service	8	17

the largest proportion (47 percent) while the U.S. Fish and Wildlife Service (FWS) manages the smallest proportion (about 2 percent). The proportion of U.S. rangelands managed by State governments is about 6 percent.

The CRP, administered by the U.S. Department of Agriculture, Farm Service Agency, has impacts on rangelands and rangeland sustainability. CRP lands are not considered rangeland in the NRI because the cover is not "permanent"; however, CRP lands planted to grasses, forbs, or shrubs may provide similar ecological functions and act to decrease fragmentation in landscapes dominated by rangeland vegetation. These lands can provide connectivity between disjunctive patches of rangelands that are often fragmented by agricultural or urban land uses (Reeves et al. 2018, Augustine et al. 2021) and provide benefits from reduced erosion and wildlife viewing and hunting (Sullivan et al. 2004). In addition, CRP lands generally improve ecological condition when compared with agricultural land uses. Enrollment in CRP has led to enhanced soil productivity, increased provision of wildlife habitat, and improved water quality, all of which are also traits of healthy rangelands. Moreover, CRP lands have the potential to sequester a significant quantity of atmospheric carbon dioxide (Yang et al. 2019). Participation in the CRP has also led to unintended negative consequences (Bakker and Higgins 2009). For example, millions of hectares enrolled in the CRP are seeded with nonnative species, such as crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass (*Thinopyrum intermedium*), and smooth brome (*Bromus inermus*). CRP area reached a national peak in 2007 of about 14.7 million ha followed by a steady decline to 9.1 million ha in 2018, representing a loss of 38 percent (figure 8-1). Regionally, the Rocky Mountain Region had the most CRP land (peaking at 7.5 million ha in 2007), followed by the South Region (3.7 million ha in 1993), North Region (3.5 million ha in 1993), and Pacific Coast Region (920,000 ha in 2007) (figure 8-1). The amount of CRP land has decreased steadily since 2007 in all regions, and in 2018 the Rocky Mountain Region exhibited 41 percent less CRP land than in 2007. The Pacific Coast Region has exhibited losses of about 24 percent since 2007, while the South and North Regions have lost 32 and 28 percent, respectively, since 2007.

Figure 8-1. Area of CRP under contract from 1986 to 2018 for the RPA regions and the conterminous United States.



CONUS = conterminous United States; CRP = Conservation Reserve Program; ha = hectares.

Source: https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index (20 May 2021).

Rangeland Condition and Health

- ❖ Relatively healthy conditions were found on approximately 75 percent of non-Federal rangeland from 2011 to 2015 and between 79 to 86 percent of BLM rangelands from 2011 to 2018. Relatively healthy is defined as less-than-moderate departure from reference conditions for all three rangeland health attributes—soil and site stability, hydrologic function, and biotic integrity.
- ❖ Invasive species are having a relatively larger impact on rangeland health than other factors.
- ❖ This inaugural RPA evaluation of vegetation trends across all lands using remote sensing corroborates findings from both the NRI and the Assessment Inventory and Monitoring (AIM) processes.
- ❖ The northern Great Plains exhibited the largest increases in perennial herbaceous cover while the Interior West and California exhibited the largest declines. Annual grasses and forbs are increasing almost universally across rangelands, with the largest increases observed in Washington, Oregon, northern Nevada, and southern Idaho.
- ❖ Annual net primary productivity has been generally increasing in the North while decreasing in the South, especially the desert Southwest, while interannual variability has been increasing almost universally since 2000. Drought events since 2000 have created continually lower production in California, New Mexico, and Arizona.
- ❖ Bare ground is decreasing in many areas due to the increasing trend of annual herbaceous species. The exception is the desert Southwest, particularly New Mexico and west Texas, which has experienced increased bare ground attributable to reduced annual net primary productivity since 2000.

Rangeland health assessments provide information on the function of ecological processes relative to ecological potential. The process most commonly used to evaluate rangeland health in the United States considers 17 indicators relating to the attributes of biotic integrity, hydrologic function, and soil and site stability (Pellant et al. 2020, USDA NRCS 2018). The NRI uses the rangeland health assessment process to regularly monitor rangeland health on non-Federal lands, although inferences from this monitoring are only applicable for non-Federal lands and for relatively large areas (i.e., bigger than most counties). On Federal lands, the BLM regularly collects data on rangeland health attributes and vegetation composition and structure as part of the AIM Program (Toevs et al. 2011a, 2011b). The AIM sampling effort reports on the status, condition, and trend of rangeland resources in 13 Western States by annually surveying thousands of random locations across BLM lands (Yu et al. 2020). The USDA Forest Service does not collect all of the data necessary for rangeland health assessment (i.e., biotic integrity, hydrologic function, and soil and site stability), but does collect data on vegetation composition and structure from nonforest lands using Forest Inventory and Analysis (FIA) protocols through the All Conditions Inventory (ACI) project (Bush 2012). The capacity to quantify rangeland conditions and trends across large areas has significantly increased since the last RPA rangeland assessment due to the addition of the AIM program (the NRI has been collecting data since 1982) and increased remote sensing analytical capabilities (Reeves et al. 2014b). While remotely sensed indicators of rangeland trends can enhance our understanding of rangeland condition and health, they are not necessarily directly comparable to the ground sampling efforts documented in this report given sample size issues, spatial autocorrelation, and other considerations.

Non-Federal Lands

Rangeland Health

Our examination of non-Federal rangeland health was based on the 2018 NRI Rangeland Resource Assessment (USDA NRCS 2018), where the data collected for 17 rangeland health indicators at individual sample locations, assessed based on guidance by Pellant et al. (2005), were aggregated to a broader spatial scale (Major Land Resource Area). Each indicator was assigned a degree of departure based on the extent to which the indicator fell outside the range of natural variability for a site: none-to-slight, slight-to-moderate, moderate, moderate-to-extreme, extreme-to-total. The smaller the degree of departure, the "healthier" the site. The data collected during the 2011 to 2015 time period were compared against a 2004 to 2010 reference period; trend analysis is not possible until multiple data points can be compared against the reference period. When considering rangeland health attributes individually, a large majority of non-Federal rangeland in the Western United States showed relatively minor departures from reference conditions during the 2011 to 2015 period. Rangelands exhibited the best health for the soil and site stability attribute, with 87.3 percent exhibiting none-to-slight or slight-to-moderate departure from reference conditions and only 3.2 percent exhibiting moderate-to-extreme or extreme-to-total departure. Conversely, rangelands departed most significantly from reference conditions for the biotic integrity indicator, with 77.3 percent of rangelands exhibiting none-to-slight or slight-to-moderate departure and 5.8 percent exhibiting moderate-to-extreme or extreme-to-total departure (table 8-3). The biotic integrity indicator factors in the presence of nonnative species, explaining in part why this element of rangeland health departs the most from reference conditions (table 8-3).

Between 77 and 87 percent of non-Federal rangeland in the conterminous United States was in relatively healthy condition from 2011 to 2015, depending on the attribute being examined. The remaining 12 to 23 percent of non-Federal rangeland showed moderate or greater departures from reference conditions for at least one of the rangeland health attributes, while 10.5 percent showed moderate or greater departures for all three rangeland health attributes (figure 8-2). For all three rangeland health attributes, the extent of departure from reference condition varied widely across Western States. Relatively large departures for all three attributes were found in Texas, Oklahoma, eastern Colorado, western Kansas, and eastern Washington and Oregon, along with smaller areas in other places such as northern Utah and southern Idaho.

Prolonged periods of severe or extreme drought encompassed portions of Arizona, New Mexico, southeast Colorado, northwest Texas, western Oklahoma, and southwest Kansas from 2011 to 2015. These areas also experienced at least moderate departures from reference conditions for each rangeland health attribute during this same time period, suggesting that extended droughts may impact rangeland health (figure 8-2).

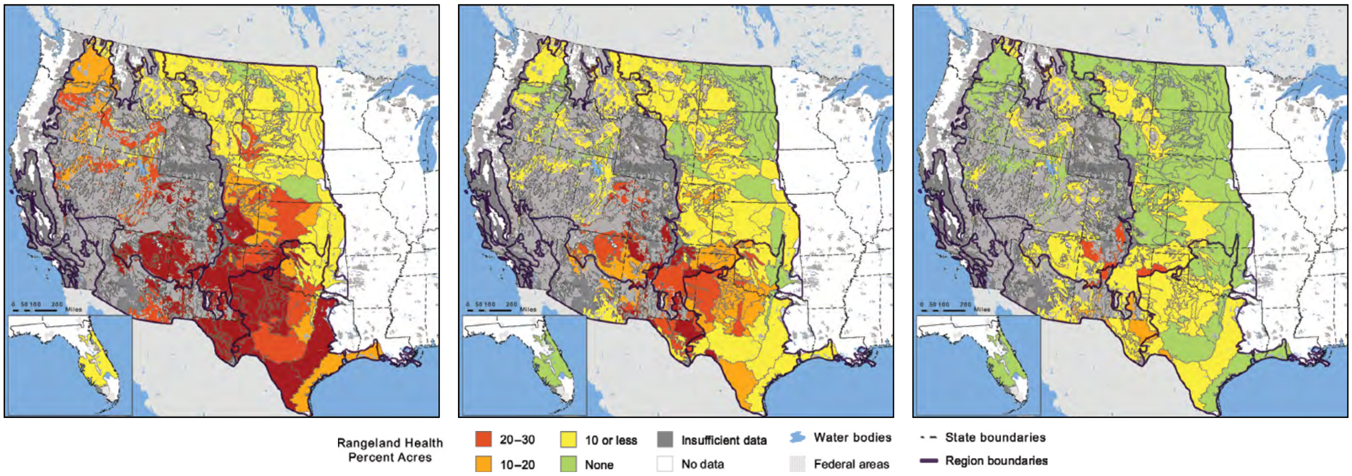
Table 8-3. Proportion of non-Federal rangelands (2011 to 2015) in different categories of departure from reference conditions for rangeland health.

Attribute	None-slight, slight-moderate	Moderate	Moderate-extreme, extreme-total
	percent of rangeland area[a] (margin of error)		
Soil/site stability	87.3 (1.0)	9.5 (0.9)	3.2 (0.5)
Hydrologic function	84.0 (1.2)	12.2 (1.1)	3.8 (0.5)
Biotic integrity	77.3 (1.4)	16.9 (1.2)	5.8 (0.6)

[a] *Rangeland with no data (5.5 percent) is excluded.*

Source: USDA NRCS 2018.

Figure 8-2. Area of non-Federal rangeland where rangeland health attributes exhibit moderate or larger departures from reference condition from 2011 to 2015: (left) locations where at least one attribute exhibits moderate departures (25.8 ±1.4 percent), (middle) locations where all three attributes exhibit moderate departures (10.5 ±0.9 percent), and (right) locations where all three attributes exhibit above moderate departures (2.0 ±0.3 percent). The colored portions of the maps represent Major Land Resource Areas where sufficient non-Federal rangeland was sampled by the National Resources Inventory to estimate the rangeland health parameters.



Source: USDA NRCS 2018.

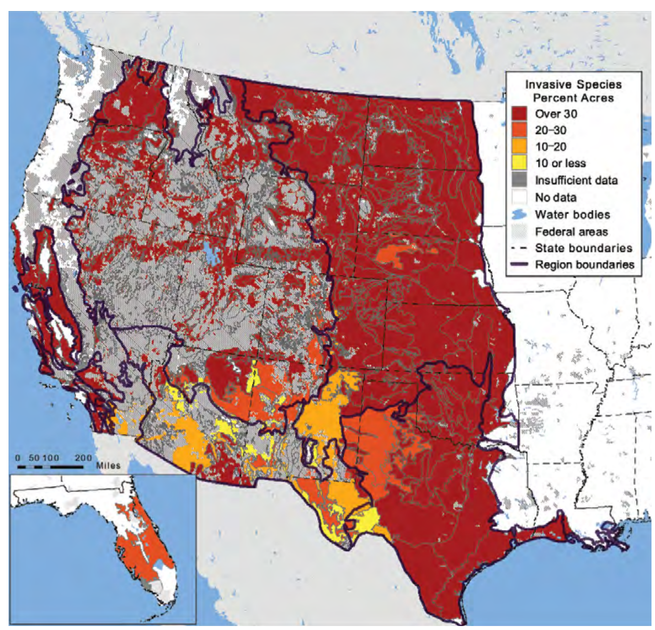
Invasive Species

Invasive plant species on rangelands are nonnative plant species that are harmful to rangelands. Nonnative species are introduced from other countries or were native to the United States but historically absent from (or only minor components of) rangeland plant communities. Not every nonnative species is considered invasive; most nonnative species do not pose a significant problem, and some are considered beneficial. For example, crested wheatgrass is commonly recommended and introduced onto rangelands in semiarid regions for forage production and soil stabilization even though its presence can affect some species composition-related measures of rangeland health in the biotic integrity category.

We examined specific groups of invasive grasses, forbs, and woody plant species selected because of their prevalence in rangeland plant communities. We provide a cursory overview of dominant themes and offer some specific examples of problematic invasive species influencing relatively large areas of U.S. rangelands. A comprehensive evaluation describing dozens of invasive species on non-Federal rangelands is provided in the 2018 NRI Rangeland Resource Assessment (USDA NRCS 2018).

Invasive species occupy every State in the rangeland domain (figure 8-3). With the exception of the Southwestern United States, invasive species are found on 30 percent or more of the non-Federal rangelands. Invasive annual brome grasses are particularly abundant in shrub communities like sagebrush and pinyon-juniper and often outcompete native

Figure 8-3. Percent of non-Federal rangeland area where invasive species were present between 2011 to 2015. The colored portions of the maps represent Major Land Resource Areas where sufficient non-Federal rangeland was sampled by the National Resources Inventory to estimate the rangeland health parameters.

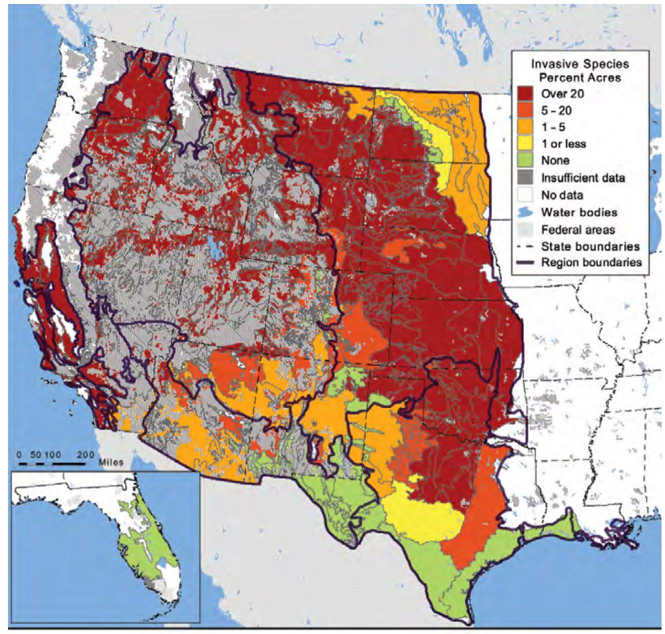


Source: USDA NRCS 2018.

grasses and forbs. Invasive annual bromes were present on 30 (±1.4) percent of non-Federal rangelands during the 2011 to 2015 time period, with over 70 percent of rangelands affected in the States of California, Washington, and Oregon that comprise the Pacific Coast Region (figure 8-4, table 8-4). Cheatgrass is the most prevalent invasive annual brome species, and has the potential to dramatically alter the ecosystems it invades by completely replacing native vegetation and increasing fire-return intervals (Brooks et al. 2004, Bush et al. 2004, Chambers et al. 2007, DiTomaso 2000, Pyke et al. 2016; see the Disturbance Chapter). Cheatgrass was present on 18.6 (±1.0) percent of non-Federal rangeland from 2011 to 2015, with 50 percent or more occupation of non-Federal rangelands in Oregon, Washington, Idaho, Nevada, South Dakota, and Utah (table 8-4). In addition to annual brome grasses, the 2018 NRI Rangeland Resource Assessment indicates that other annuals such as medusahead *(Taeniatherum caput-medusae)* and ventenata *(Ventenata dubia)* have a significant presence, especially in the Pacific Coast Region.

Like invasive annual grasses, some nonnative perennial grasses such as Kentucky bluegrass *(Poa pratensis)*, Canada bluegrass *(P. compressa)*, and smooth brome are also negatively impacting U.S. rangelands in some regions. Kentucky and Canada bluegrass are perennial sod-forming

Figure 8-4. Percent of non-Federal rangeland area where annual bromes (*Bromus* spp.) meet the criteria of covering a majority (at least 50 percent) of the soil surface from 2011 to 2015.



Source: USDA NRCS 2018.

Table 8-4. Proportion of State area where select invasive species occur, provided only for States where NRI rangeland samples are collected. The values in parentheses represent margins of error as the 95th percent confidence intervals. Estimates with a double asterisk denote that the species was not detected on non-Federal rangelands within the State. Some estimates with a large margin of error in relation to the estimate are based on very few observations. The lower bound of the confidence interval may also be inappropriately negative.

State	RPA region	Annual *Bromus* spp.	*Bromus tectorum*	*Poa pratensis* or *P. compressa*	*Centaurea* and *Acropitolon* spp.	*Euphorbia esula*	*Juniperus* spp.	*Prosopis* spp.
Florida	South	**	**	**	**	**	**	**
Louisiana	South	**	**	**	**	**	**	**
Oklahoma	South	37.3 (5.4)	24.2 (5.9)	0.5 (1.1)	**	**	20.9 (5.8)	6.9 (3.4)
Texas	South	6.2 (1.8)	1.3 (0.7)	**	**	**	14.5 (3.8)	54 (4.7)
Arizona	RM	3.6 (3)	1.5 (1.9)	**	**	**	11.4 (5.4)	18.4 (5.5)
Colorado	RM	19.4 (5.7)	14.5 (4.3)	7.1 (2.3)	0.3 (0.6)	0.2 (0.2)	5.3 (3.0)	**
Idaho	RM	72 (6.1)	58.1 (8.6)	18.1 (7.2)	1.8 (2.2)	**	2.3 (2.2)	**
Kansas	RM	57.7 (5.1)	32.2 (4.8)	39.8 (5.8)	**	**	3.9 (1.4)	**
Montana	RM	48.9 (7.1)	22.2 (4.3)	32.1 (5.6)	1.4 (1.1)	2.3 (1.6)	8.4 (4.0)	**
Nevada	RM	52.4 (12.3)	52.4 (12.3)	1.9 (3.5)	2.1 (3.2)	**	6.3 (4.0)	**
Nebraska	RM	41 (5.8)	27.7 (5.1)	37.8 (4.8)	**	0.7 (0.8)	5.4 (2.3)	**
New Mexico	RM	1.5 (0.9)	1.5 (0.9)	0.2 (0.4)	**	**	14.8 (3.9)	15.7 (3.8)
North Dakota	RM	9.1 (3.4)	0.7 (0.9)	86 (3.7)	**	9.8 (4.0)	4.5 (1.7)	**
South Dakota	RM	54 (5)	45.4 (4.9)	62.9 (3.4)	**	0.4 (0.5)	2.1 (1.2)	**
Utah	RM	53.1 (7.1)	51 (7.4)	9.6 (5.1)	0.6 (1.1)	**	14.2 (4.9)	**
Wyoming	RM	47.2 (6.3)	31.8 (5.6)	12.2 (4.1)	0.2 (0.5)	0.3 (0.5)	1 (0.7)	**
California	PC	73.2 (8.4)	9.3 (4.2)	**	16.6 (6.2)	**	2.6 (2.2)	**
Oregon	PC	83.7 (6.7)	78.5 (6.7)	6.9 (4.5)	2.1 (2.4)	**	15.7 (7.6)	**
Washington	PC	87.1 (5.1)	82.6 (6.7)	5.6 (3.8)	4.1 (3.4)	**	**	**
National		30 (1.4)	18.6 (1.0)	14.5 (0.8)	1.1 (0.4)	0.6 (0.2)	9.4 (1.2)	15.8 (1.3)

NRI = National Resources Inventory; PC = Pacific Coast; RM = Rocky Mountain.

Source: USDA NRCS 2018.

species commonly planted on pasturelands (Hall 1996) but are listed as invasive in the Great Plains (Bush 2002, Toledo et al. 2014, Wennerberg 2004). While providing reasonable sources of forage, both bluegrass species can displace native vegetation if not properly managed (St. John et al. 2012, Toledo et al. 2014). Kentucky and Canada bluegrass were present on 14.5 (±0.8) percent of all non-Federal rangeland from 2011 to 2015, with the largest presence in the eastern part of the Rocky Mountain Region (table 8-4). These species occupy 86 (±3.7) percent of non-Federal rangelands in North Dakota alone.

The 2018 NRI Rangeland Resource Assessment also provides information on invasive forbs; here we evaluated leafy spurge *(Euphorbia esula)*, knapweeds *(Acroption* spp.*)*, and starthistles *(Centaurea* spp.*)*. Leafy spurge is a difficult to eradicate, deep-rooted invasive plant that forms nearly monocultural stands. It is generally considered poisonous to cattle and horses because it contains the alkaloid euphorbon, a known co-carcinogen also toxic to humans (Washington State Noxious Weed Control Board 2021). However, sheep and goats appear relatively unaffected by the plant. Leafy spurge was found on 0.6 (±0.2) percent of non-Federal rangelands from 2011 to 2015 but is relatively common in non-Federal rangelands in North Dakota (table 8-4). Leafy spurge occurs in the same habitats as knapweeds and starthistles in some areas, which were present on 1.1 (±0.4) percent of non-Federal rangelands. In California, however, these species are found on 16.6 (±6.2) percent of non-Federal rangelands (table 8-4). Knapweeds and starthistles inhibit other plants through production of chemical substances reducing germination or growth (Alford et al. 2009). As a result, knapweeds and starthistles can rapidly replace native species, especially perennial graminoids, making lands less resilient to drought and other disturbances.

Some native woody plant species such as junipers *(Juniperus* spp.*)* and mesquite *(Prosopis* spp.*)* can also replace native grasses and forbs. Encroachment by shrubs, especially *Juniperus* spp., has rapidly escalated since pre-Euro-American settlement (Coates et al. 2017). These invasions have significantly changed fire effects and behavior where they have occurred, and decreased resiliency to drought. Juniper species were present on 9.4 (±1.2) percent of non-Federal rangelands, with the largest presence in Oklahoma, followed by Oregon, New Mexico, Texas, Utah, Arizona, and Montana (table 8-4). Like junipers, mesquite species typically have a deep root system that enables them to withstand droughts and outcompete grasses. Honey mesquite *(P. glandulosa)* and velvet mesquite *(P. velutina)* are the two most common species found in the Southwestern United States (Ansley et al. 1997). Mesquite species were present on 15.8 (±1.3) percent of non-Federal rangelands, observed most commonly in Texas, Arizona, New Mexico, and Oklahoma (table 8-4).

In terms of invasive species threats to rangelands, annual grasses, especially cheatgrass, are often posited as the largest threat to U.S. rangelands. They are the most commonly occurring group of invasive species in non-Federal rangelands (table 8-4), and their ability to alter fuel compositions facilitates fire spread and reduces fire-return intervals (Balch et al. 2013, Pilliod et al. 2017), leading to larger and more frequent wildfires (Chambers et al. 2014). Other species such as Kentucky bluegrass negatively impact rangeland health through reduction of biotic integrity, even though they also provide beneficial services like offering good forage for native and domestic ungulates.

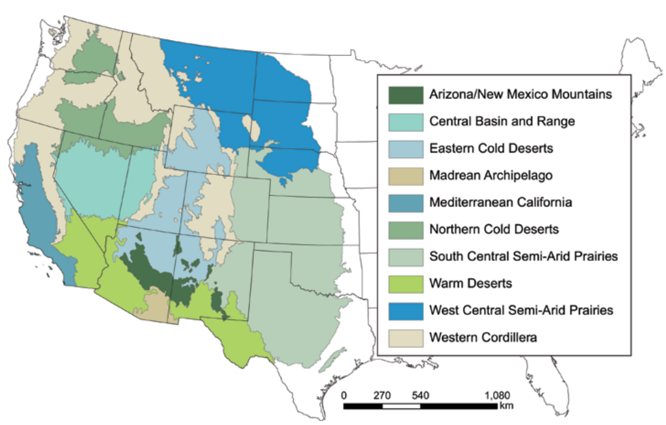
Federal Lands

U.S. Bureau of Land Management

The BLM manages approximately 98.7 million ha of Federal lands in the conterminous United States and Alaska for the U.S. Department of the Interior, of which 78.5 million ha are rangelands (BLM 2013). The BLM manages rangelands to ensure their health and productivity for the use and enjoyment of current and future generations (Public Law 95–514; PRIA 1978). Although the NRI Rangeland Resource Assessment reported results at the scale of Major Land Resource Areas, BLM rangelands are characterized here using nine Level II Ecoregions to maintain consistency with other BLM reporting efforts (Omernik 1987; figure 8-5). Because almost half of BLM-administered lands fall within the Cold Deserts Level II Ecoregion, this ecoregion was further divided into Level III Ecoregions: Northern Cold Deserts, Eastern Cold Deserts, and Central Basin and Range (Karl et al. 2016; figure 8-5).

In this section we describe the status and trends of BLM rangelands nationally and within ecoregions from 2010

Figure 8-5. Level II and III Omernik ecoregions used for the BLM rangeland health assessment.



BLM = U.S. Bureau of Land Management.
Source: Omernik 1987.

to 2020 using data from the BLM Landscape Monitoring Framework (LMF), part of the AIM project. The LMF annual survey of approximately 2,000 random locations across BLM lands (Yu et al. 2020) gathers information on attributes of rangeland health using the same process as the NRI (Pellant et al. 2005), in addition to gathering information on BLM terrestrial core metrics (Herrick et al. 2017) for reporting national-level status and trends. We also separately provide data on the trend of bare ground on BLM lands and the presence of nonnative invasive species to allow subsequent comparison with consistent national-level trends derived from remote sensing in the section All Lands Trends. Percent cover of bare ground was determined using the line-point intercept method (Herrick et al. 2017) while presence of nonnative invasive species is derived from the species inventory method (Herrick et al. 2017).

Results of the BLM rangeland health assessment are provided as either the proportion of the area within a condition class or as an average status across the area, and are weighted based on the BLM land area sampled. Each indicator estimate is presented using four categories of departure from reference conditions (similar to the NRI Rangeland Resource Assessment): (1) none-to-slight or slight-to moderate departure from reference for biotic integrity, (2) none-to-slight or slight-to moderate departure from reference for hydrologic function, (3) none-to-slight or slight-to-moderate departure from reference for soil and site stability, and (4) none-to-slight or slight-to-moderate departure from reference for biotic integrity, hydrologic function, and soil and site stability. Although the same rangeland health evaluation process is used by both the BLM and NRI, these two programs report their official results slightly differently. The BLM focuses on proportion of *healthy* rangelands, framing and reporting rangeland health in terms of none-to-slight or slight-to-moderate departure from reference conditions. In contrast, the 2018 NRI Rangeland Resource Assessment results span the scoring spectrum, although most of the figures focus on *unhealthy* rangelands by showing only moderate-to-extreme departures. Even though these similar data are portrayed and described from opposite ends of the rangeland health scoring perspective, they can be interpreted the same way. For example, when the BLM reports that 79 percent of all rangelands in its jurisdiction exhibit none-to-moderate levels of departure, this means that approximately 21 percent of BLM lands exhibit moderate or greater departure. This can be directly compared to the results in figure 8-2 (left), which show that non-Federal rangelands exhibit moderate-to-extreme departure on 25.8 (±1.4) percent of the land base (and conversely that 74 percent of non-Federal rangelands exhibit none-to-moderate departure). By taking the inverse of either the BLM or NRI results we can make direct health comparisons between BLM and non-Federal rangelands.

Rangeland Health

The LMF rangeland health assessments show that the majority of BLM rangelands are relatively healthy, with only none-to-slight or slight-to-moderate departure from reference conditions in terms of any one attribute (figures 8-6, 8-7, 8-8). Between 79 and 86 percent of BLM rangelands from 2011 to 2018 exhibited less-than-moderate departure from reference conditions for the three rangeland health attributes (figures 8-6, 8-7, 8-8). Conversely, 14 to 21 percent of BLM rangelands exhibited moderate-to-extreme departure in one of the three rangeland health categories. Of the three rangeland health attributes, biotic integrity exhibited the highest values (i.e., had the greatest amount of departure), consistent with non-Federal lands.

Compared to national conditions, the Western Cordillera and the West-Central Semiarid Prairies have a larger percentage of BLM rangeland in better condition (more area with none-to-slight or slight-to-moderate departure from reference for at least one attribute of rangeland health), while the Warm Deserts have a larger percentage of rangeland in worse condition (less area with none-to-slight or slight-to-moderate departure from reference). Rangeland health attributes appear to be stable or improving in all ecoregions. These BLM rangeland health results support the results found on non-Federal rangelands, however the wide confidence intervals (figures 8-6, 8-7, 8-8) suggest that some trends may not be significant and more research is needed to establish the level of significance.

Figure 8-6. Percent of BLM rangelands where biotic integrity exhibits none-to-slight or slight-to-moderate departure from reference conditions (80 percent confidence interval). The remaining rangeland area corresponds to relatively higher departure.

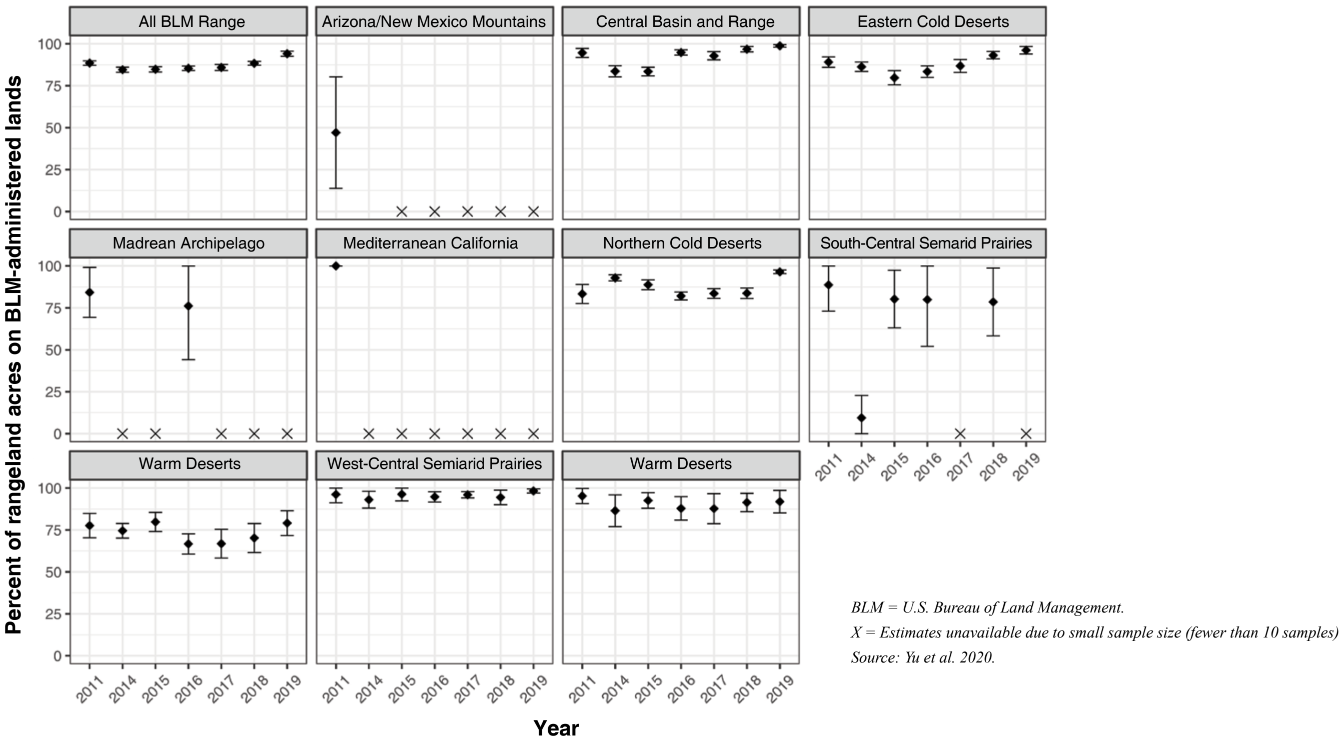


Figure 8-7. Percent of BLM rangelands where soil and site stability exhibits none-to-slight or slight-to-moderate departure from reference conditions (80 percent confidence interval). The remaining rangeland area corresponds to relatively higher departure.

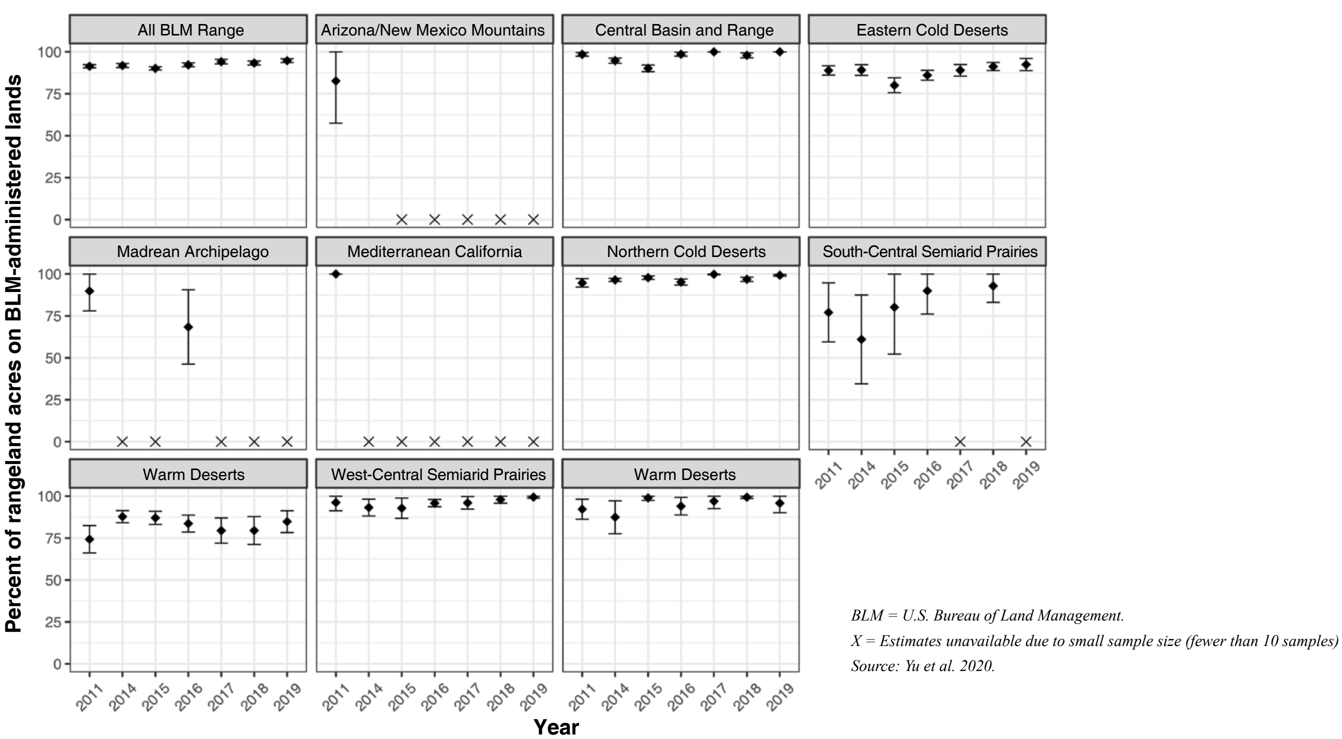
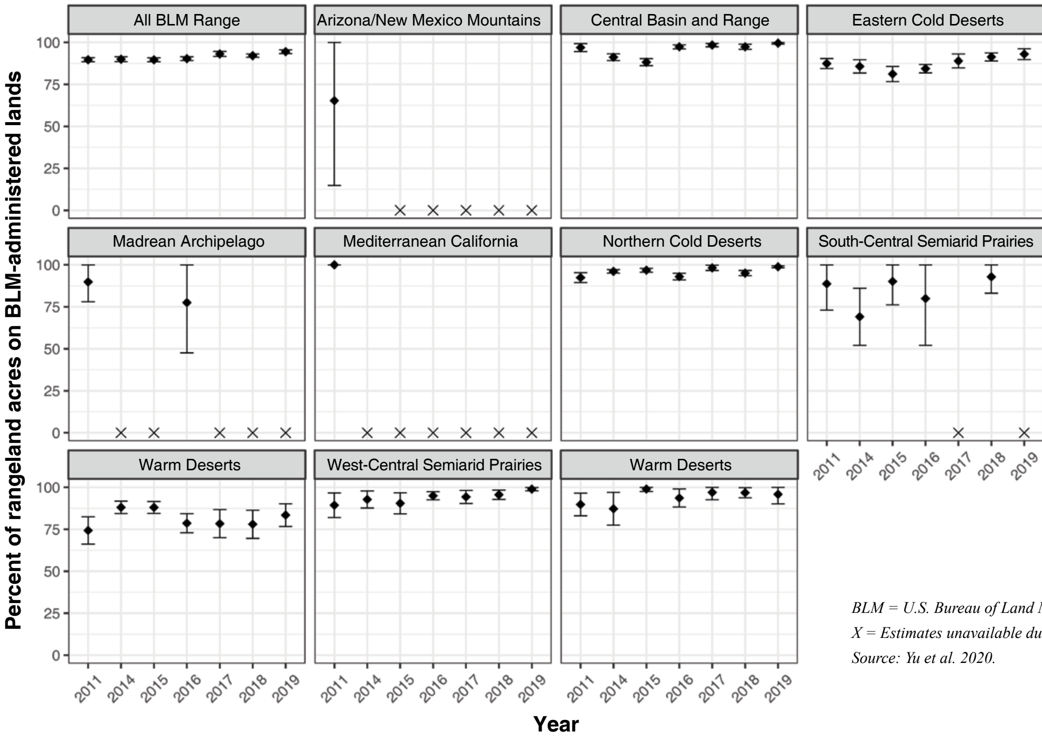


Figure 8-8. Percent of BLM rangelands where hydrologic function exhibits none-to-slight or slight-to-moderate departure from reference conditions (80 percent confidence interval). The remaining rangeland area corresponds to relatively higher departure.



BLM = U.S. Bureau of Land Management.

X = Estimates unavailable due to small sample size (fewer than 10 samples)

Source: Yu et al. 2020.

Invasive Species

Nonnative invasive species occurred on BLM rangelands in all ecoregions, present on about half and abundant (≥25 percent absolute foliar cover) on 15.8 million ha of BLM rangelands in 2018 (table 8-5). Nonnative invasive species appear to be constant or increasing for nearly all ecoregions except South-Central Semiarid Prairies. The Northern Cold Deserts, Central Basin and Range, and Mediterranean California (at least for 2015) are most affected by nonnative invasive species, which are increasing in presence across these ecoregions (figure 8-9). In the Mediterranean California ecoregion, although the sample size has been too small for inclusion in figure 8-9 in most years, nonnative invasive species presence was 100 percent in 2015. Increases in nonnative invasive species also occurred in the Warm Desert and West-Central Semiarid Prairie ecoregions (figure 8-9), while the amount of bare ground in these areas has generally decreased (figure 8-10).

Table 8-5. Estimated BLM rangeland area where nonnative invasive species were present and abundant (absolute foliar cover ≥25 percent) in 2018. The - indicates insufficient data to make the estimate.

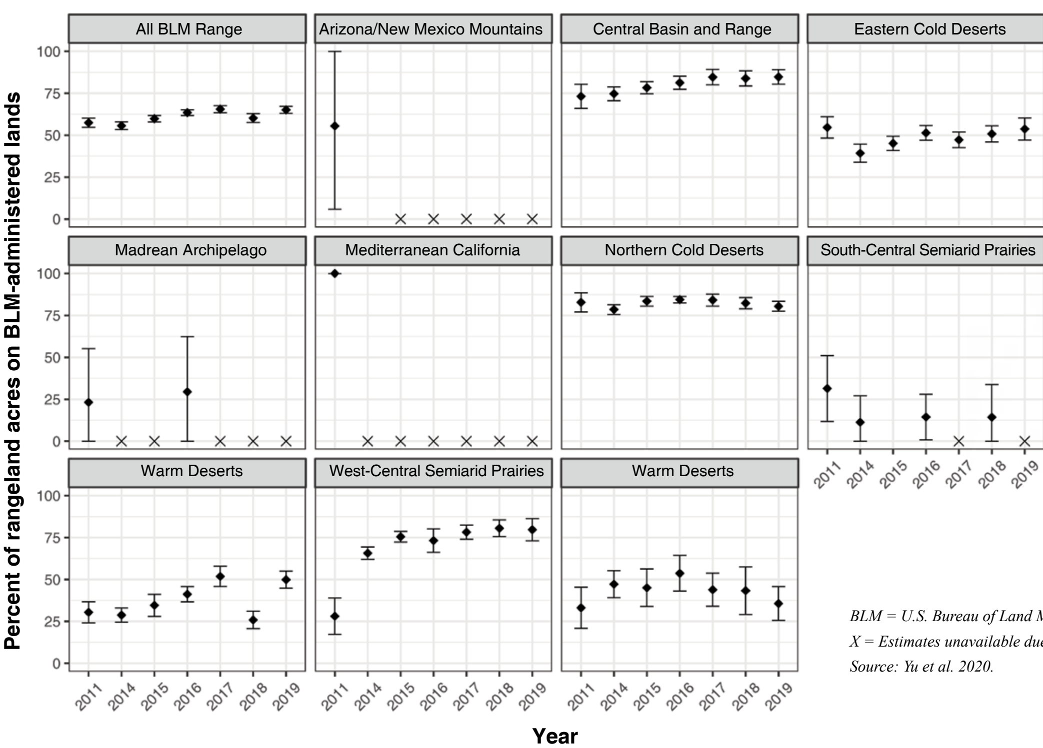
Ecoregion	Nonnative invasive species present		Absolute foliar cover composed of ≥25% nonnative invasive species	
	million ha	standard error	million ha	standard error
Arizona/New Mexico Mountains	-	-	-	-
Central Basin and Range[a]	13.8	0.69	6.03	0.9
Eastern Cold Deserts	7.43	0.48	2.32	0.55
Madrean Archipelago[a]	-	-	-	-
Mediterranean California[a]	0.38	0.38	0.38	0.38
Northern Cold Deserts[a]	8.89	0.3	5.02	0.44
South-Central Semiarid Prairies	0.11	0.12	-	-
Warm Deserts	3.12	0.48	0.82	0.26
West-Central Semiarid Prairies	2.46	0.26	0.71	0.21
Western Cordillera	1.67	0.5	0.58	0.34
All BLM Lands	**37.86**	**1.33**	**15.87**	**1.27**

[a] Level III ecoregion.

BLM = U.S. Bureau of Land Management; ha = hectares.

Source: Yu et al. 2020.

Figure 8-9. Percent of BLM rangelands with presence of nonnative invasive plant species (80 percent confidence interval). See Karl et al. (2016) for a list of plant species considered nonnative invasive species.

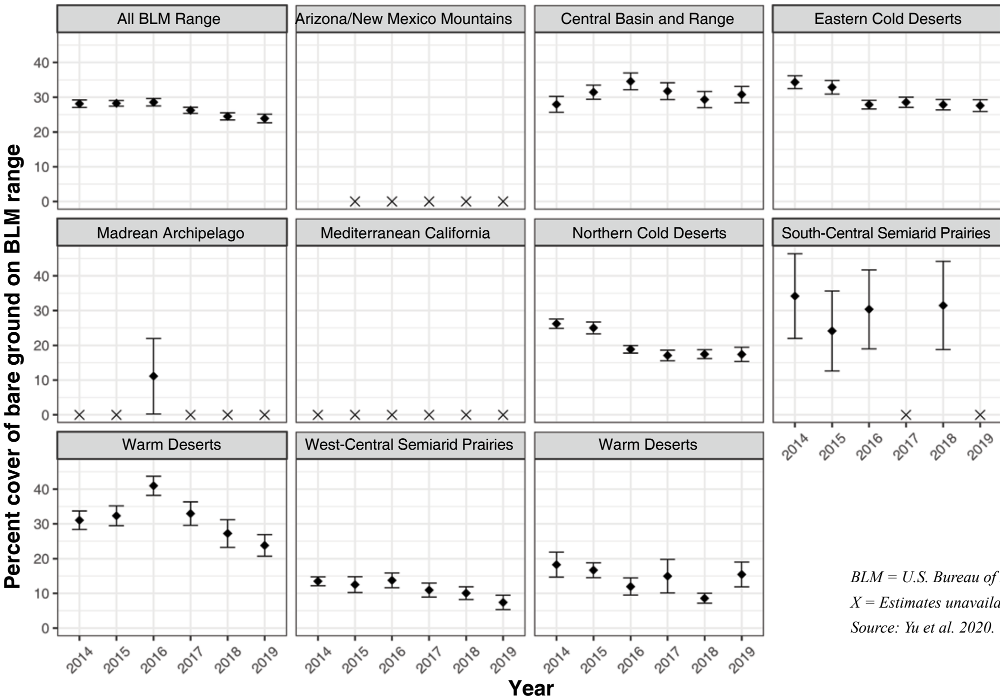


BLM = U.S. Bureau of Land Management.

X = Estimates unavailable due to small sample size (fewer than 10 samples)

Source: Yu et al. 2020.

Figure 8-10. Average bare ground cover on BLM rangelands (80 percent confidence interval).



BLM = U.S. Bureau of Land Management.

X = Estimates unavailable due to small sample size (fewer than 10 samples)

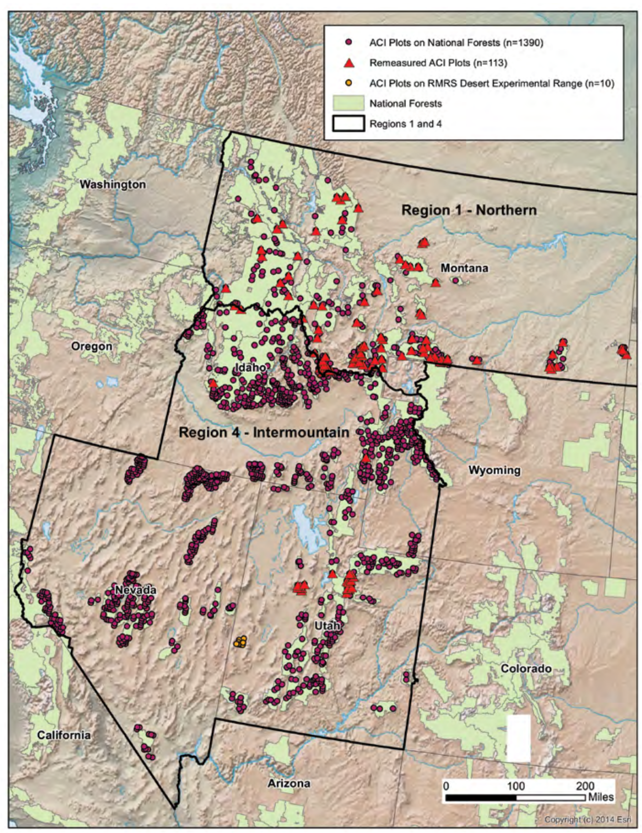
Source: Yu et al. 2020.

USDA Forest Service

The USDA Forest Service has conducted the FIA All Conditions Inventory (ACI) sporadically on National Forest System lands in the Western United States since 2004. Unlike the NRI and AIM projects, the ACI protocols do not evaluate rangeland health attributes so no formal comparison can be made with non-Federal (NRI) or BLM (AIM/LMF) lands. In addition, not all national forests participate in this program. Approximately 1,400 ACI plots have been established throughout USDA Forest Service Regions 1 (northern Idaho, western Montana) and 4 (southern Idaho and Utah) as of July 2017 (figure 8-11). Of these, 113 plots (8.1 percent) were remeasured within 10 years of their initial installation (91 plots in Region 1 and 22 plots in Region 4; table 8-6). ACI plots were found in all 21 national forests in USDA Forest Service Regions 1 and 4 (table 8-7). Only limited inferences can be made given the relatively small sample size and plot density and the low number of plots that were revisited at the time of this analysis (2017). We can confirm the presence of key invasive species such as cheatgrass, knapweed, toadflax *(Linaria dalmatica)*, and leafy spurge in plots across these regions; all of these species have the propensity to significantly change ecological conditions.

For all plots with initial measurements, 217 plots contained at least one of the four key invasive plants, with 21 plots occurring in Region 1 and 196 in Region 4. Cheatgrass was most prevalent, occurring in 215 of these plots (table 8-7). Plots with cheatgrass had a weighted average cheatgrass foliar cover of 5.9 percent across all ACI plots.

Figure 8-11. Spatial distribution of All Conditions Inventory (ACI) plots, administered by the USDA Forest Service Forest Inventory and Analysis Program throughout the Western United States.



Source: Bush 2012.

Table 8-6. Distribution of ACI plots and associated 2005 to 2017 remeasurement information, by USDA Forest Service region and State.

USDA Forest Service Region	Location	ACI plots	Remeasured
		n	
1	Northern Idaho	42	7
1	Montana	225	84
4	Nevada	372	0
4	Utah	212	20
4	Southern Idaho	412	2
4	Wyoming	137	0
Total		**1,400**	**113**

ACI = All Conditions Inventory.
Source: Bush 2012.

These findings show cheatgrass occurring on 15 percent of the sampled area within USDA Forest Service rangelands, less than the 18-percent occurrence on non-Federal rangelands (tables 8-4, 8-7). The Payette and Sawtooth National Forests in Idaho had the highest mean cheatgrass cover, each with approximately 12-percent cover and an occurrence rate in ACI plots of 38 and 19 percent, respectively. In comparison, cheatgrass was found on 58 (±8.6) percent of non-Federal rangelands in Idaho (table 8-4). While the ACI and NRI both yield valuable information, differences in sample size and sample design mean that the data are not directly comparable and limit our ability to make statistical comparison and inferences. In addition, lands managed by the USDA Forest Service are typically higher in elevation than the non-Federal counterparts and cheatgrass currently exhibits preferences for lower elevation (warmer and drier) landscapes. As a result, the findings could reflect the biophysical preferences of cheatgrass for relatively warmer lower elevation sites, more so than land use history. Although this introduction to the ACI program does not quantify rangeland health on USDA Forest Service lands, it raises awareness of data that have previously been underutilized for rangeland assessments.

Table 8-7. Total number and density of All Conditions Inventory (ACI) plots in USDA Forest Service Regions 1 and 4. Number of plots and mean foliar cover of cheatgrass occurring on initial measurement ACI plots are also provided. Plots with no cheatgrass are indicated by "-". Plot data current as of 2017.

USDA Forest Service Region	Forest name	ACI plots	Plots/ million acres	Plots with cheatgrass	Foliar cover of cheatgrass (%)
1	Bitterroot	11	6.6	1	10.8
1	Idaho Panhandle	7	2.4	-	-
1	Nez Perce-Clearwater	30	7.4	7	8.8
4	Boise	44	17.4	22	5.6
4	Caribou-Targhee	112	36.4	7	3.9
4	Payette	26	10.8	10	11.8
4	Salmon-Challis	133	30.3	25	6.4
4	Sawtooth	108	49.3	21	12.2
1	Beaverhead-Deerlodge	85	23.5	-	-
1	Custer-Gallatin	89	26.1	7	3.7
1	Flathead	11	4.2	-	-
1	Helena-Lewis and Clark	22	6.9	3	3.5
1	Kootenai	5	1.9	-	-
1	Lolo	7	2.7	1	1.3
4	Humboldt-Toiyabe	372	55.5	82	3.7
4	Ashley	46	32.8	7	6
4	Dixie	36	21	7	5.8
4	Fishlake	45	25.2	8	8.8
4	Manti-La Sal	31	21.9	-	-
4	Uinta-Wasatch-Cache	55	18.9	4	1.5
4	Bridger-Teton	115	33.2	-	
4	RMRS Desert Experimental Range	10	179.6	3	
Total (average)		**1,400**	**(23)**	**215**	**(5.9)**

ACI = All Conditions Inventory; RMRS = Rocky Mountain Research Station.
Source: Bush (2012).

All Lands Trends

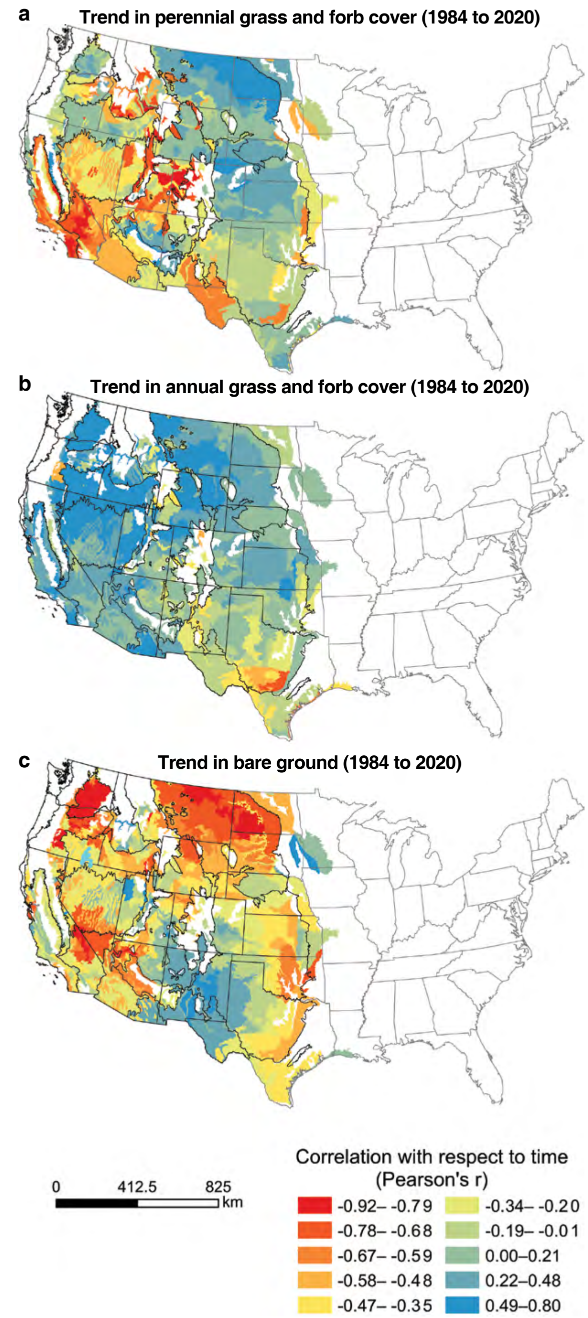
While national-level sampling programs offer valuable information about the status of U.S. rangelands, they do not provide the spatial or temporal resolution needed to evaluate rangeland trends consistently for all ownerships. The widespread availability of remotely sensed data and the dramatic increase in computational power over the last few decades has improved the capability for rangeland trend analysis. In this section we highlight these new capabilities by describing trends of annual forb and grass cover (AFGC), perennial forb and grass cover (PFGC), bare ground (BG), net primary productivity (NPP), and interannual variability of NPP. Evaluation of AFGC, PFGC, and BG come from the Rangeland Analysis Platform (RAP) (Jones et al. 2018) due to availability on the Google Earth Engine platform, although the U.S. Geological Survey Back in Time data (Homer et al. 2020, Rigge et al. 2021) could also have been used. The NPP data come from the Rangeland Productivity Monitoring Service (RPMS) (Reeves et al. 2020).

Rangeland Cover

Evaluating trends in AFGC, PFGC, and BG can indicate emerging problems, such as reduced rangeland health or reduced resiliency to drought or climate change. By examining changes in the foliar cover of different life forms and cover of bare ground, we can make general statements about the condition of the landscape. For example, decreases in cover of perennial species suggests reduced rangeland health, carrying capacity, and resiliency to drought. To perform this analysis, we calculated the linear trend (correlation with respect to time; Pearson's r) of AFGC, PFGC, and BG from 1984 to 2020 across most rangelands of the conterminous United States. While the original data were available at a 30-m resolution, we aggregated the information to Bailey's ecoregions at the ecological subsection level (Bailey and Hogg 1986), and to Omernik regions (table 8-8) and the Major Land Resource Areas used previously for comparative purposes with the AIM/NRI analyses. Because preliminary analysis suggested that the post-2000 period ushered in significant changes in rangelands of the conterminous United States, we divided the time series into two periods (1984 to 1999 and 2000 to 2020) to confirm when most of the changes in rangeland attributes took place.

At the ecological subsections spatial scale (Bailey and Hogg 1986), PFGC is strongly increasing on the northern Great Plains, principally eastern Montana, most of North Dakota, and northern South Dakota (figure 8-12), due in part to significant increases in growing season precipitation (Reeves et al. 2020). The most widespread declines in PFGC occur in California, most of Utah, western

Figure 8-12. Correlation of (a) perennial forb and grass cover, (b) annual forb and grass cover, and (c) bare ground with respect to time on rangelands, derived using Pearson's r from 1984 to 2020 for ecological subsections (Bailey and Hogg 1986). Negative Pearson's r values correspond to declining trends. Rangeland Analysis Platform data are not available for the Eastern United States.



Source: Rangeland Analysis Platform (Jones et al. 2018). (20 May 2021).

Colorado, and western Montana. In contrast to declines in PFGC, AFGC has increased in magnitude and extent throughout much of the West. The significant increases in AFGC are likely due to invasive annual grasses such as cheatgrass, red brome *(Bromus rubens)*, and ventenata noted throughout this assessment. Eastern Washington and Oregon, as well as southern Idaho, central Utah, and northern Nevada have experienced the greatest increases in AFGC, with additional increases found in eastern Montana and Wyoming (figure 8-12). These findings are consistent with recent evidence suggesting that annual grasses are expanding across the West, including at higher elevations than previously expected (Nicolli et al. 2020, Pawlak et al. 2014).

Evaluation of the two separate time periods (1984 to 1999 and 2000 to 2020) reveals that most changes in the remotely sensed rangeland indicators have taken place since 2000. The national average for both PFGC and BG were reduced by approximately 8 percent when comparing 1984 to 1999 with 2000 to 2020. Seventy-three percent of rangelands experienced losses of PFGC from 2000 to 2020, while 72 percent of rangelands experienced decreases of BG. In contrast, the national average for AFGC increased by 15 percent when comparing the period 1984 to 1999 versus 2000 to 2020. Eighty-five percent of rangelands experienced increases of AFGC from 2000 to 2020 relative to 1984 to 1999. These data coincide with the distribution of invasive annual bromes found on non-Federal land in the NRI Rangeland Resource Assessment (figure 8-4).

The widespread increases in annual forbs and grasses are directly responsible for the accompanying decreases in bare ground over much of the Western U.S. rangelands (figure 8-12). Decreases in bare ground are often considered positive, indicating that annual NPP is likely increasing or at least maintaining yields. Many of these decreases in bare ground, however, are related to increases in invasive annual forbs and grasses, which are causing significant ecological changes manifested through increased fire frequencies and behavior (Pilliod et al. 2017), and changes in forage quantity, quality, and phenology. The majority of U.S. rangelands have been exhibiting decreasing bare ground trends since 1984. While most rangelands have exhibited some decrease in bare ground, there are some notable exceptions, including the areas of west Texas and most of New Mexico (figure 8-12).

This remotely sensed evaluation of rangeland components has also been summarized across the Omernik ecoregions, to allow comparison with the AIM rangeland health evaluation (table 8-8). For example, the increase in invasive species in the Central Basin and Range on BLM lands (figure 8-9) corresponds with the finding that AFGC is increasing on all rangelands in the Central Basin and Range (r = 0.44),

Table 8-8. Correlation of perennial forb and grass cover (PFGC), annual forb and grass cover (AFGC), and bare ground (BG) with respect to time on rangelands, derived using Pearson's r from 1984 to 2020 for Omernik's ecoregions. Negative Pearson's r values correspond to declining trends, while positive numbers indicate an increasing trend. Larger numbers indicate a higher positive correlation of cover over time (cover is going up over time).

Omernik Level II Ecoregion	Rangeland sampled	PFGC	AFGC	BG
	million ha	correlation (r)		
All Rangelands	124.9	-0.3	0.3	-0.3
Arizona/New Mexico Mountains	2	-0.1	0.1	0
Central Basin and Range	11.8	-0.4	0.4	-0.4
Eastern Cold Deserts	15.7	-0.3	0.2	-0.2
Madrean Archipelago	1.7	-0.2	0.3	-0.1
Mediterranean California	3.5	-0.5	0.5	-0.2
Northern Cold Deserts	10.8	-0.2	0.6	-0.4
South-Central Semiarid Prairies	28.5	0	0.1	-0.2
Warm Deserts	17.9	-0.5	0.2	-0.3
West-Central Semiarid Prairies	23.9	0.1	0.3	-0.5
Western Cordillera	9.1	-0.3	0.3	-0.3

Source: Rangeland Analysis Platform (Jones et al. 2018). (20 May 2021).

with concomitant decreases in bare ground as a result (table 8-8). Notable differences between the remotely sensed data and those from AIM include the fact that remotely sensed data cover all rangeland ownerships while AIM covers only BLM lands and that BG is the only attribute approached consistently by both efforts.

Rangeland Annual Production

Net primary productivity is a critical indicator of rangeland health, and it serves as forage for native and domestic ungulates, small mammals, and insects. The RPMS provides spatially explicit estimates of rangeland NPP across the conterminous United States from 1984 to 2021 and beyond, at a 30-m spatial resolution, but 2020 is the most recent data included in this report because of the RPA production schedule. Using these data, we quantified the average NPP values, trend in NPP values, and interannual variability (standard deviation of the time series compared to the mean). Because trends and variability from 1984 to 1999 differ from results for the 2000 to 2020 time period (Reeves et al. 2020), we analyzed rangeland NPP trends and variability for three timeframes: 1984 to 2020, 1984 to 1999, and 2000 to 2020. As with the analysis of the trends in cover data, we calculated the linear trend of NPP (correlation with respect to time; Pearson's r).

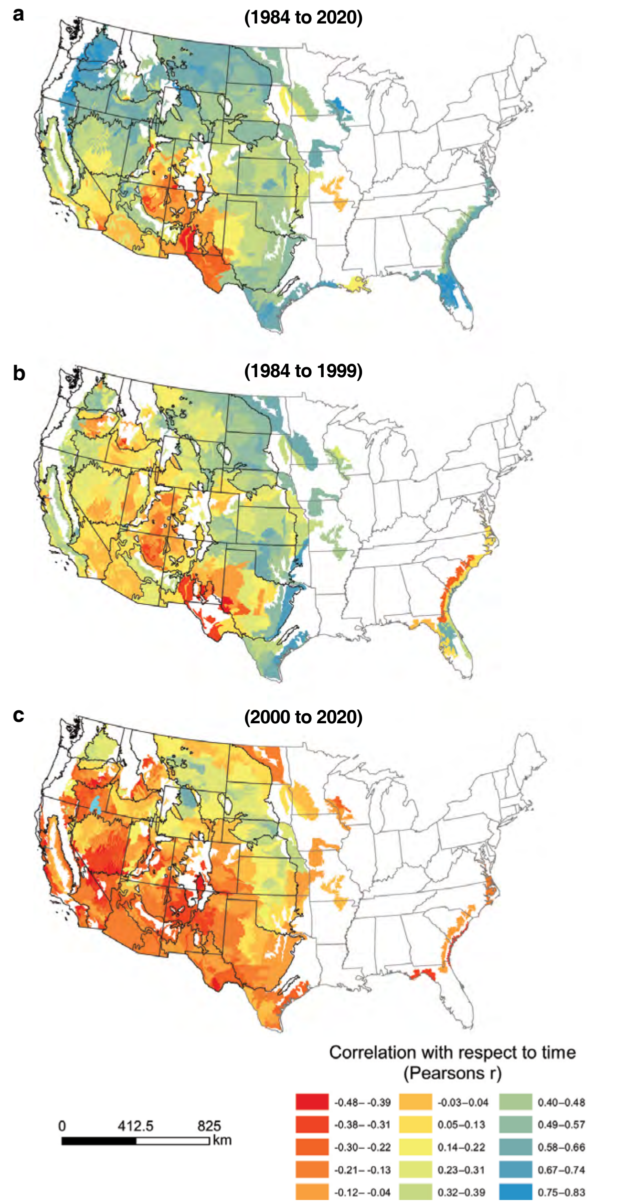
Increases in annual NPP have occurred in all RPA regions since 1984 (table 8-9). The highest NPP values (>4,400 kg ha^{-1}) were observed in the North Region. Conversely, the Rocky Mountain Region exhibited the lowest NPP values (1,140 kg ha^{-1}). Interannual variability was highest in the South and Pacific Coast Regions, with coefficients of variability (CV) of 0.17 and 0.16, respectively, meaning that NPP (and forage) varied about 17 percent annually on average from 1984 to 2020. Variability in NPP was higher from 2000 to 2020 compared to 1984 to 1999—with both higher highs and lower lows in NPP—while NPP trends, which were positive from 1984 to 1999, stagnated or declined from 2000 to 2020.

These broad national and regional averages, however, mask trends taking place on rangelands at the subregional level (figure 8-13). In all time periods (1984 to 2020, 1984 to 1999, and 2000 to 2020) the desert Southwest exhibited declining trends in NPP. In contrast, increases in NPP occurred east of the Cascade Mountains in the Pacific Northwest and the northern Great Plains of North Dakota, South Dakota, and Montana (Reeves et al. 2020, figure 8-13). In addition to these asymmetric trends in annual NPP, interannual variability after 2000 was greater than from 1984 to 1999 for all regions (table 8-9). The cause of increased variability is not known but could be linked to more intense rainfall events and greater occurrences of extreme temperatures (Frame et al. 2020). The increased variability in annual NPP has significant implications for rangeland forage supplies.

We estimated forage quantity, the relative proportion of herb cover to total vegetation cover, and a universal estimate of forage beneath forest canopies using RPMS data. Forage quantities on rangelands were estimated for average, above-average, and below-average forage conditions, calculated as the average plus or minus one standard deviation from the mean from 1984 to 2020. Key assumptions made in the analysis are outlined in table 8-10.

Private lands are the largest contributor to rangeland forage pools (table 8-10), due to both the large extent of private rangelands (55 percent) relative to public rangelands (table 8-2) and the higher NPP rates relative to other jurisdictions.

Figure 8-13. Correlation of annual net primary productivity with respect to time on rangelands derived using Pearson's r from (a) 1984 to 2020, (b) 1984 to 1999, and (c) 2000 to 2020. Negative Pearson's r values correspond to declining trends.



Source: Rangeland Production Monitoring Service (Reeves et al. 2020). (20 May 2021).

Table 8-9. Rangeland NPP characteristics including mean, coefficient of variability (a measure of interannual variability), and correlation (r) with respect to time for three periods: 1984 to 2020, 1984 to 1999, and 2000 to 2020.

	1984 to 2020	1984 to 1999	2000 to 2020	1984 to 2020	1984 to 1999	2000 to 2020	1984 to 2020	1984 to 1999	2000 to 2020
RPA region	**Mean kg ha^{-1}**			**Coefficient of variability**			**Correlation (Pearson's r)**		
	percent								
North	4,402	4,125	4,620	0.08	0.05	0.07	0.75	0.58	0.07
South	1,590	1,410	1,720	0.17	0.13	0.15	0.56	0.33	0.07
Rocky Mountain	1,140	1,043	1,207	0.14	0.13	0.13	0.60	0.42	0.27
Pacific Coast	1,300	1,168	1,399	0.16	0.14	0.15	0.53	0.37	-0.05

ha = hectares; kg = kilograms; NPP = net primary productivity.

Source: Rangeland Production Monitoring Service (Reeves et al. 2020). (20 May 2021).

Table 8-10. Total forage by ownership and land cover class and the associated number of animal units these lands can support on an annual basis under different conditions in the conterminous United States from 1984 to 2020.

Ownership or Management	Average total NPP (favorable conditions)	Average total NPP	Average total NPP (unfavorable conditions)	Average herbaceous NPP (favorable conditions)	Average herbaceous NPP	Average herbaceous NPP (unfavorable conditions)
	teragrams					
U.S. Bureau of Land Management	42.2	32.9	23.6	26.1	20.4	14.6
U.S. National Park Service	2.6	2	1.4	1.3	1	0.7
Tribal	18.5	14.2	9.9	14.8	11.2	7.7
Private land	236.7	182	127.2	184.5	141.6	98.6
U.S. Army	3.5	2.6	1.7	2.1	1.6	1
U.S. Fish and Wildlife Service	2.9	2.2	1.6	1.7	1.3	0.9
USDA Forest Service	18.1	14.4	10.7	10	7.9	5.8
Other	118	91	64	87.5	67.2	47
Rangeland total	442.5	341.3	240	328.1	252.2	176.3
Pastures[a]	151.3	151.3	151.3	151.3	151.3	151.3
Forage beneath forested canopies[b]	64.3	64.3	64.3	64.3	64.3	64.3
Total forage (rangeland, pasture, forests)	**721**	**556**	**391**	**606**	**467**	**329**
	estimated animal units per year[c]					
AUY from all forage pools[d]	**49,383,562**	**38,082,192**	**26,780,822**	**41,506,849**	**31,986,301**	**225,342,467**

Assumptions:

[a] The national annual average yield from pastures of 3,235 kg ha^{-1} (2,886 pounds per acre) was derived from RPMS (Reeves et al. 2020). Irrigated pastures are not included on this assessment.

[b] In areas not considered rangeland and where tree canopy cover exceeded 1 percent we assumed a conservative forage estimate of 241 kg ha^{-1} (215 pounds per acre) (Gaines et al. 1954, Reeves and Mitchell 2012).

[c] An animal unit is defined as one mature cow of about 450 kg, either dry or with calf up to 6 months of age, and has a general nutritional requirement of about 12 kg of dry matter per day (Smith et al. 2017). We assumed that 30 percent of the forage in a given year could be sustainably harvested to support animals.

[d] Excluding agronomically derived feedstuffs such as corn or soy meal.

AUY = animal units per year; kg = kilogram; NPP = net primary productivity; RPMS = Rangeland Productivity Monitoring Service.

Source: Rangeland Analysis Platform (Jones et al. 2018) (20 May 2021) and Rangeland Production Monitoring Service (Reeves et al. 2020). (20 May 2021).

The higher NPP rates on private lands reflect the spatially explicit settlement patterns of the Western United States; the most productive lands were usually privatized during settlement while less productive areas—areas predisposed to reduced NPP due to abiotic factors such as drier climatology, thin soils, and juxtaposition on the landscape (e.g., rain shadow)—were left in the public domain. Production on USDA Forest Service land averages 1,544 kg ha^{-1}, approaching the level of non-Federal lands (1,614 kg ha^{-1}) and more than twice the level of BLM productivity (622 kg ha^{-1}). Rangelands managed by the USDA Forest Service tend to occur on higher elevations, which typically receive greater precipitation than lower elevation landscapes. Despite lower NPP, the BLM is the second largest producer of forage in conterminous United States rangelands due to the large extent of lands under its jurisdiction (table 8-10).

The average annual rangeland forage pool across all rangelands in the conterminous United States is roughly 341.3 Tg, including 252.2 Tg of herbaceous forage (table 8-10; Reeves et al. 2020). The average annual pasture forage pool is 151.3 Tg (table 8-10) and the forage pool beneath forested canopies is approximated at 64.3 Tg. These forage calculations do not include areas dominated by transitional rangelands identified in Reeves and Mitchell (2011). Transitional rangelands are lands where the dominant vegetation is shrubs and grasses, but because the site will transition to forest it does not meet the criteria for being classified as rangeland. In some regions, transitional rangelands represent large pools of forage suitable for herbivory, but their contribution to the forage base is relatively smaller and ephemeral from a national perspective (Allen 1988).

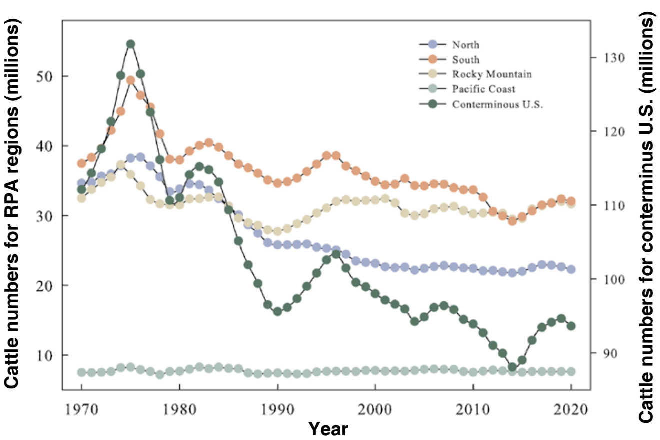
The animal units that can be supported annually (animal unit year) by this total forage pool ranges from 45 to 84 million depending on the growth conditions (below-average, average, or above-average production year). Not all livestock receive sustenance solely on rangelands, however; many livestock also consume hay or other agronomically derived feedstuffs such as corn, oats, and barley. This is especially true for public land permittees who often have only temporary access to public land forage and are eventually required to move livestock in accordance with the terms of their permits, or in areas where snowfall limits access to forage. This analysis also does not account for forage that may be unavailable due to terrain or distance from water which may prohibit some classes of ungulates from accessing some forage.

Livestock Trends

❖ The average number of cattle in the conterminous United States decreased almost 30 percent between the 1975 peak and 2020. Despite these declines, the beef yield has remained relatively steady, attributable to larger cattle.

The number of cattle in the United States peaked at about 132 million in 1975, followed by a continual decline (figure 8-14). By 2020 the average number of cattle in the conterminous United States decreased almost 30 percent to approximately 93 million. Despite this decline, total beef production remained stable due to increased efficiencies leading to larger cattle, including advances in growth enhancers, feed milling, and feed additives. The average yearling bodyweight of Angus breed bulls and heifers increased from the early 1970s to the mid-2000s by 3.6 and 2.6 kg per year, respectively (Ohio Country Journal 2017, NASS 2021).

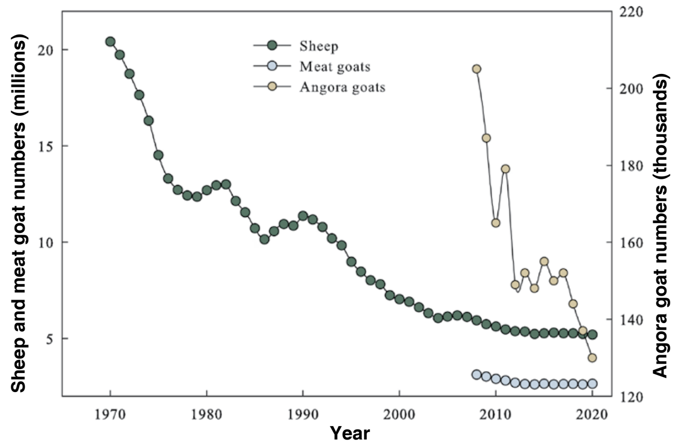
Figure 8-14. Number of beef cattle in the conterminous United States, nationally and by RPA region.



Source: NASS 2021. (20 May 2021).

Cattle production in the Pacific Coast and Rocky Mountain Regions remained relatively steady over this time period, while the North Region experienced the largest declines (figure 8-14). The South Region, which was significantly impacted by droughts during 2011 and 2012, experienced some rebounds in cattle numbers following those years, but not enough to reverse long-term decline. The number of sheep in the conterminous United States has declined even more rapidly: sheep numbers have decreased about 74 percent since 1970 (to an average of 5.3 million since 2015). While commercially raised goats have not been monitored for as long as cattle and sheep, both meat goats and Angora goats have seen declines of 15 and 37 percent, respectively since 2008 (figure 8-15).

Figure 8-15. Number of sheep, meat goats, and Angora goats in the conterminous United States.



Source: NASS 2021. (20 May 2021).

Outlook for Rangelands

This section focuses on the impacts of climate change on rangeland phenology, NPP, and land use. Changes in these vegetation metrics and use patterns were estimated under two bounding climate futures: Representative Concentration Pathway (RCP) 4.5, which represents a lower warming future, and RCP 8.5, which represents a high-warming future. We paired these two climate futures with five different climate models that capture the range of projected future temperature and precipitation across the conterminous United States to provide 10 distinct climate projections (two RCPs, five climate models). The five climate models selected by RPA represent least warm, hot, dry, wet, and middle-of-the-road climate futures for the conterminous United States (table 8-11); however, characteristics can vary at finer spatial scales. The Scenarios Chapter describes how these climate models were selected; Joyce and Coulson (2020) provide more extensive information. To facilitate interpretation, although we run our analyses using each RPA climate projection, we only present minimum and maximum results below (each the result of using a different climate projection), as well as an ensemble result that reduces complexity by providing the average amount of change projected for various attributes across climate projections and across U.S. rangelands (performed for RCP 4.5 and RCP 8.5 separately). We also examine how to interpret projected changes in climate using statistical analogs. The goal of these statistical analogs is to identify what city (or location) today best represents the expected future climate of a given city by 2080.

Table 8-11. Five climate models selected to reflect the range of U.S. climate futures in the year 2070. Each model was run under RCP 4.5 and RCP 8.5, and therefore provides distinct climate projections for each RCP.

	Least warm	Hot	Dry	Wet	Middle
Climate model	MRI-CGCM3	HadGEM2-ES	IPSL-CM5A-MR	CNRM-CM5	NorESM1-M
Institution	Meteorological Research Institute, Japan	Met Office Hadley Centre, United Kingdom	Institut Pierre Simon Laplace, France	National Centre of Meteorological Research, France	Norwegian Climate Center, Norway

RCP = Representative Concentration Pathway.
Source: Joyce and Coulson 2020.

Projections of Rangeland Phenology

- Growing seasons are projected to be 3 to 4 days shorter by early century and 6 to 10 days shorter by mid-century, primarily due to nutrient limitations. Local growing seasons could be reduced by as much as 20 days under the RCP 8.5 ensemble scenario.
- Earlier projected shifts to the start of the rangeland growing season are most pronounced in eastern Washington and Oregon and throughout the Great Basin, relative to other areas.
- Earlier projected shifts to the end of the growing season are more pronounced than changes to the start of the growing season, especially on the southern plains of Texas and Oklahoma where the end of the season is projected to occur up to 31 days earlier by 2070 under RCP 8.5.

Phenology—the timing of plant lifecycle events—influences the abundance and distribution of organisms, ecosystem services, food webs, and global cycles of water and carbon (https://www.usanpn.org/). Climate change can create a mismatch between the time specific vegetation (food) is available and the time when consumers are seeking that vegetation. For example, if pollinators such as bees and butterflies arrive to an area after vegetation flowering, there would be little opportunity for pollination and seed development, thereby threatening food webs and the ability of the species to reproduce. In this section we explore projected changes in phenology represented by alterations in phenological timing, which we define as the time from the onset of greenness to the cessation of greenness (https://www.usgs.gov/special-topics/remote-sensing-phenology). This should not be confused with the growing season length associated with plant hardiness zones, which is defined by the frost-free period and has been increasing across U.S. rangelands (https://www.epa.gov/climate-indicators/climate-change-indicators-length-growing-season). While increasing frost-free periods could theoretically result in longer growing seasons, we found that critical nutrients such as water and nitrogen were not sufficiently abundant to support extended growing seasons, and that limitations in the availability of these nutrients actually lead to shorter growing seasons across U.S. rangelands.

The impact of climate change on rangeland phenology is relatively understudied at the national level; however, spatially explicit metrics of key phenological attributes, including start of season (SOS), end of season (EOS), and length of vegetation growth (referred to here as the growing season), are available for the period between 2000 to 2020 from the U.S. Geological Survey (https://www.usgs.gov/core-science-systems/eros/phenology) (Gu et al. 2010). To better understand potential future changes in rangeland phenology we used these data to model future changes in SOS and EOS (Zimmer et al. 2022). The phenology models developed in Zimmer et al. (2022) relate a series of abiotic and biotic predictors to SOS and EOS including vegetation type, elevation, and basic climatic forcing, including solar radiation, maximum temperature, vapor pressure deficit, and accumulated growing degree days (Zimmer et al. 2022). Relatively little modeling was conducted in desert areas, particularly the Sonoran and Chihuahuan deserts, because phenology is notoriously difficult to characterize in these areas (Zimmer et al. 2022). In addition, vegetation phenology in the North Region was not modeled due to a lack of available data from Gu et al. (2010). Results portrayed here represent the change in Julian days compared against the 2000 to 2014 baseline period (selected due to data availability at the time of analysis).

Results were summarized to ecological subsections and provided for the individual RPA climate projections that produce the minimum and maximum amount of change by early- and mid-century (2020 to 2040 and 2041 to 2070, respectively), as well as for the ensemble phenological response. The climate projections that produce the minimum and maximum amount of change in SOS or EOS provide information about the full range of potential future change in rangeland growing seasons, while ensemble results provide the average projected change in vegetation phenology (based on all five climate model projections). Climate projections that produce minimum and maximum change were selected based on results for the entire extent of rangelands across the conterminous United States and are therefore not always representative of the minimums and maximums for individual regions.

Start of Season

Growing seasons are projected to both start and end earlier in the future, and these shifts are projected to intensify over time, with SOS starting even earlier in mid-century than early century (table 8-12). Compared with the baseline period, the growing season was projected to start 4 to 5 days earlier on average across all three regions for early century (2020 to 2040) under RCP 4.5, while the growing season for mid-century (2041 to 2070) was projected to start 6 to 8 days earlier (table 8-12). Projected SOS generally occurs earlier under RCP 8.5 than under RCP 4.5, a likely result of the intensified radiative warming, with the exception of SOS minimum change projected by the least warm climate projection.

The Pacific Coast Region is projected to see the largest average earlier shift in SOS, followed by the Rocky Mountain and South Regions, however the potential exists for the Rocky Mountain Region to experience a similar early shift in SOS, shown by the maximum SOS result. Local patterns exhibit greater variability in modeled phenological changes than the regional patterns described above. In addition to growing seasons starting and ending earlier under RCP 8.5 than RCP 4.5, there is also more spatial variability in the amount of change exhibited across U.S. rangelands under RCP 8.5 (figure 8-16). For both early- and mid-century under RCP 4.5 and 8.5, the Great Basin, eastern Washington and Oregon, and the southern reaches of the Colorado Plateau (especially near northeastern Arizona) showed the largest shift to an earlier SOS (up to 22 days; figure 8-16).

End of Season

As with SOS, the EOS is projected to occur earlier in the future, more so under RCP 8.5 than RCP 4.5 due to the intensified radiative warming. EOS is projected to shift more than SOS—for all regions, in both time periods, and under both RCPs—resulting in a shorter annual growing season. The growing season is projected to see the largest average earlier shift in EOS in the South Region, followed by the Pacific Coast and Rocky Mountain Regions (table 8-12). Compared with the baseline period, early century EOS ensemble projections under RCP 4.5 ranged from 6 days early in the Rocky Mountain Region to 9 days early in the South Region, increasing at mid-century to 10 and 16 days early, respectively (table 8-12). As with SOS, local patterns of EOS exhibit greater variability than in the regional patterns described above (figures 8-16 and 8-17). The EOS projections show a different spatial pattern than SOS, with the southern Great Plains (principally Texas and Oklahoma) projected to experience the largest change, ending the growing season up to 31 days earlier by mid-century under RCP 8.5 (figure 8-17).

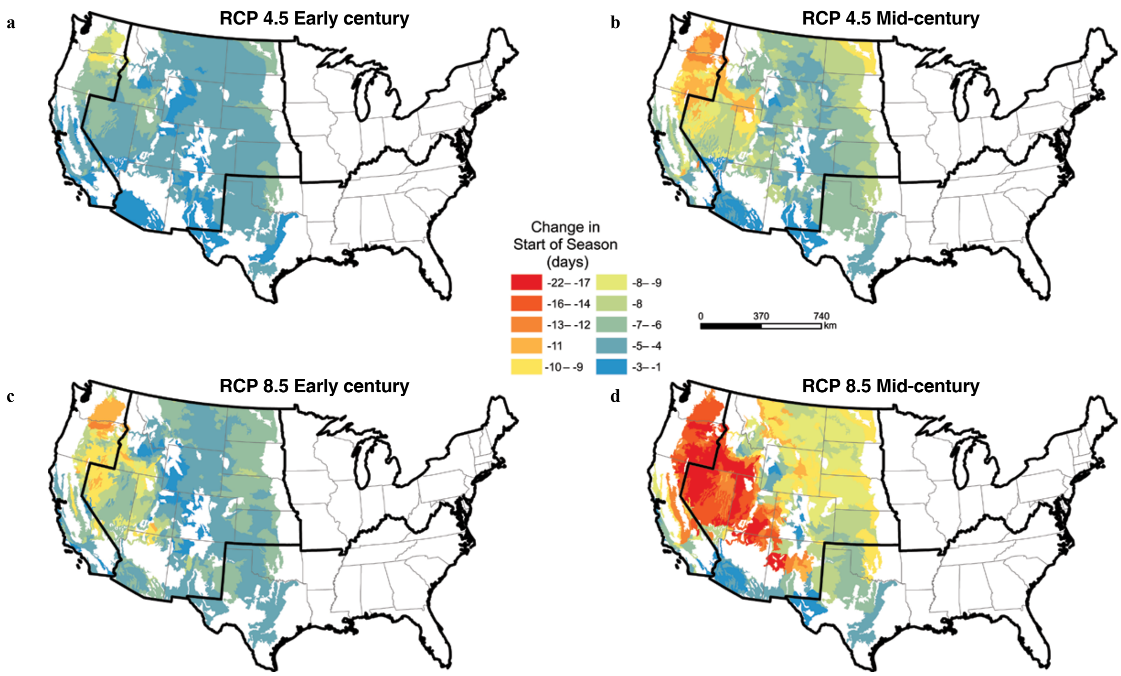
Table 8-12. Projected changes in start of season (SOS) and end of season (EOS) phenology (Julian days) for early century (2020 to 2040) and mid-century (2041 to 2070), compared with the baseline period of 2000 to 2014. The ensemble result provides the average amount of change that is projected nationally and for each region across all five climate projections. The least warm climate projection produces the minimum amount of change in SOS under RCP 4.5 and 8.5. The wet and hot climate projections produce the maximum amount of change in SOS under RCP 4.5 and RCP 8.5, respectively. The least warm and hot climate projections produce the minimum and maximum amount of change in EOS, respectively, under both RCPs 4.5 and 8.5. Climate projections that produce minimum and maximum change were selected based on results for the entire extent of rangelands in the conterminous United States and are therefore not always representative of the minimums and maximums for individual regions.

	RCP 4.5		RCP 8.5	
Phenology Parameter	2020 to 2040	2041 to 2070	2020 to 2040	2041 to 2070
	change in Julian Days			
National				
SOS (Ensemble)	-4.7	-7.1	-5.6	-8.1
SOS (Max)	-4.0	-6.8	-8.2	-12.2
SOS (Min)	-5.6	-7.2	-2.8	-4.1
EOS (Ensemble)	-7.9	-13.1	-9.2	-17.8
EOS (Max)	-8.3	-14.2	-11.6	-23.8
EOS (Min)	-5.6	-10.0	-7.7	-17.5
South Region				
SOS (Ensemble)	-4.2	-5.8	-5.5	-6.3
SOS (Max)	-1.5	-2.5	-7.5	-9.2
SOS (Min)	-3.9	-6.6	-3.6	-3.6
EOS (Ensemble)	-9.4	-16.5	-11.3	-22.9
EOS (Max)	-12.8	-21.3	-14.6	-31.1
EOS (Min)	-4.6	-9	-7.9	-20.8
Rocky Mountain Region				
SOS (Ensemble)	-4.8	-7.2	-4.8	-8.3
SOS (Max)	-5.2	-8.9	-7.8	-13.2
SOS (Min)	-6.4	-7.5	-1.9	-3.5
EOS (Ensemble)	-6.5	-10	-6.9	-13.8
EOS (Max)	-7.9	-13.8	-9	-18.8
EOS (Min)	-4.2	-4.9	-5.9	-13.6
Pacific Coast Region				
SOS (Ensemble)	-5.1	-8.2	-6	-9.7
SOS (Max)	-5.2	-8.9	-9.3	-14.3
SOS (Min)	-6.4	-7.5	-2.8	-5.1
EOS (Ensemble)	-7.9	-12.9	-9.3	-16.8
EOS (Max)	-4.1	-7.4	-11.3	-21.5
EOS (Min)	-8.1	-16	-9.3	-18.2

EOS = end of season; max = maximum; min = minimum; RCP = Representative Concentration Pathway; SOS = start of season.

Source: Zimmer et al. 2022.

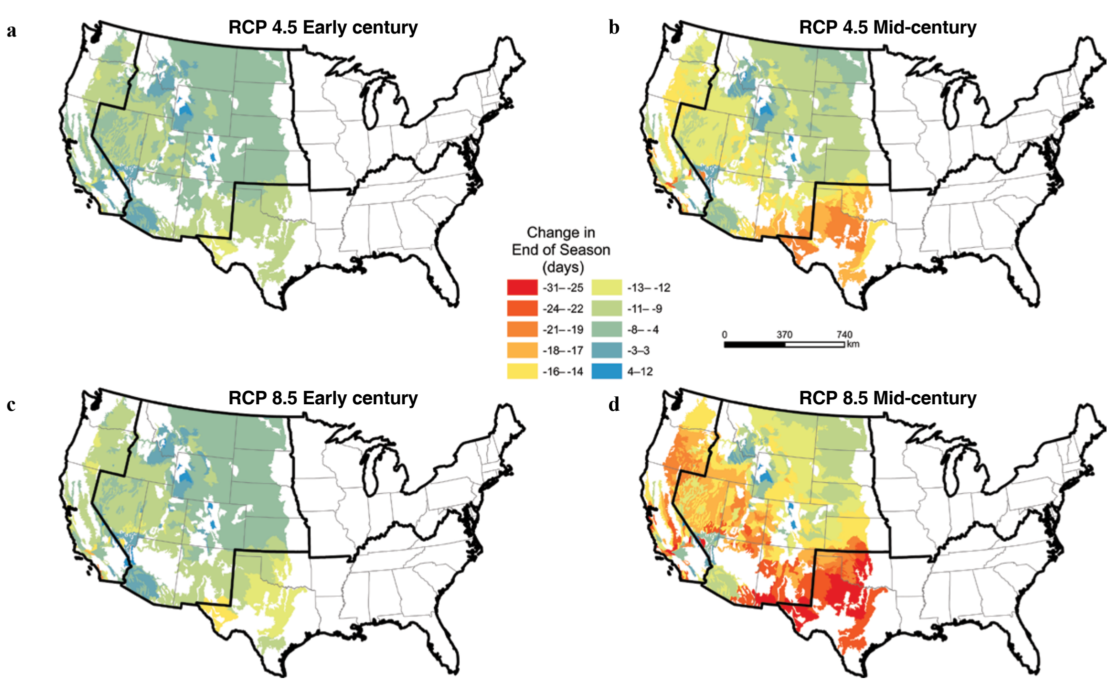
Figure 8-16. Projected ensemble change in the start of the growing season compared to a 2000 to 2014 baseline for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century. The ensemble result provides the average amount of projected change across all five RPA climate projections. Pixel-level phenology projections were aggregated to ecological subsections (Bailey and Hogg 1986).



RCP = Representative Concentration Pathway.

Source: Zimmer et al. 2022.

Figure 8-17. Projected ensemble change in the end of the growing season compared to a 2000 to 2014 baseline for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century. The ensemble result provides the average amount of projected change across all five RPA climate projections. Pixel-level phenology projections were aggregated to ecological subsections (Bailey and Hogg 1986).



RCP = Representative Concentration Pathway.

Source: Zimmer et al. 2022.

Growing Season Considerations

Regardless of the RCP or climate projection evaluated, shorter growing seasons and an earlier onset of greenup were universally projected. While EOS timing has often been overlooked in phenology research, our findings confirm it may be as or more significant than SOS timing in the future. Nationally, earlier EOS and SOS suggest the potential for growing seasons to be between 3 to 4 days shorter by early century and 6 to 10 days shorter by mid-century.

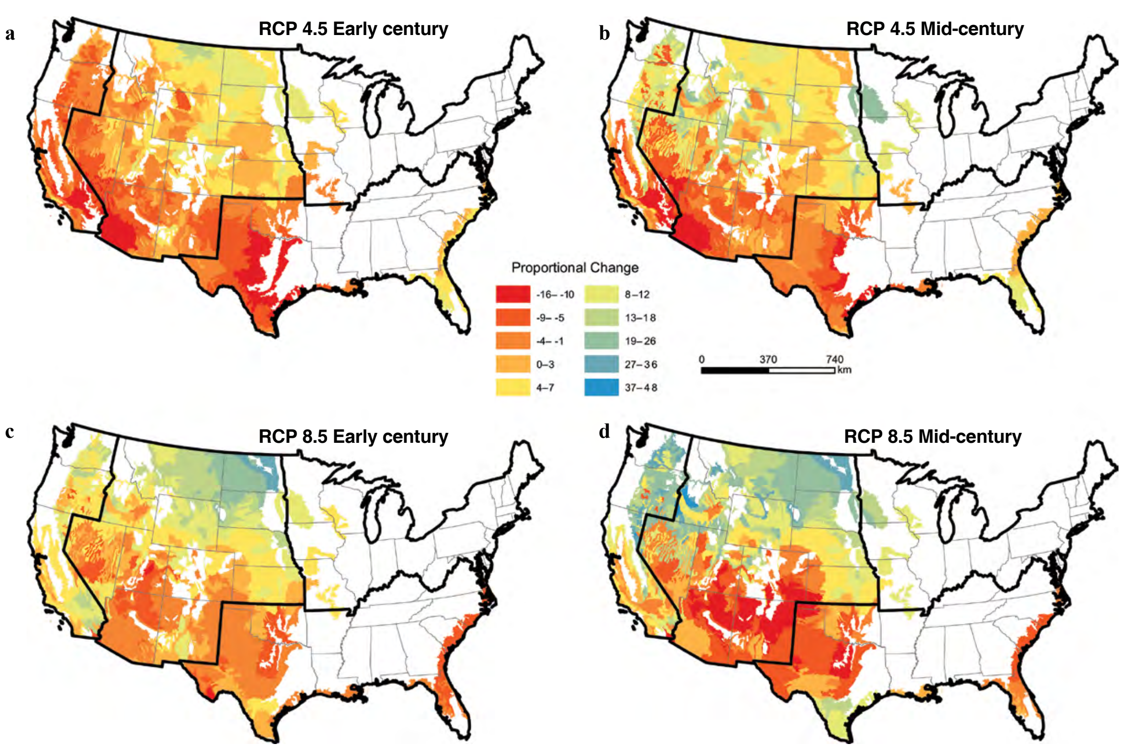
Projections of Rangeland Productivity

- ❖ Productivity changes will have modest effects on the total national forage supply in the future, but impacts will be significant regionally and locally.
- ❖ Projections suggest that many of the trends that have been observed since 1984—including decreased NPP in the South, increased NPP in the North, and greater interannual variability—will continue and possibly intensify in the future.
- ❖ The Southwestern United States is projected to experience the largest and most widespread NPP reductions, especially in desert areas, followed by the southern plains and Four Corners area.
- ❖ The northern Great Plains, especially North Dakota, South Dakota, and Montana, are projected to experience the largest gains in productivity.

We developed annual projections of aboveground NPP on rangelands under RCP 4.5 and 8.5 using the RPA climate projections and the MC2 dynamic global vegetation model (Bachelet et al. 2015, Kim et al. 2018) using a 2015 to 2019 baseline due to data availability. Results were summarized to ecological subsections (Bailey and Hogg 1986) and RPA regions and provided for the individual climate projections that produce the minimum and maximum NPP values as well as the ensemble NPP response (the average NPP across all five RPA climate projections). Climate projections that produce minimum and maximum NPP projections were selected based on results for the entire extent of rangelands across the conterminous United States and may not always be representative of the minimums and maximums for individual regions.

NPP is projected to increase with increasing latitude in all regions relative to the baseline when examining the ensemble results, particularly for mid-century under RCP 8.5 (figure 8-18). NPP is projected to increase over time in both the North and Rocky Mountain Regions for the ensemble results, with the largest gains occurring in the North and with gains for both

Figure 8-18. Projected ensemble proportional change in NPP compared to a 2015 to 2019 baseline for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century. The ensemble result provides the average amount of projected proportional change across all five RPA climate projections.



RCP = Representative Concentration Pathway.

Source: Kim et al. 2018.

regions being larger under RCP 8.5 than RCP 4.5 (table 8-13; figure 8-18). The hot and dry climate projections, however, produce NPP declines for the Rocky Mountain Region, while the dry climate projection produces NPP decline for the North Region by mid-century (table 8-13; figure 8-19). The South Region is projected to experience declines in NPP by the hot, dry, and ensemble results, but is projected to experience increases in NPP by the least warm climate projection (table 8-13; figures 8-19, 8-20). Results for the Pacific Coast Region are the most variable between RCPs, with the largest NPP declines of any region projected under RCP 4.5 over all timescales, and increases in NPP projected by all climate projections and under RCP 8.5 at levels meeting or exceeding those projected for the Rocky Mountain Region (table 8-13; figures 8-18, 8-19, 8-20).

Table 8-13. Projected proportional changes in NPP for early century (2020 to 2040) and mid-century (2041 to 2070), compared with the baseline period of 2015 to 2019. The ensemble result provides the average amount of change that is projected nationally and for each region across all five RPA climate projections. The hot and dry climate projections produce the minimum NPP values under RCP 4.5 and 8.5, respectively. The least warm climate projection produces the maximum NPP values under RCP 4.5 and 8.5. Climate projections that produce minimum and maximum NPP values were selected based on results for the entire extent of rangelands in the conterminous United States and are therefore not always representative of the minimums and maximums for individual regions.

	RCP 4.5		RCP 8.5	
NPP Parameter	**2020 to 2040**	**2041 to 2070**	**2020 to 2040**	**2041 to 2070**
		percent		
National				
NPP (Ensemble)	-1.5	3.0	3.0	6.5
NPP (Max)	2.3	10.5	8.0	22.0
NPP (Min)	-7.8	-2.5	3.0	-6.3
North Region				
NPP (Ensemble)	4	10	5	11
NPP (Max)	7	27	17	36
NPP (Min)	3	1	4	-7
South Region				
NPP (Ensemble)	-4	-2	-2	-2
NPP (Max)	1	8	7	13
NPP (Min)	-8	-3	-9	-23
Rocky Mountain Region				
NPP (Ensemble)	0	4	4	7
NPP (Max)	3	9	6	20
NPP (Min)	-9	-2	9	-2
Pacific Coast Region				
NPP (Ensemble)	-6	0	5	10
NPP (Max)	-2	-2	2	19
NPP (Min)	-17	-6	8	7

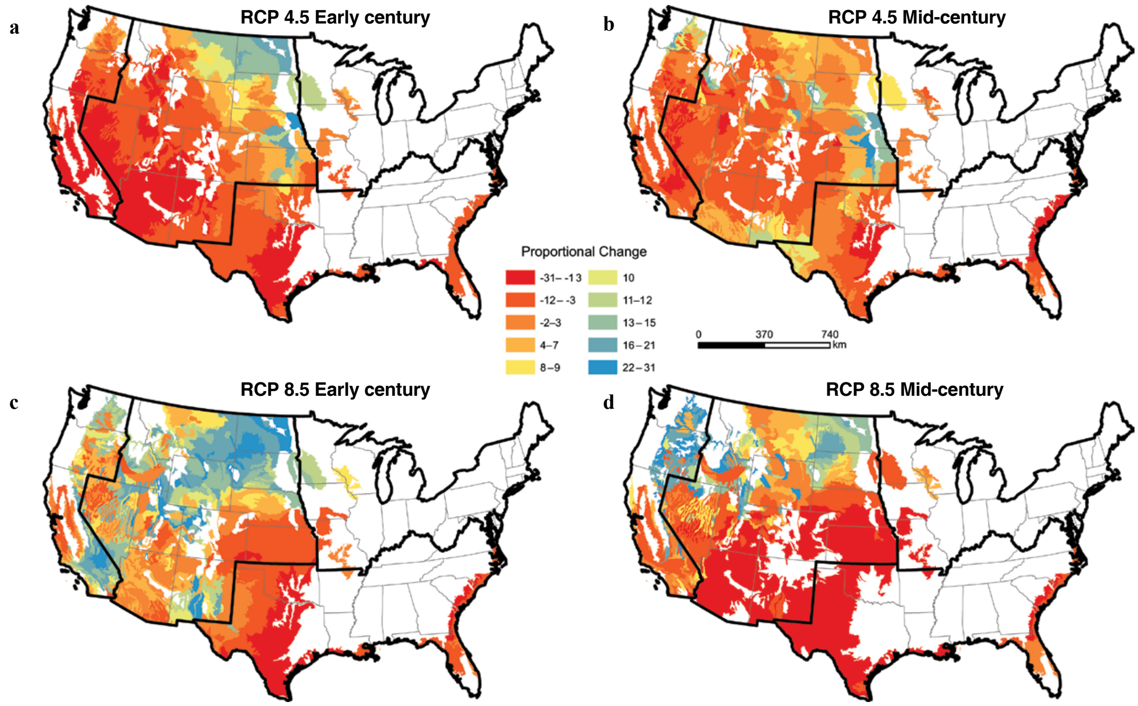
Max = maximum; Min = minimum; NPP = net primary productivity; RCP = Representative Concentration Pathway.

Source: Kim et al. (2018).

These large regional averages, however, mask noteworthy subregional patterns that are evident when comparing the projected smallest and largest future overall levels of NPP (figures 8-19, 8-20). The northern Great Plains tend to outperform all other areas, especially in North Dakota and eastern Montana, ranging from moderate losses of NPP (figure 8-19) to substantial gains (figure 8-20). However, these increasing NPP trends could be partly caused by expanding shrub and other woody species cover (Klemm et al. 2020). Productivity is projected to decrease by as much as 31 percent under the worst-case scenario in much of the desert Southwest and southern plains, especially Kansas, Oklahoma, and eastern Colorado, with similar losses in Utah and southern California (figure 8-19). Although the extent of severe declines is reduced under the best-case scenario, these areas are still under high risk (figure 8-20). The least warm climate projection produced the highest overall NPP projections; however, the desert Southwest is still projected to experience declines from 5 to 25 percent by mid-century, depending on the locality.

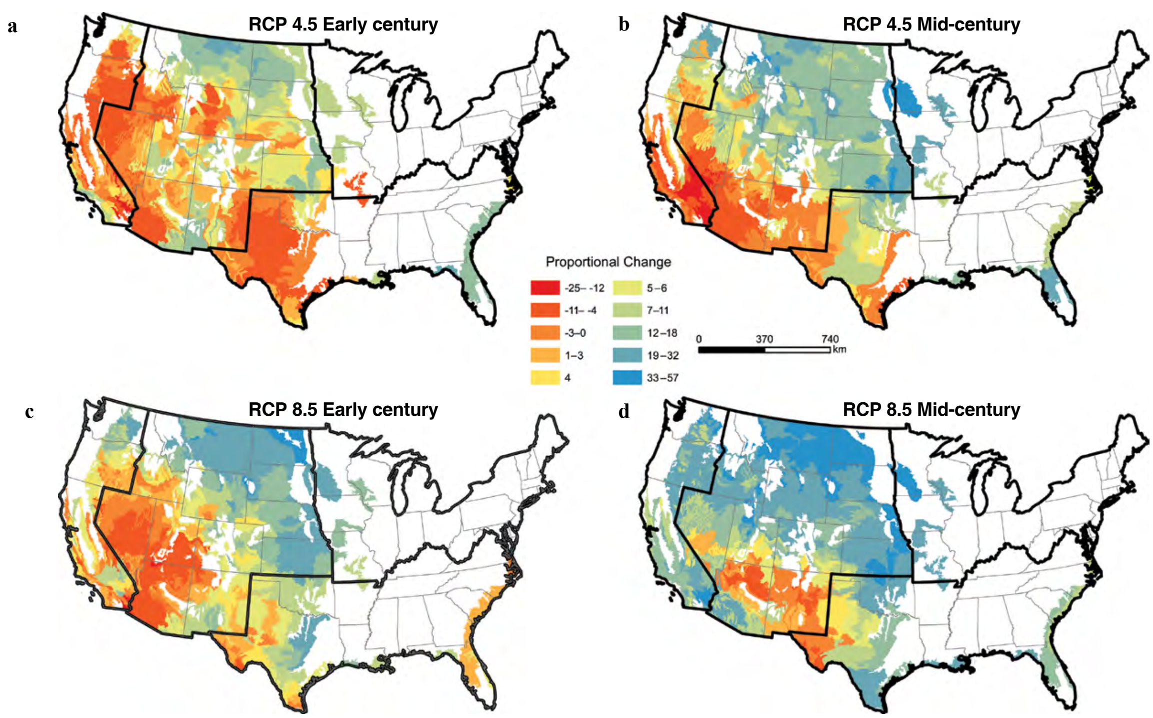
Increasing temperatures throughout the entire projection period are likely responsible for driving patterns in most regions (Reeves et al. 2014a); however, some offsetting is possible as increasing CO_2 concentrations may also increase soil moisture via reduced evapotranspiration, especially in the presence of warm season species (C4 photosynthetic pathway) (Morgan et al. 2011). While increased temperatures are expected across most regions, variable projected precipitation patterns and trends create most of the subregional differences in NPP and forage quality (Augustine et al. 2018).

Figure 8-19. Projected proportional change in NPP from the 2015 to 2019 baseline representing the lowest NPP projections (NPP min) for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century. The hot climate projection produced the lowest overall NPP projections under RCP 4.5, while the dry climate projection produced the lowest NPP projections under RCP 8.5.



NPP = net primary productivity; RCP = Representative Concentration Pathway.
Source: Kim et al. 2018.

Figure 8-20. Projected proportional change in NPP from the 2015 to 2019 baseline representing the highest NPP projections (NPP max) for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century. The least warm climate projection produced the highest overall NPP projections under both RCPs.



NPP = net primary productivity; RCP = Representative Concentration Pathway.
Source: Kim et al. 2018.

Land Use Projections

- ❖ Rangeland losses are expected to be minor nationally, decreasing 2.7 percent to a base of 257 million ha by mid-century, but regional and local impacts will be significant.
- ❖ The Pacific Coast Region is projected to lose the most rangeland area, about 6 percent under both RCPs, but some counties within that region may lose up to 25 percent of their rangelands to urbanization.
- ❖ Some gains in rangeland area are projected where agricultural land use decreases, particularly in Nevada.

Land use projections and the associated methodology are discussed in the Land Resources Chapter, as well as in Mihiar and Lewis (2019) and Brooks et al. (2020). Our calculations of changes to the rangeland land base differ from calculations in the Land Resources Chapter. Here, we calculate the average change in projected rangeland area across the early century period (2020 to 2040) and mid-century period (2041 to 2070) to compare against the observed NRI 2012 baseline rangeland land base. This method incorporates fluctuations to the rangeland land base that occur over the early- and mid-century time periods and makes comparisons against observed values. The Land Resources Chapter, however, compares projected rangeland area in the years 2040 and 2070 (not averaged) against a projected 2020 baseline, thus eliminating interannual variability in the rangeland land base and confining results to the 2020 to 2070 RPA projection period.

We provide results and interpretation focused on estimated changes in rangelands by RPA region and counties under RCPs 4.5 and 8.5 for the early- and mid-century periods, although it is important to note that the land use projections are influenced by economic factors (in the form of Shared Socioeconomic Pathway, SSP) in addition to RCP and climate. While there are not many differences in the national results between RCPs 4.5 and 8.5, there are notable differences among RPA regions and between the early century and mid-century periods. We again provide results for the individual climate projections that produce the minimum and maximum amount of percentage change in rangeland area, as well as for the ensemble response (the average projected change in rangeland area across all five climate projections). The minimum and maximum selections were again based on analysis for the entire extent of rangelands across the conterminous United States and may therefore not always represent the minimums and maximums for individual regions. The North Region was not included in this analysis because rangelands are not projected in the North Region by Brooks et al. (2020). Missouri is the only State in the North Region where rangelands are monitored by the NRI Assessment (USDA NRCS 2018) due to the scarcity of rangelands in the Northeastern United States; the lack of available monitoring data restricts the ability to make projections.

All regions are projected to lose rangelands in the future, and these losses are projected to increase from early- to mid-century (table 8-14). Results from both RCPs are similar, as are results across the different climate projections. The South Region exhibits the slowest rate of rangeland loss under all climate projections, scenarios, and time periods (rangeland

Table 8-14. Projected percent change in rangeland land use for early century (2020 to 2040) and mid-century (2041 to 2070), compared with the 2012 baseline under RCPs 4.5 and 8.5. Data represent the change in land use as a percentage of the baseline. The ensemble result provides the average amount of change that is projected nationally and for each region across all five RPA climate projections. The wet and hot climate projections produce the minimum change under RCPs 4.5 and 8.5, respectively. The dry climate projection produces the maximum change under RCPs 4.5 and 8.5. Climate projections that produce minimum and maximum change were selected based on results for the entire extent of rangelands across the conterminous United States and are therefore not always representative of the minimums and maximums for individual regions.

	2020 to 2040 (%)			2041 to 2070 (%)		
	RCP 4.5					
RPA region	**Minimum**	**Ensemble**	**Maximum**	**Minimum**	**Ensemble**	**Maximum**
National	-1.1	-1.1	-1.1	-3.3	-3.4	-3.5
South	-0.4	-0.4	-0.4	-1.3	-1.3	-1.3
Rocky Mountain	-0.5	-0.5	-0.5	-1.4	-1.5	-1.5
Pacific Coast	-2.3	-2.4	-2.4	-7.2	-7.4	-7.7
	RCP 8.5					
National	-0.9	-1.1	-1.2	-2.3	-3.2	-3.7
South	-0.4	-0.4	-0.5	-0.9	-1.3	-1.4
Rocky Mountain	-0.4	-0.5	-0.5	-1.2	-1.4	-1.6
Pacific Coast	-1.8	-2.3	-2.5	-4.9	-7	-8.1

RCP = Representative Concentration Pathway.

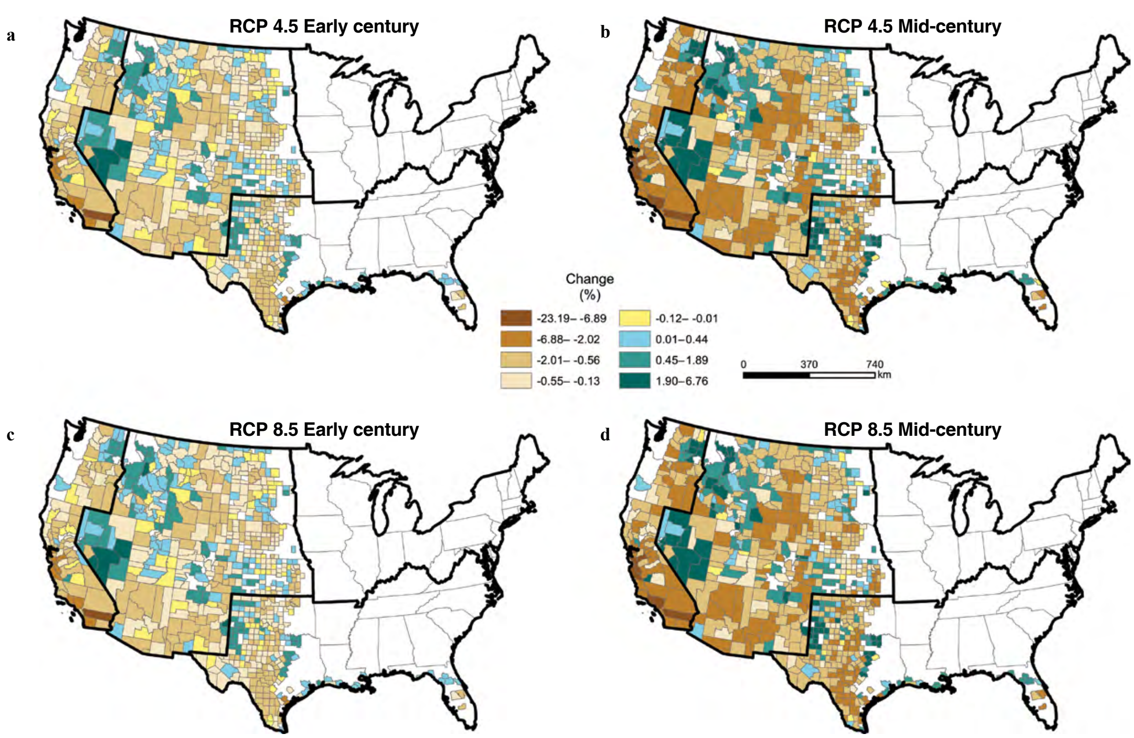
Sources: Mihiar and Lewis 2019; Brooks et al. 2020.

losses are never projected to exceed 1.5 percent), while the Pacific Coast Region exhibits the fastest rate of rangeland loss, as high as 8.1 percent by mid-century under RCP 8.5 (table 8-14).

These national and regional trends obscure subregional patterns of change in rangeland area (figure 8-21). Under RCP 8.5, ensemble results project that 63 counties will lose at least 1 percent of their rangeland base in the early century period, with 7 counties in California projected to exhibit losses greater than 3 percent. By mid-century, 326 counties were projected to lose at least 1 percent of their rangeland base (or between 296 and 343 counties in the minimum and maximum results, respectively), with 61 counties projected to exhibit losses exceeding 3 percent (63 counties in the maximum change results). Three counties in California were projected to exhibit losses exceeding 10 percent of their rangeland base by mid-century under RCP 8.5, primarily to urban expansion, including Riverside (-21 percent), Santa Clara (-17 percent), and Stanislaus (-13 percent). Wyoming, southeastern Oregon, and northern Arizona are also projected to lose substantial amounts of rangeland relative to other areas. Reeves et al. (2018) demonstrated how large urban growth rates have been observed and are projected to continue in the near future in hotspots around the West such as Bozeman, MT; Boise, ID; and Phoenix, AZ.

In contrast, Nevada appears to increase in rangeland area in several counties, especially White Pine and Nye. Rangelands in White Pine County are projected to increase by up to 6 percent under RCP 8.5. Causes for the increased rangeland area are unclear but these data suggest that the climate in those areas will likely become unsuitable for agriculture, and abandoned croplands will transition to rangelands. Abandoned cropland typically becomes weedy, however, and the usefulness of these lands is therefore likely low from a rangeland health perspective or from a habitat perspective for wildlife species that depend on properly functioning rangelands.

Figure 8-21. Projected change in rangeland area compared with the 2012 baseline as the ensemble of results across the five RPA climate projections for (a) RCP 4.5 early century, (b) RCP 4.5 mid-century, (c) RCP 8.5 early century, and (d) RCP 8.5 mid-century.



RCP = Representative Concentration Pathway.
Source: Mihiar and Lewis 2019; Brooks et al. 2020.

Management Implications

This RPA rangeland assessment identified current and future trends on rangelands that may present ongoing challenges to managers, producers, and policymakers. Managers will likely be facing both decreasing rangeland area and health in the future, as the changing climate results in increasing invasive species, asymmetric and increasingly variable NPP in some regions, and shorter growing seasons that both start and end earlier in the year. The increasing frequency of drought and wildfires on rangelands (see the Disturbance Chapter) could exacerbate these impacts. Given the trends and projected futures documented in this Assessment, managers and policymakers will likely face increasingly difficult choices based on tradeoffs. Maintaining flexibility in the management of public land grazing leases and reconsidering and updating annual operating instructions (USDA Forest Service 1997) more frequently as changing conditions are identified in new data streams (e.g., availability of remotely sensed rangeland) can help managers adjust to changing conditions. Managers may need to consider social factors more consistently than in the past and may benefit from widening their circle of stakeholders to address issues that increasingly demand cross-discipline and cross-boundary solutions (Reed et al. 2009).

Land managers have new tools and resources available, such as the Climate Change Adaptation Library (http://adaptationpartners.org/library.php), a searchable database that contains ideas for increasing ecological resiliency for all lands including rangelands. Similarly, the 2021 Rangeland Technology Summit (https://vimeo.com/showcase/8429328/h) brought together and discussed more than 30 technologies that range managers can use to enhance monitoring-informed adaptive management and professional development. Using new tools and improved communication styles can help managers quantify and cope with the increased variability occurring on U.S. rangelands.

Conclusions

In this RPA rangeland assessment, we assembled the available nationally consistent data to examine the conditions and trends of rangelands in the conterminous United States, along with the impacts of climate change. Technological advancements in computer processing power and remotely sensed data, combined with new sampling programs from the BLM (AIM) and the USDA Forest Service (ACI), enabled enhanced analyses over past RPA Assessments. The inaugural assessment of vegetation trends across all lands using remotely sensed data from 1984 to 2020 corroborated findings from both the NRI and AIM processes. We also developed projections of phenology, NPP, and land use across plausible future climates that can be used by the USDA Forest Service and the broader range management community to address policy and management needs.

Through these analyses, we identified three significant findings for U.S. rangelands. First, the U.S. rangeland base has been decreasing at a rate of about 161,874 ha (399,000 acres) per year since 1982, with the most significant losses resulting from transitions to urban and agricultural land uses. Future losses are expected to remain relatively constant at about 98,101 ha (242,412 acres) per year, totaling additional losses of around 4.7 million ha (11,613,935 acres) by 2070. While this is a small percentage of the total rangeland base, these rangeland losses have spatially explicit ramifications, including increasing difficulty associated with maintaining critical habitat and corridors for wildlife and genetic diversity.

Second, rangelands are experiencing a range of disturbances, some of which are changing ecosystem dynamics in unprecedented ways, including invasive species, wildfires, and drought. Rangelands are exhibiting increases in invasive annual herbaceous species (e.g., cheatgrass and red brome) and woody species of concern (e.g., mesquite and juniper); these trends are visible in data from all evaluated plot-level rangeland monitoring programs (NRI on non-Federal lands, AIM on BLM lands, and FIA ACI on USDA Forest Service lands) as well as through remote sensing. Increases in invasive annual herbaceous species influence fire regimes and create continuing feedback cycles. The amount of area burned in rangelands has nearly doubled since 2000 (see the Disturbance Chapter), caused in large part by the increasing prevalence and density of invasive annual herbaceous species. These changes, combined with increasing drought intensity and frequency (see the Disturbance Chapter), are creating increased interannual variability of forage with impacts to rangeland health. Importantly, the combination of increasing drought and presence of invasive annual grasses reduces resiliency to drought (Chambers et al. 2014). Prolonged droughts in the Southwestern United States and California are creating novel conditions that have not been experienced since well before Euro-American settlement (Szejner et al. 2021). These conditions are expected to occur with greater frequency in the future, creating ecological, social, and economic challenges. These disturbances are already negatively affecting social fabrics and economic patterns around rangelands in the conterminous United States (Maczco et al. 2022), and projected future disturbances may exacerbate existing stressors such as reduced incomes from rangelands, fewer recreational opportunities (e.g., greater restrictions on public land when wildfire risk is extreme), and higher costs for red meat. These plausible outcomes suggest the need for novel ways of communicating about and responding to disturbance, with an emphasis on adaptation to prepare for potentially more severe conditions in the future.

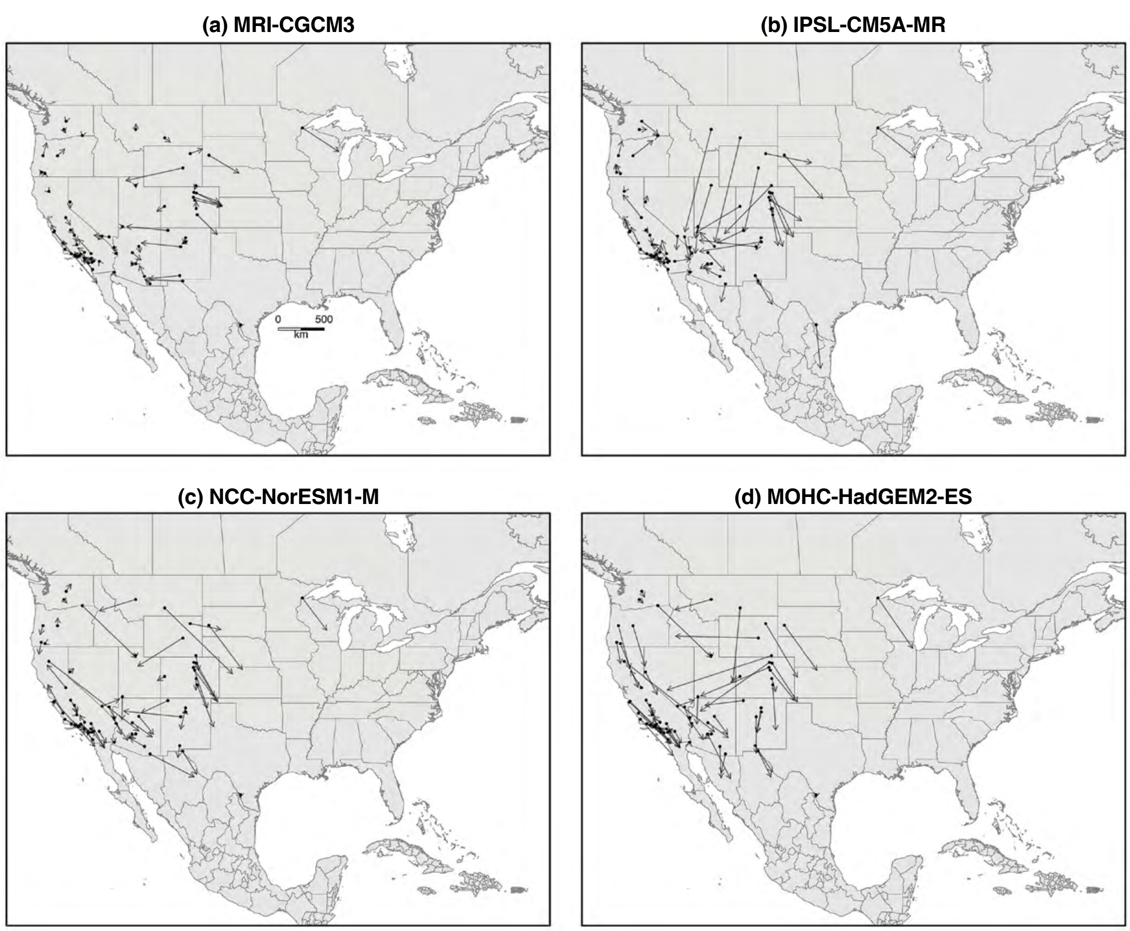
Third, the past and current trends documented here are projected to continue at least through the mid-century period. The start and end of the vegetation growing season are both projected to continue to shift earlier through time, with the end shifting more than the start resulting in shorter periods of plant growth overall. At the same time, NPP declines are projected to continue in southern rangelands, along with continued increases in interannual variability. Although NPP increases are projected in many northern rangelands, this is likely attributable to increasing annual grass presence. In addition, rangeland area is projected to continue to decline as the result of conversion to urban land use, with the largest declines projected for the Pacific Coast Region. The projected continuation of the trends identified in this assessment suggest ecological challenges to the sustainability of goods and services provided by U.S. rangelands.

Analog Projections

Translating climate model projections into intuitive assessments for the public is a major challenge for the scientific community. Climate-analog mapping involves matching the expected future climate at a location (such as a city or national forest) with the current climate of a different location. This method provides a relatable, place-based assessment of potential impacts of climate change. Here we demonstrate a climate analog analysis to provide a sense of the magnitude of projected climate change for cities in regions dominated by rangelands (Fitzpatrick and Dunn 2019). Future climate for the 2080s (30-year running mean of the period 2070 to 2099) were obtained from the Consultative Group for International Agricultural Research program on Climate Change, Agriculture and Food Security (http://www.ccafs-climate.org/). Four Earth system models, which are similar to the climate models selected for the RPA Assessment, were used to estimate climate futures under RCPs 4.5 and 8.5: MOHC-HadGEM2-ES (similar to RPA hot model), MRI-CGCM3 (similar to RPA least warm model), IPSL-CM5A-MR (similar to RPA dry model), and NCC-NorESM1-M (similar to RPA middle model).

We focused on a group of 65 cities surrounded by rangelands, primarily in the Western United States, and performed climate-analog mapping (Fitzpatrick and Dunn 2019, Mahony et al. 2017, Williams et al. 2007) (figures 8-22, 8-23). Averaged across the 65 cities and 4

Figure 8-22. Vectors show the distance and direction from each city (filled circles) to the location of the best contemporary climatic analog for that city's projected 2080 climate under RCP 4.5 for these climate projections: (a) MRI-CGCM3 (similar to RPA least-warm model), (b) IPSL-CM5A-MR (similar to RPA dry model), (c) NCC-NorESM1-M (similar to the RPA middle model), and (d) MOHC-HadGEM2-ES (similar to the RPA hot model).



Source: Fitzpatrick and Dunn 2019.

climate models, annual mean temperature was projected to increase by nearly 5 °C, with the largest seasonal increases in temperature expected in the summer and autumn under RCP 8.5. Average annual precipitation was projected to decline by 6 percent, with seasonal precipitation projected to decrease by at least 10 percent in all seasons except winter, where a 15-percent increase was projected. Averaging across cities obscures important regional variation. For example, cities in the Southwest were projected to experience declines in annual precipitation, whereas cities in the Pacific Northwest, northern Great Plains, and portions of California were projected to experience increases in precipitation. However, some of these same regions were also expected to experience the largest temperature increases, which could offset increases in precipitation through reductions in soil moisture.

To aid comprehension of the results, we provide case studies for Helena, MT, and Denver, CO. Table 8-15 shows current climate attributes of Helena and Denver, along with the current climate attributes for the cities that serve as the best analog during the late century period (30-year running mean of the period 2070 to 2099). The analogs suggest that Helena's climate will become most like St. Ignatius, MT; Lapwai, ID; Kooskia, ID; or Salt Lake City, UT. Comparing the climates of these analog cities against the climate normals for Helena allows for some generalizations. First, average high temperature in July increases from 28 to 33 °C. Second, the average January minimum temperature increases from -11 to -5 °C. These increases in temperature have a negative effect on snowfall, projected to decline by 300 mm (about 12 inches), which will likely negatively impact skiing and other winter recreation activities. Precipitation is expected to stay near normal or increase, but the effectiveness of the rainfall to improve hydrologic conditions (fill reservoirs, keep streams running with cold-enough water to protect endangered bull trout, etc.) decreases due to significantly higher temperatures. The decrease in effective precipitation will likely alter both native and domestic vegetation assemblages; for example, the climate in Lapwai is presently suitable for vineyards, while currently growing tomatoes in Helena is difficult.

Analog conditions for Denver suggest that its climate will come to resemble current conditions in Tyrone, OK; Clarendon, TX; Plains, TX; or Seminole, TX. These analog cities occur at 954 m above sea level, on average, while Denver is 1,609 m above sea level; these analog cities represent a 40-percent decrease in elevation, and climate expectations vary significantly with a 650-m change in elevation. The average of the analog cities

Table 8-15. Results of the climate analog analysis for RCP 8.5. The current climate attributes of Helena, MT, and Denver, CO, are shown, along with the current climate attributes for the cities that serve as the best analog during the late century period (30-year running mean of the period 2070 to 2099).

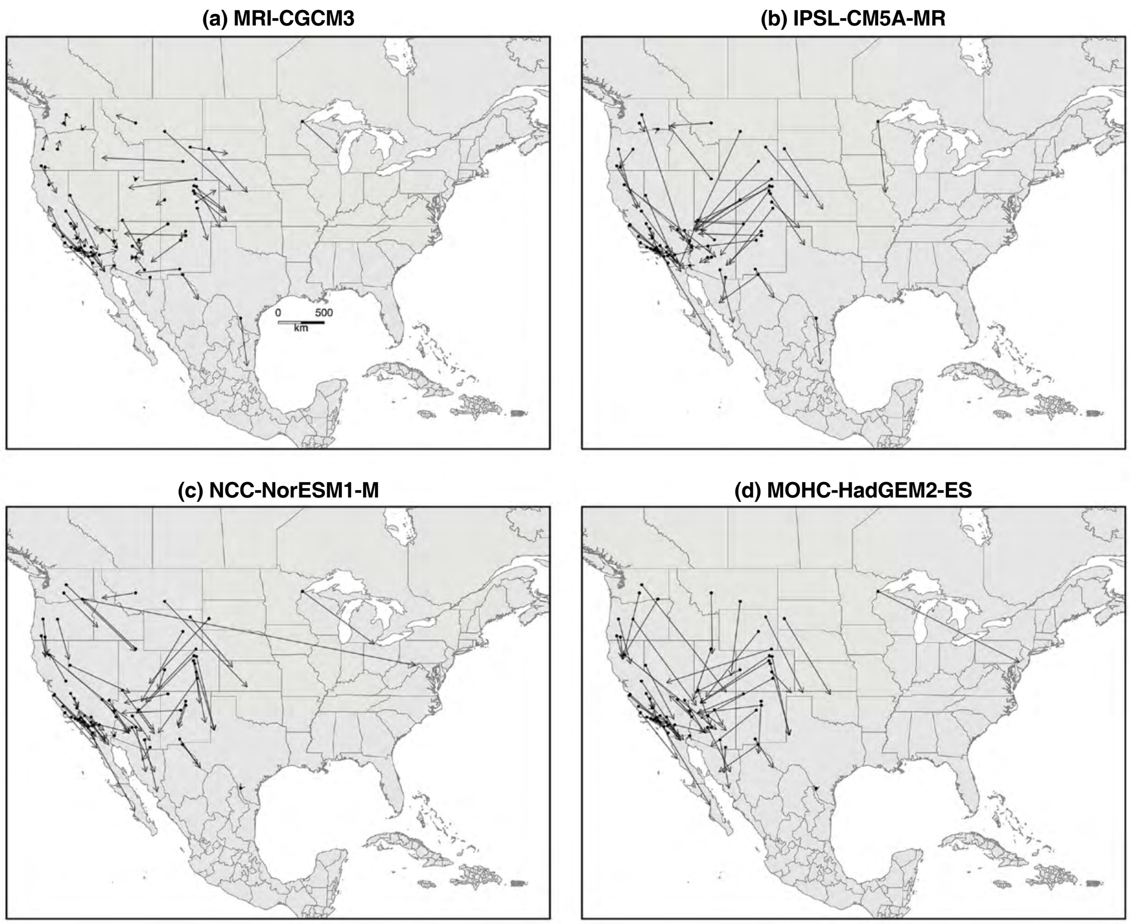
City	Climate normal	MRI-CGCM3	IPSL-CM5A-MR	NCC-NorESM1-M	MOHC-HadGEM2-ES	Average change relative to present day
Denver, CO	1,948 - 2,005	Tyrone, OK	Clarendon, TX	Plains, TX	Seminole, TX	
Elevation (m)	1,609	890	823	1,097	1,006	-655
Average July high temperature (°C)	31	34	35	33	34	3
Average January low temperature (°C)	-8	-7	-4	-3	-2	4
Rainfall (mm)	406	483	610	457	457	95
Snowfall (mm)	1,524	432	127	76	178	-1,321
Helena, MT	1,938 - 2,016	Saint Ignatius, MT	Lapwai, ID	Kooskia, ID	Salt Lake City, UT	
Elevation (m)	1,181	884	290	393	1,280	-469
Average July high temperature (°C)	28	29	34	33	34	5
Average January low temperature (°C)	-11	-8	-4	-4	-6	6
Rainfall (mm)	305	406	432	635	406	165
Snowfall (mm)	1,270	1,118	559	660	1,524	-305

m = meters; mm = millimeters; RCP = Representative Concentration Pathway.

Source: Fitzpatrick and Dunn 2019.

suggests that temperatures in Denver will increase in both July and January by 3 and 4 °C, respectively. The most dramatic change expected in Denver is a sharp decrease in snowpack. Presently, Denver receives about 1,524 mm of snowfall annually, and analog conditions suggest a loss of nearly 1,300 mm. This decrease in snowfall has the potential to substantially disrupt local economies dependent on winter activities. Some of the impact could be buffered at higher elevation areas where skiing is a major economic driver—such as in Telluride, CO, which has relatively high-elevation ski runs (top at 4,010 m)—however, less snow overall will likely increase competition for these resources, creating more crowded situations.

Figure 8-23. Vectors show the distance and direction from each city (filled circles) to the location of the best contemporary climatic analog for that city's projected 2080 climate under RCP 8.5 for these climate projections: (a) MRI-CGCM3 (similar to RPA least-warm model), (b) IPSL-CM5A-MR (similar to RPA dry model), (c) NCC-NorESM1-M (similar to the RPA middle model), and (d) MOHC-HadGEM2-ES (similar to the RPA hot model).



Source: Fitzpatrick and Dunn 2019.

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Authors:

Matt Reeves, USDA Forest Service, Rocky Mountain Research Station

Michael Krebs, Consulting Ecologist

Sarah E. McCord, USDA Agricultural Research Service

Matt Fitzpatrick, University of Maryland Center for Environmental Science

Roger Claassen, USDA Natural Resources Conservation Service

Emily Kachergis, U.S. Department of the Interior, Bureau of Land Management

Loretta J. Metz, USDA Natural Resources Conservation Service

Brice B. Hanberry, USDA Forest Service, Rocky Mountain Research Station