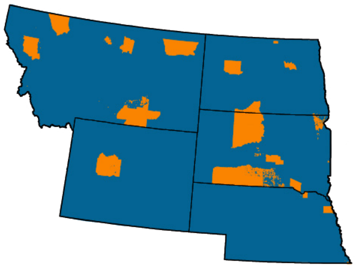
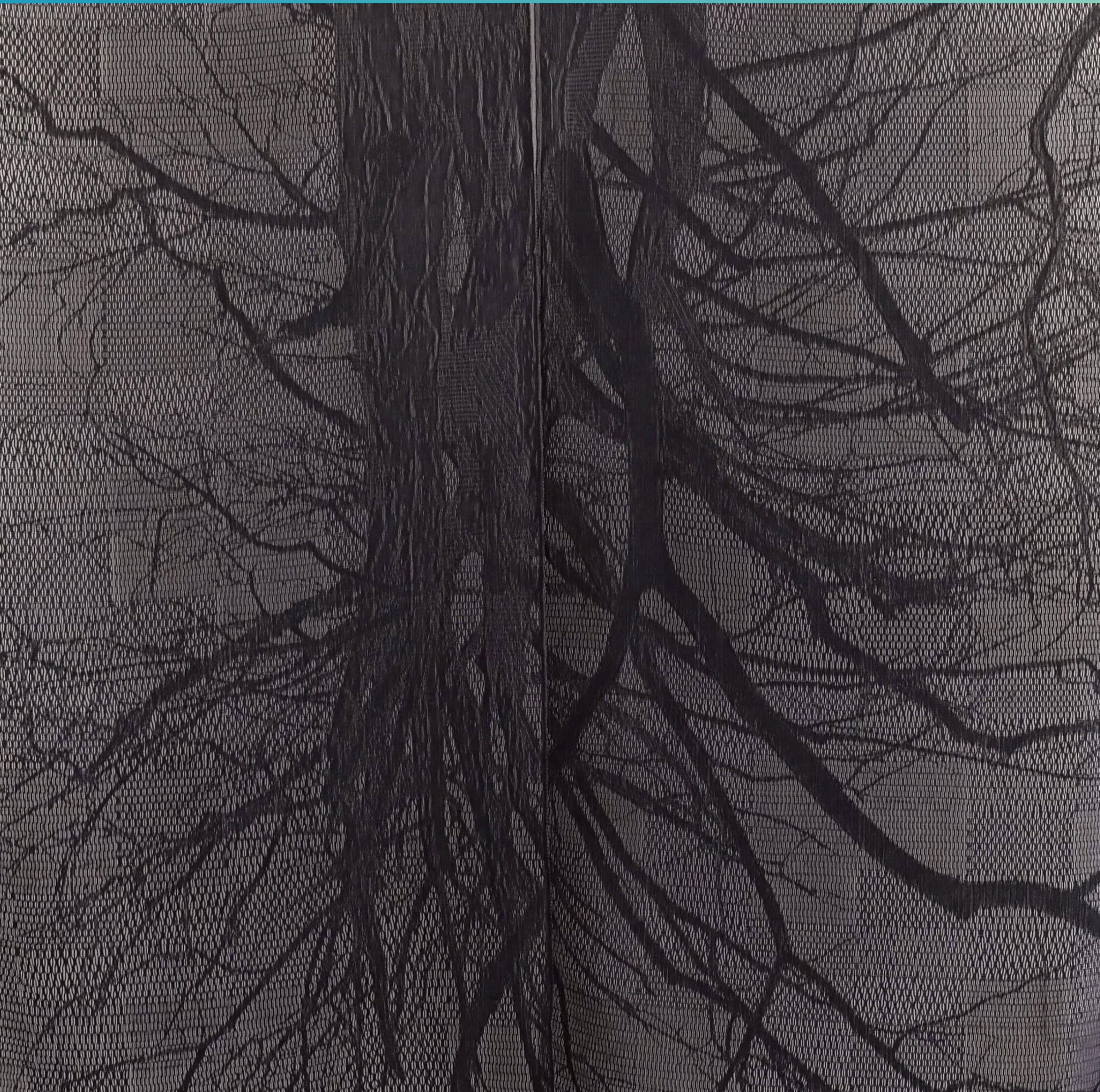
Fifth National Climate Assessment: Chapter 25

Northern Great Plains





Chapter 25. Northern Great Plains

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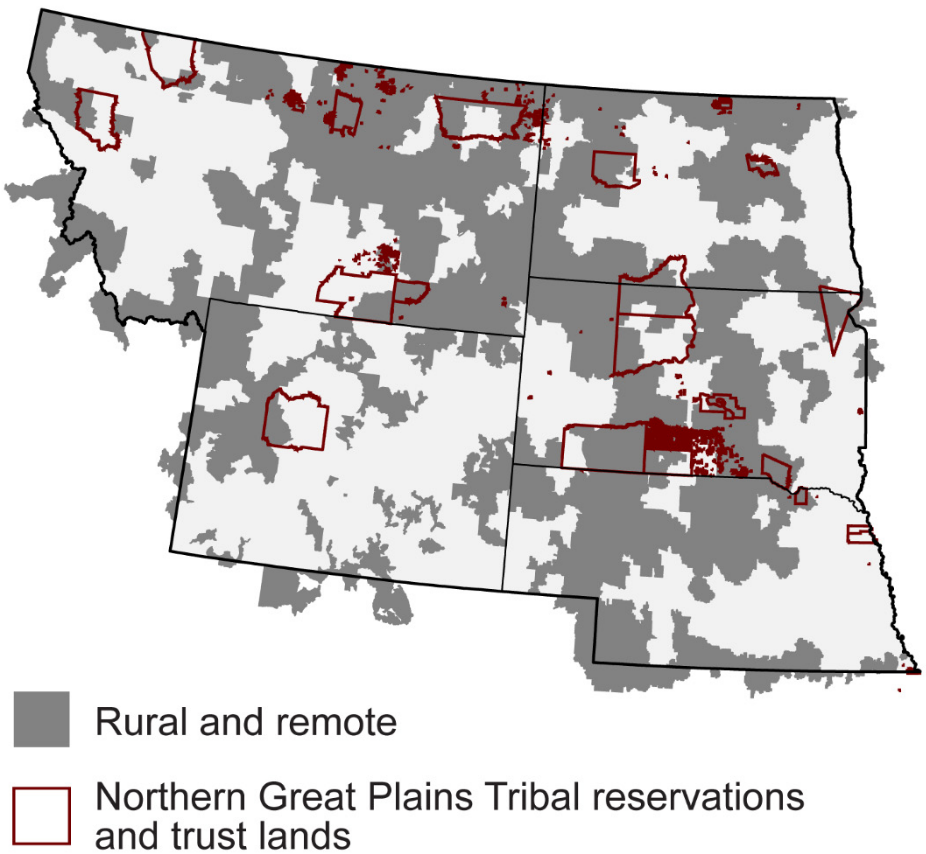
Introduction

The Northern Great Plains region, which includes Montana, Nebraska, North Dakota, South Dakota, and Wyoming (Figure 25.1), has a wealth of natural resources supporting economies, sense of place, and leisure activities. Climate change impacts on individuals and communities will differ, and it is critical to consider equity dimensions (Ch. 20). Economic dependence on crops, rangelands, and recreation makes residents with land-based livelihoods vulnerable to climate-related changes in weather, as well as flows of water, nutrients, and wildlife across the landscape.[1,2,3] This region is largely rural, and its intact natural areas, farms, and wildlands serve as habitat for resident and migrating species, which are threatened by changing water scarcity. The region is an energy and food exporter and vulnerable to policy decisions and markets outside the region. Historical processes may lead to unequal distribution of harms, with Indigenous communities, service and energy workers, and rural residents more sensitive to impacts. Values related to place, community, and stewardship are strong. Residents of small towns express strong place attachment in comparison with their urban counterparts.[4] The region's population grew by 10% between 2008 and 2020. Ten metropolitan counties accounted for two-thirds of growth, while 75% of the region's rural counties lost population.[5] Among rural counties, energy-dependent and tourism-focused counties both grew by 14%,[6] and farm-dependent communities experienced a 3% decline in population over the same period.[7,8] An indication that more people are willing to move to the region due to climate conditions was the influx of remote workers from large cities during the COVID-19 pandemic.[9]

This region also has many vibrant Indigenous communities with a rich cultural heritage (Figure 25.1). There is increased environmental action from Indigenous communities to protect waters and lands, to navigate climate change, and to maintain cultural continuity.[10] Culturally appropriate adaptation strategies, such as the restoration of buffalo, which serve a valuable ecological role and reestablish historic relationships to landscapes, are rooted in this region.[11] "Buffalo" is the preferred term of Indigenous communities based on their culture and history; this term is used in reference to Indigenous actions while acknowledging that the scientific name of the species is American bison (*Bison bison*). Although the share of the non-White population remains small in absolute numbers, the region is becoming more culturally diverse. The Indigenous and Hispanic populations grew by 20% and 42%, respectively, between 2010 and 2019, and in 2019, Indigenous and Hispanic populations accounted for 4% and 7% of the total population.[8]

Tribal Lands and Rurality Measures

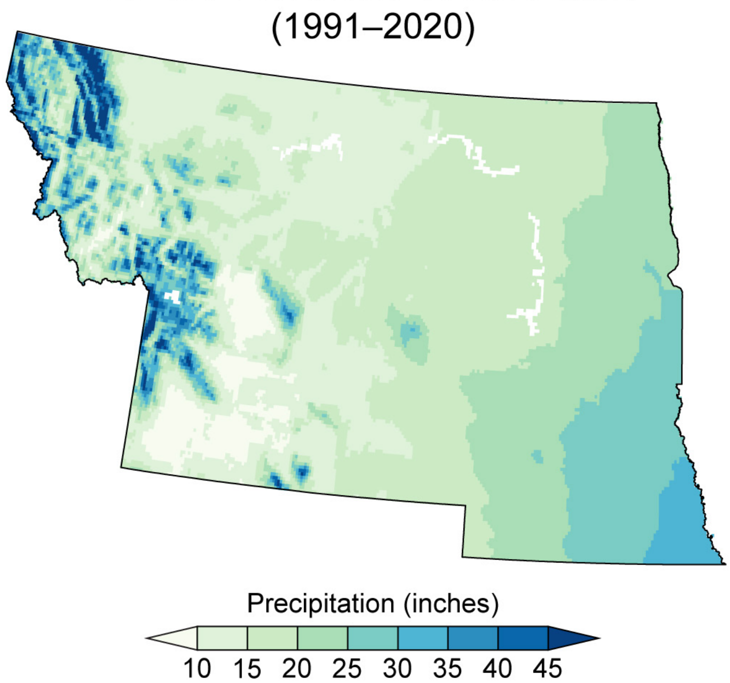


Rural areas, including those controlled by Indigenous Peoples, are often under-resourced and therefore less resilient to climate change.

Figure 25.1. Tribal reservations and American Indian trust lands (red outlines) overlap rural areas (dark gray; as defined by the USDA) across the Northern Great Plains. Rural and historically marginalized communities are often under-resourced and lack capacity to prepare for and recover from climate-driven natural disasters, making large portions of the Northern Great Plains less resilient to climate change.[12] White sections represent areas that fail to meet the criteria for "remote from urban" as defined by the USDA.[13] Figure credit: University of Wyoming, Center for American Progress, NOAA NCEI, and CISESS NC.

The Northern Great Plains region is known for its climate extremes and variability, but climate change is intensifying these characteristics.[14,15,16,17,18] The region has strong east–west precipitation (Figure 25.2) and north–south temperature gradients (Figure 25.3). Moving east to west across the region, the landscape becomes drier and elevation increases, forming three distinct areas: the humid eastern plains, semiarid high plains, and mountainous west. This complexity makes it challenging to summarize climate impacts across the region, but there are some common changes. Climate extremes in this region are expected to continue, compounded by climate change (KM 25.1). Human and ecological health will be impacted by these compounding hazards (KM 25.2). Human communities reflect the dependence on natural resources, historical policy legacies, and market forces that left a patchwork of land ownership and use (such as crop versus range, energy development, and recreation; Figure 25.8), and these livelihoods are at risk (KM 25.3). Climate change response will involve navigating complex tensions and trade-offs (KM 25.4), but communities are already building their capacity to adapt and transform (KM 25.5).

Average Precipitation for the Northern Great Plains



The region has distinct east–west precipitation gradients.

Figure 25.2. The map shows annual precipitation averaged over 1991–2020. Distinct precipitation gradients are evident from east to west and with elevation. These gradients highlight the complexity of the climate across the Northern Great Plains. White areas are large water bodies. Figure credit: USGS, University of Wyoming, NOAA NCEI, and CISESS NC.

Key Message 25.1

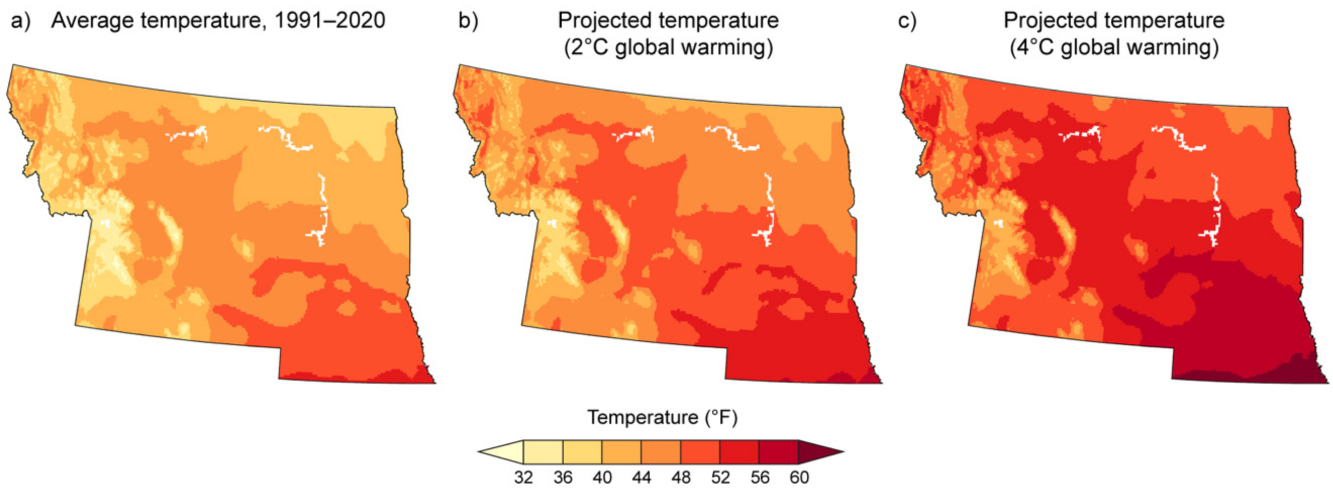
Climate Change Is Compounding the Impacts of Extreme Events

The Northern Great Plains region is experiencing unprecedented extremes related to changes in climate, including severe droughts (*likely*, *high confidence*), increases in hail frequency and size (*medium confidence*), floods (*very likely*, *high confidence*), and wildfire (*likely*, *high confidence*). Rising temperatures across the region are expected to lead to increased evapotranspiration (*very likely*, *very high confidence*), as well as greater variability in precipitation (*very likely*, *high confidence*).

Temperatures and Precipitation

Given the frequency of extremes and weather variability in the region, it is challenging to quantify long-term climate change trends. Even so, significant temperature trends and projections are clear (Figure 25.3). Since 1900, annual average temperature has increased in the region by 1.6°–2.6°F, with the largest increase in North Dakota and the smallest increase in southern Nebraska. Warming has occurred in all seasons but is most pronounced in winter. Summers have warmed little in North Dakota, South Dakota, and Nebraska. However, warm nights (minimum temperature of 70°F or higher), which were once rare, have become more common in Montana and Wyoming. The region has experienced fewer very cold days (maximum temperature of 0°F or lower) than the long-term average (1900–2020) for several decades. For instance, the number of very cold days has been below the long-term average in Montana since 1985, in Nebraska since 1990, and in Wyoming, North Dakota, and South Dakota since 2000.[14,15,16,17,18] Decreasing snowpack will alter surface water availability for irrigation and may increase pressure on groundwater resources.[3,19] Overall aridity has increased and is projected to continue to do so because of increases in potential evapotranspiration, suggesting that the demarcation line between the humid East and arid West, traditionally defined by the 100th meridian, is moving eastward.[20,21]

Temperature for the Northern Great Plains



Distinctive gradients of temperature will hold with projected warming.

Figure 25.3. The maps show temperature averages for 1991–2020 (**a**) and projected temperature for global warming of 2°C (3.6°F; **b**) and 4°C (7.2°F; **c**) above preindustrial levels for the Northern Great Plains region. Current and projected values demonstrate distinctive gradients of temperature from southeast to northwest, with implications for climate impacts and effective adaptation. White areas are large water bodies. Figure credit: USGS, NOAA NCEI, CISESS NC, and University of Wyoming. See figure metadata for additional contributors.

All states in the Northern Great Plains region recorded their wettest five-year period between 1995 and 2019.[14,15,16,17,18] Total annual precipitation will be relatively stable across the region (Figure 4.3), but shifts in the form and timing of precipitation are expected. More intense precipitation events highlighting the projected increased variability in precipitation are expected to occur in all seasons, especially in the spring (Figure 2.12).[22] Temporal and spatial variability continues to be a dominant factor with precipitation and temperature.

Much of the runoff in the Northern Great Plains region contributes to the Missouri River and eventually the Gulf of Mexico, but portions contribute to the Columbia River, Colorado River, and Red River of the North basins. Much of the increasing streamflow in North Dakota shown in Figure 25.4 occurs in the Red River of the North basin and has prompted an approximately $3.2 billion (in 2022 dollars) infrastructure project to divert flood water around Fargo, North Dakota, and Moorhead, Minnesota.[23] The upper Colorado River basin (Colorado, Wyoming, Utah, and New Mexico), with headwaters in the western Northern Great Plains region, has been experiencing extensive drought for the last 20 years. Flows in the upper Colorado River basin, which account for about 90% of the streamflow of the entire basin,[24] have decreased over the past 20 years.[25,26] Increases in evaporative demand (the loss of water from Earth's surface to the atmosphere; Figure 25.5) have decreased runoff efficiencies, meaning that less rain and melted snow end up reaching the streams that feed the Colorado River.[27] Model-based analysis shows that continued warming is expected to further reduce flows in the upper Colorado River basin.[26]

Hail

The region is prone to damaging hailstorms; southeastern Wyoming and the southwestern part of the Nebraska Panhandle lie in "hail alley," the most hail-prone area in the United States.[17,18] Changes in low-level moisture, convective instability, melting level height, and wind shear will create shifts in hail occurrence.[28] From 1979 to 2017, the number of days favorable to significant (2 inches or greater diameter) hail in the central and eastern United States increased by 2 to 4 days each year.[29]

Research on the response of severe convection to climate change has focused on a very high scenario (RCP8.5).[30,31,32,33] Hail size, frequency of large hail, and length of hail season are projected to increase through the rest of this century in the Northern Great Plains.[33] By 2071–2100, under a very high scenario (RCP8.5), projections for the Northern Great Plains show a 27% increase in moderate-size (0.79–1.4 inches) hail days, a 49% increase in large (1.4–2.0 inches) hail days, and a 302% increase in very large (2 inches and larger) hail days, with increases in hail coverage of 73%, 157%, and 882% for moderate, large, and very large hail, respectively.[33] Projections also indicate a lengthened hail season.[33] The largest increases in hail risk anywhere in the United States are in this region and in July.[33] Projections by late this century using the SRES (Special Report Emissions Scenarios) A2 scenario (a scenario with increasing greenhouse gas emissions, similar to those in RCP8.5) indicate more hail days and an increase in the potential size, with a correspondent increase in accumulated kinetic energy and damage potential.[34] Comparing intermediate (RCP4.5) and very high (RCP8.5) scenario projections for severe convection indicates that the projected trends for RCP4.5 are in the same direction with lower amplitude compared to RCP8.5.[35]

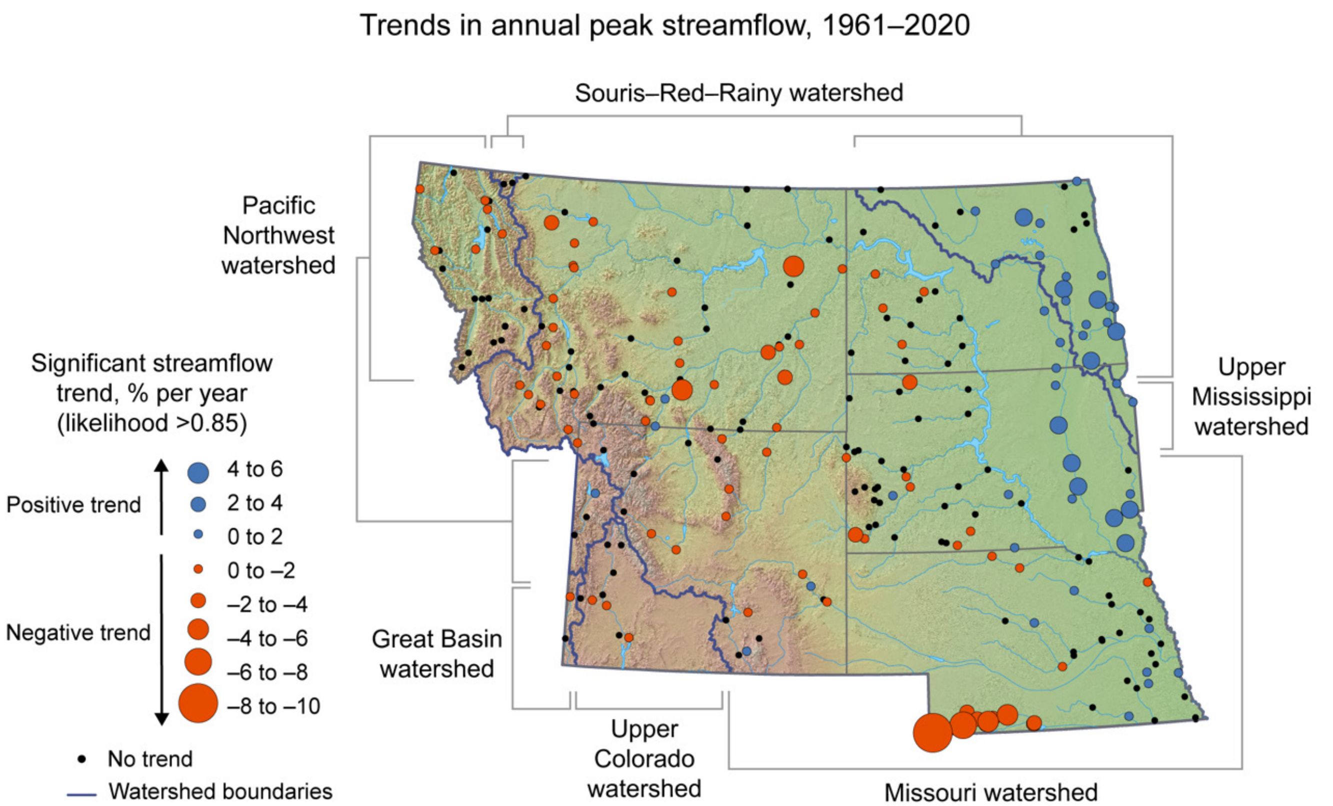
Flooding

Precipitation changes do not have a one-to-one relation with flooding. Many factors influence floods, including short- and long-term antecedent moisture conditions, presence of frozen soils, snowpack accumulation, rain-on-snow events, storm tracks, and rainfall rates.[36,37,38,39]

The Missouri River transects the region through 10 US states and 28 Tribal territories and is emblematic of the complex intergovernmental relations that will become increasingly important under climate change.[40] Record floods along the Missouri River and its tributaries in 2011 and 2019 caused evacuations, cost billions in damages,[41] and created interstate closures. Research suggests that recent large floods were caused by natural variability within the system;[42] however, model simulations suggest that climate change will reduce runoff in the upper Missouri basin.

Trends in annual peak streamflow, a proxy for flooding, differ across the 100th meridian divide (Figure 25.4). Observations show that annual peak streamflow is decreasing in the west and increasing in the east.[43] With few exceptions, the eastern Dakotas are an area of increasing peak streamflow (and flooding), while the western Dakotas, Montana, and Wyoming have decreasing peak streamflow. With 2° to 4°C (3.6° to 7.2°F) of global warming, the Northern Great Plains would expect to see some of the highest increases in annual flooding damage costs in the contiguous US due to climate change.[44]

Water Resource Regions and Rivers



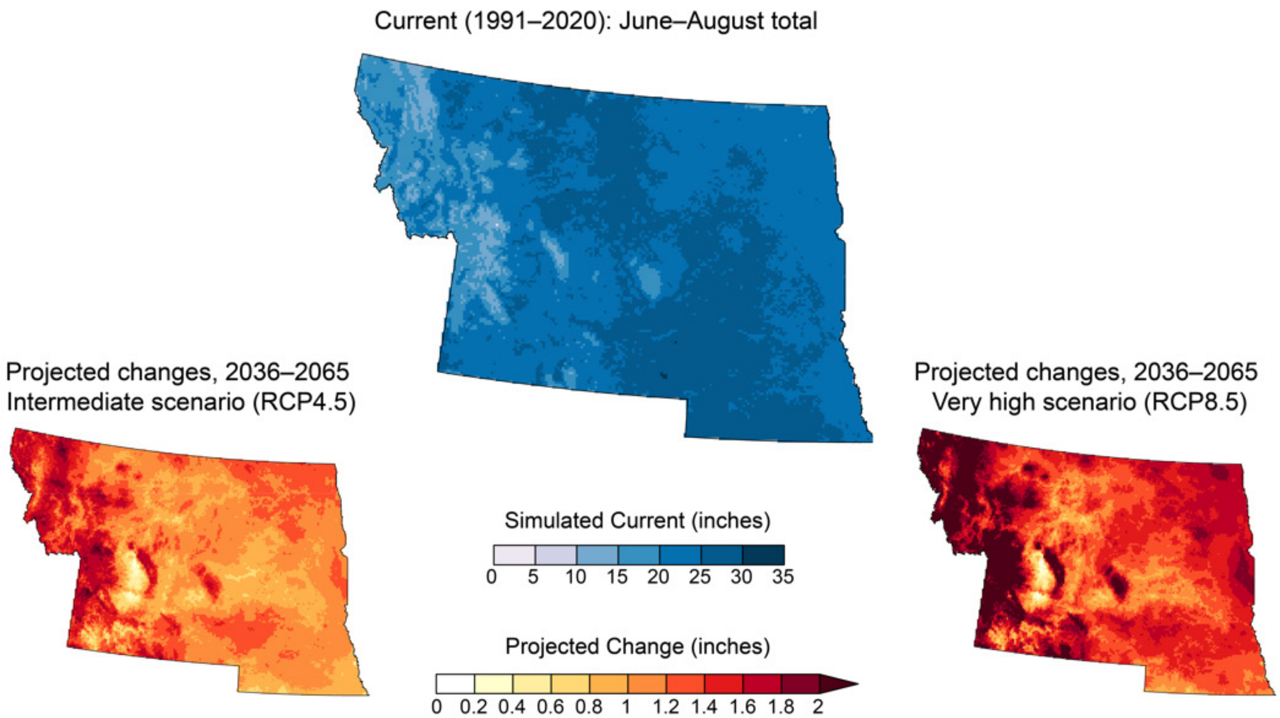
Annual peak streamflow—a proxy for flooding—has been rising in eastern portions of the region and declining in the west.

Figure 25.4. This map of the water resource regions and rivers within the region shows distinct east–west differences in trends in annual peak streamflow for 1961–2020, expressed as percent per year, where the size of the dot is relative to the size of the trend. Red dots are downward trends, and blue dots are upward trends. A likelihood-based approach is used to report these trend results. When a trend is identified, the trend likelihood value (likelihood = 1 – p-value/2) associated with the trend is between 0.85 and 1.0. In other words, the chance of the trend occurring in the specified direction is at least 85 out of 100. Smaller black dots are sites for which there were sufficient data for trend analysis but likelihood was less than 0.85; that is, these sites do not exhibit a substantial trend in either direction. Figure credit: USGS, NOAA NCEI, and CISESS NC.

Drought

Drought is projected to increase in the region, with localized droughts increasing by 2040 and more widespread regional droughts by 2070, under intermediate (RCP4.5), high (RCP6.0), and very high (RCP8.5) scenarios across wet or dry global climate models.[22,45] After precipitation, the most significant component of the water budget is evapotranspiration—the moisture transfer from Earth's surface and plants to the atmosphere.[46] Projected warming is expected to increase evapotranspiration (Figure 25.5), which may lead to drier soils later in the growing season (Figure 25.6).[47,48,49] Summer drought will be more probable than spring drought.[22,50] Multiple future climate scenarios indicate future increases in moderate, severe, and extreme drought, occurring approximately 10% and 20% more frequently by 2050 and 2100, respectively.[45] Recent droughts in the upper Missouri River basin between 2000 and 2010 were the most severe in the instrumental record,[51] and flash droughts are a growing concern.[52,53]

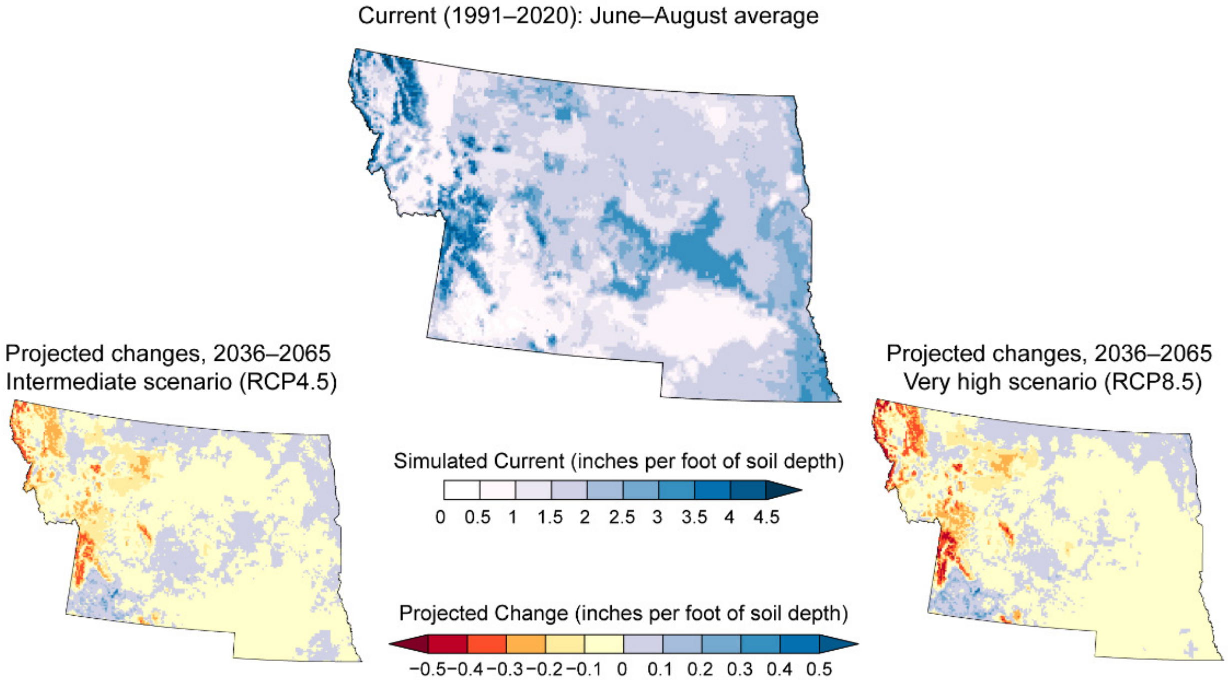
Current and Projected Potential Evapotranspiration



Warming is expected to increase evapotranspiration.

Figure 25.5. Figure shows (**center**) simulated current evapotranspiration and its projected change for the summer months under (**left**) intermediate and (**right**) very high scenarios. Data presented were obtained from Variable Infiltration Capacity models driven by the Coupled Model Intercomparison Project Phase 5 and Localized Constructed Analogs downscaling methods. Potential evaporative demands in the summer months (June, July, and August) increase regionally, especially in western areas under moderate climate change, and in both western and eastern areas under severe climate change. An increase in potential evapotranspiration typically drives a decrease in surface soil moisture (4-inch depth; Figure 25.6). Figure credit: USDA Forest Service, NOAA NCEI, and CISESS NC. See figure metadata for additional contributors.

Current and Projected Soil Moisture



Warming may not always lead to declines in soil moisture that would cause water stress in crops and natural plants.

Figure 25.6. Figure shows (**center**) simulated current soil moisture and its projected change for the summer months under (**left**) intermediate and (**right**) very high scenarios. Data presented were obtained from Variable Infiltration Capacity models driven by the Coupled Model Intercomparison Project Phase 5 and Localized Constructed Analogs downscaling methods. Soil moisture is expected to decrease slightly throughout the region in the summer months, with the largest decreases in the western mountain ranges of Montana. An increase in southwestern Wyoming is projected under both intermediate and very high scenarios. Snow water equivalent is decreasing at higher elevations in the Northern Great Plains (Figure 4.5) and can contribute to lower soil moisture in these areas. Declines in soil moisture can lead to crop, forest, and rangeland plant water stress, reduce plant growth, and increase ecosystems' susceptibility to fire. Figure credit: USDA Forest Service, NOAA NCEI, and CISESS NC. See figure metadata for additional contributors.

Wildfire

Driven by increased temperature and decreased relative humidity, fire potential in this region is projected to increase under future climate change (HadCM3-HRM3 model), especially in summer and autumn, with fire seasons becoming longer.[54] Increased evapotranspiration and drought risk raise the probability of large fire occurrence.[55,56] The number of large grassland wildfires in the four semiarid ecoregional grasslands of the Northern Great Plains increased by 213%, from 128 between 1985 and 1995 to 273 between 2005 and 2014, with total area burned increasing in the western ecoregions of the region by 350% but decreasing in eastern ecoregions by 75% or more.[57] Wildfire numbers and fire-season length increased from the 1970s to the 2000s by 889% and 85 days, respectively, in western Montana and Wyoming forests, with most ignited by lightning strikes rather than humans.[58] Historically, snow cover prevented winter wildfires and increased fuel moisture conditions during snowmelt followed by spring precipitation.[59,60] However, early spring snowmelt has been correlated with increased fire activity.[58] From 1950 to 2010, the number of snow-cover days declined within the region,[60] increasing wildfire activity due to drying fuels, which can lead to changes in flash flooding and debris flow (Focus on Western Wildfires).

Key Message 25.2

Human and Ecological Health Face Rising Threats from Climate-Related Hazards

Climate-related hazards, such as drought, wildfire, and flooding, are already harming the physical, mental, and spiritual health of Northern Great Plains region residents (*virtually certain*, *high confidence*), as well as the ecology of the region (*very likely*, *medium confidence*). As the climate continues to change, it is expected to have increasing and cascading negative effects on human health and on the lands, waters, and species on which people depend (*very likely*, *medium confidence*).

Mental Health

Climate change adversely affects mental and spiritual health in multiple ways (Ch. 15).[61,62] Although this issue affects the entire country, it is especially relevant in the Northern Great Plains, where three states are among the top 10 in highest suicide rates per capita in the Nation.[63] Suicide rates are particularly high in rural and Indigenous populations,[64] in part because of remoteness from care and the limited number of mental health professionals.[65,66] Based on geographically broad-based studies, climate change is projected to amplify these risks.[67,68] Climate anxiety, also called eco-anxiety (a feeling of doom about future climate change), is already prominent among farmers and ranchers in the region.[69] Solastalgia—the distress specifically caused by environmental change while still in a home environment[70,71]—is indicative of more subtle but potentially wider-reaching mental health impacts. Solastalgia is most often associated with Indigenous communities, who share collective ancestral ties to the lands and natural resources where they live or previously lived and which are inextricably linked to their identities, cultures, and livelihoods, as well as their physical and spiritual well-being.[72] However, solastalgia can also affect others who are connected to the land, such as ranchers and farmers.[73]

Direct impacts such as crop failure, increased disease, and biodiversity loss can lead to increased loss of Traditional Knowledge and language, further influencing the mental health of Indigenous Peoples.[61,74] Despair related to the loss of environmental, cultural, and human health is widespread among Crow Tribal elders, adversely affecting mental and spiritual health, and is exacerbated by a sense of inability to address the root causes of climate change.[75,76]

Physical Health

Climate change is impacting the physical health of the region's inhabitants in a number of ways. Wildfire is projected to increase in the region (KM 25.1), with correspondent health and property implications (Chs. 14, 15; Focus on Western Wildfires).[61] One study suggests that although the total number of premature deaths attributable to wildfire smoke is higher in states with greater population density, Montana has the highest per capita rate of such deaths in the country.[77] In addition, heat is responsible for more climate-related deaths than any other factor in the United States.[78] Although the Northern Great Plains region lacks the extreme temperature increases experienced in some other regions, people in this region are still at risk given the large number of outdoor workers and recreationists.[79] Rising temperatures, as well as other climate impacts, are expected to increase the risk of some vector-borne diseases, such as West Nile virus.[80,81,82] Flood risk patterns in the United States are inequitable on a county basis, with some of the counties in this region at increased risk, including some that encompass or are adjacent to Tribal reservations.[83] Shifts in precipitation and increased flooding (KM 25.1) are expected to raise the risk of water-borne diseases such as *Campylobacter* infection.[84]

Compound Health Impacts of Climate Events

Multiple climate pressures frequently act simultaneously, leading to compounding health-related outcomes (Ch. 15).[61,85,86] The impacts of floods resulting from earlier snowmelt combined with more intense precipitation events can be worsened by loss of ground cover from past wildfires,[87] putting people at risk of water-borne diseases, trauma and increased mental health issues, and economic losses. Wildfires are more common during hotter months when drought is more common,[55,56] exposing people to compounding risks and stress from smoke, heat, and poor water quality.[88,89]

Ecological Health

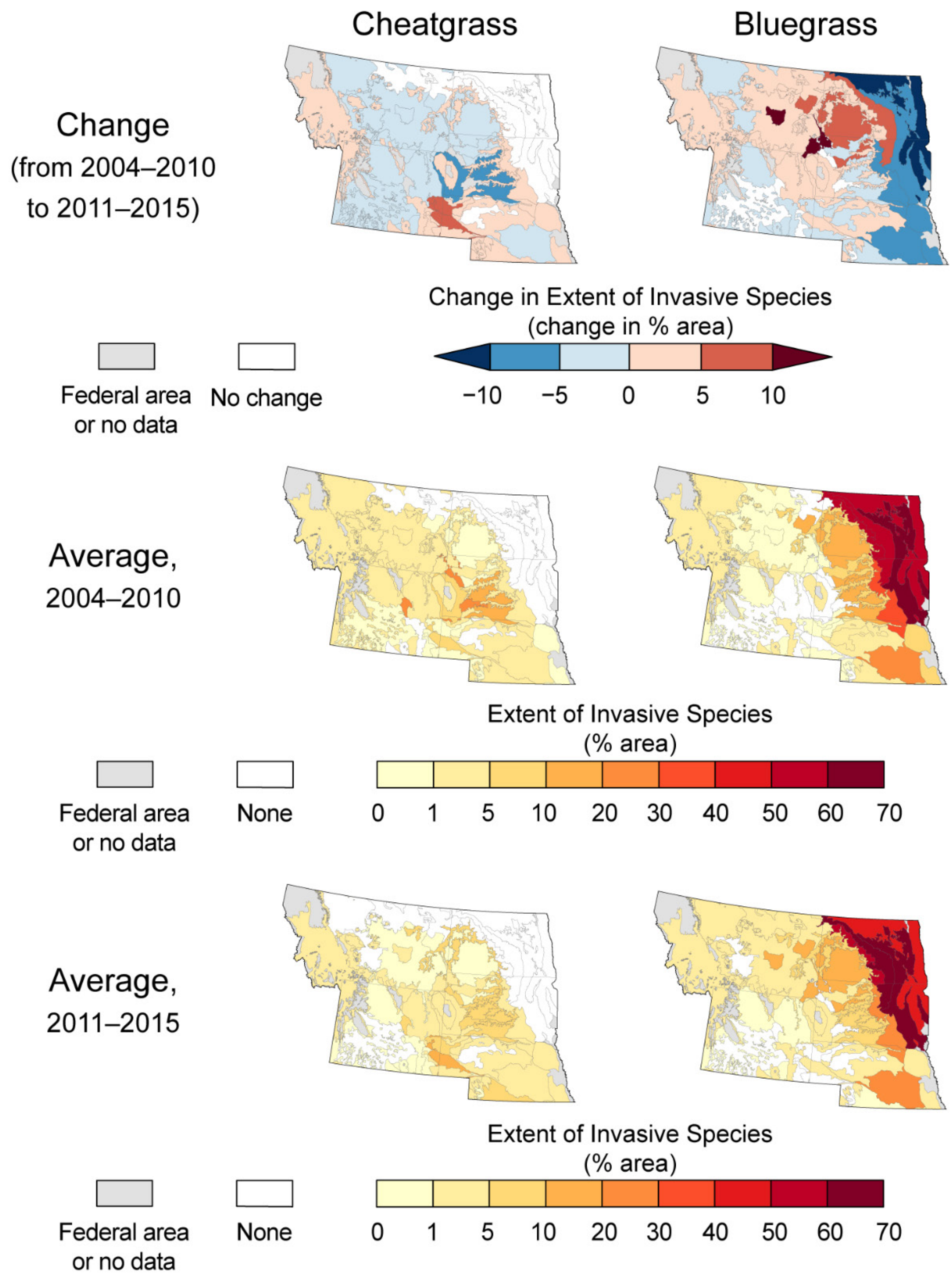
Water Quality

Excess contributions of nutrients, such as nitrogen and phosphorus from agricultural runoff or point sources such as wastewater treatment plants, can cause water quality issues, which are expected to be exacerbated by climate change.[90,91] Nutrient loads (the total amount of a nutrient transported past a single location over a set period of time) can increase after droughts, when sediment is flushed in subsequent runoff events.[92] Nutrient runoff from agricultural land spikes after heavy rain and contributes to harmful algal blooms and transport of nutrients to the Gulf of Mexico (KM 25.5).[93,94,95] Climate change has long been hypothesized as a driver of harmful algal blooms;[96] supporting these hypotheses with observations has been challenging because of gaps in monitoring, lack of long-term algae data, and changes in laboratory and remote-sensing methods.[97,98]

Cascading Impacts to Biodiversity Loss

Climate change compounds existing threats to biodiversity (Ch. 8). Within the Northern Great Plains, conversion of perennial grasslands to monocultures of annual crops results in a loss of biodiversity.[99] Invasive species are also a contributor to biodiversity loss in the region,[100,101] and the dominant invasive species of concern varies from east to west (Figure 25.7). The region is a hotspot for grassland bird diversity and encompasses the entire breeding season range for many of the most vulnerable species;[102,103] based on projections under a scenario with 5.4°F (3.0°C) warming above preindustrial levels, more than 80% of grassland bird species will be vulnerable to climate-related threats during the breeding season.[104] Both native pollinators and honeybees are important components of the region's ecosystems. The region supports approximately 40% of US honeybee colonies in the summer.[105] Over the last 15 years, pollinators have been experiencing declines.[106] Although not directly linked to climate change, changes in land-use patterns related to biofuel policies and loss of Conservation Reserve Program (CRP) lands are potentially contributing to these declines.[105,107] The CRP program pays farmers to take marginal land out of agricultural production for 10 years and plant perennial cover to reduce soil erosion and provide other ecosystem benefits. Recent modeling, however, indicates that targeting where CRP lands are planted on the landscape could improve the benefits to pollinators.[108] Finally, natural resource managers have identified a number of management strategies to help reduce biodiversity loss in the face of climate change, but for many taxa and ecological communities, there are still knowledge gaps.[109,110]

Invasive Species as Bioindicators of Ecological Condition



Invasive cool-season grasses are reducing biodiversity in the Northern Great Plains.

Figure 25.7. Acreage in the Northern Great Plains region where at least 50% of the soil surface is covered by two representative invasive plant species: cheatgrass (*Bromus tectorum*; **left**) in the western part of the region, and Kentucky bluegrass or Canada bluegrass (*Poa pratensis* or *Poa compressa*; **right**) in the eastern part of the region. The figure shows acreage for 2004–2010 (**center**) and 2011–2015 (**bottom**), as well as the change in extent of invasion between those two periods (**top**). These invasive grasses already pose a threat to the biodiversity of the region, and climate change is predicted to increase invasive species challenges for this region. Figure credits: (center left, bottom left, center right, bottom right) adapted from NRCS 2018;[111] (top left, top right) The Nature Conservancy, NOAA NCEI, and CISESS NC.

Key Message 25.3

Resource- and Land-Based Livelihoods Are at Risk

The Northern Great Plains region is heavily reliant on agriculture and resource-based economies, placing livelihoods at risk from the impacts of climate change and related policy. Agriculture and recreation will see some positive effects but primarily negative effects related to changing temperature and precipitation regimes (*likely*, *medium confidence*). Energy-sector livelihoods will be affected as emissions-reductions policies drive shifts away from fossil fuel sources (*likely*, *high confidence*). Climate change is expected to test the adaptive resilience of the region's residents, in particular rural, Indigenous, and low-income immigrant populations (*likely*, *medium confidence*).

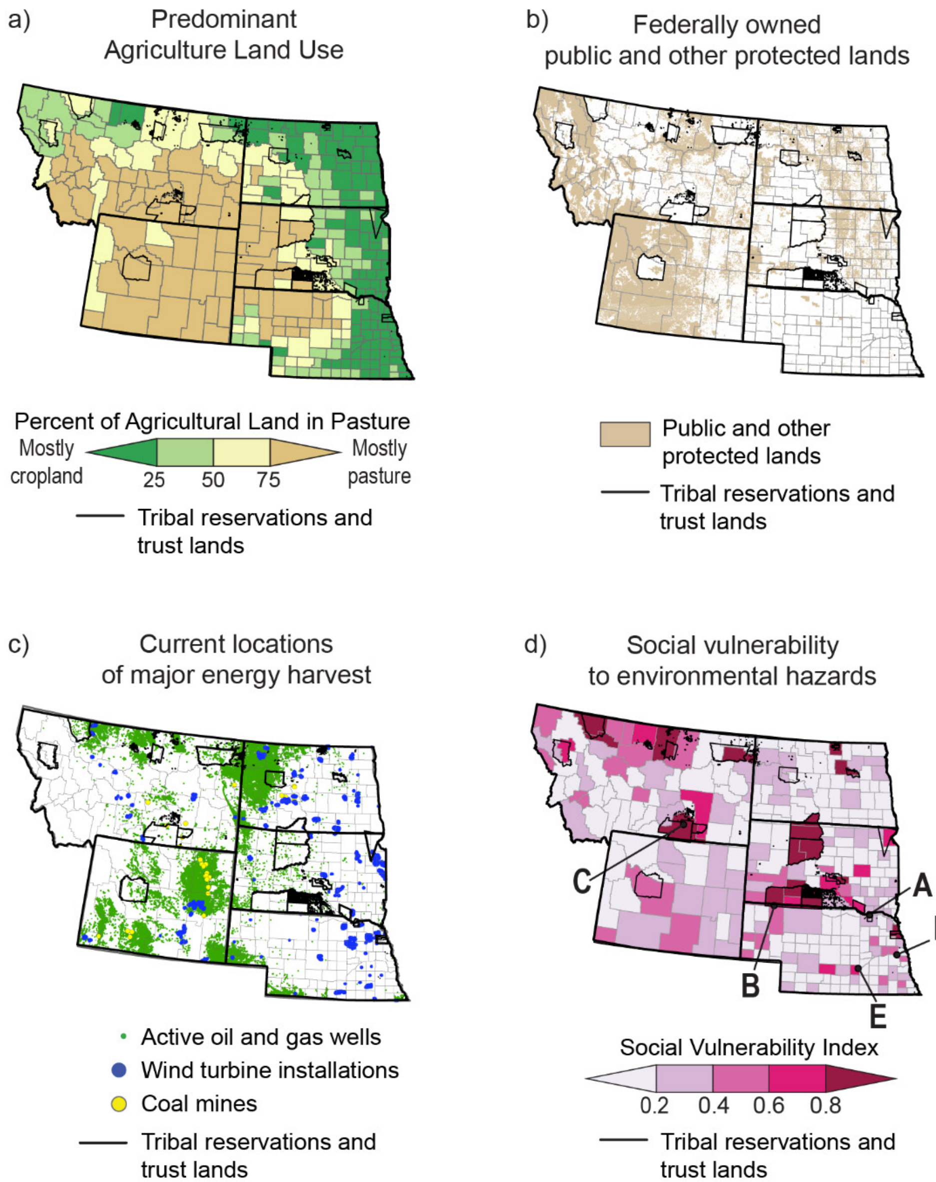
Food and Agriculture

Farming (referring to all forms of agricultural production, including livestock operations) accounts for 6% of total earnings in the region, compared to 0.4% of total earnings nationally.[112] Although growing seasons and frost-free periods are lengthening,[113,114] other factors may stress crop production.[49] Negative crop yield impacts are anticipated from rising temperatures, which increase the potential for heat and moisture stress during reproductive periods, as well as the potential for increased weed competition and pest expansion.[3] Although row crop agriculture generally occurs where greater average annual precipitation occurs (Figures 25.2, 25.8a), farmers are expanding and intensifying croplands into less productive lands in the region[99,115,116] as climate change alters growing conditions. Although crop yield decline from increased evapotranspiration may be somewhat offset by soil moisture trends, soil moisture is projected to slightly decline on an annual basis across much of the region (KM 25.1).[117,118] Overwintering crops like winter wheat are expected to benefit from reduced exposure to frost days under climate change, but reduced ground insulation from declining snow cover may offset some of this gain.[119] Additionally, higher carbon dioxide concentrations are expected to benefit the productivity of many crops.[120]

The net effect of climate change on specific crop yields is uncertain and will depend on interacting effects of temperature, moisture, carbon dioxide, and ozone, as well as adaptation through shifts in cultivars, crop mix, and management practices.[120,121,122] For example, climate change was listed as a primary challenge to both dryland and irrigated agriculture in the 2022 Blackfeet Agricultural Resource Management Plan (ARMP), due to earlier snowmelt, increased evapotranspiration, and less water available for irrigation. Recent extreme events indicate potential future impacts to livelihoods of individuals throughout the agricultural value chain.[123] Climate change negatively impacts the ability of regional Indigenous communities to grow and use traditional foods, medicines, and plants due to species movements and shifts in growing and harvesting seasons. Two significant examples are the Lakota staples wild turnips and chokecherries.[124,125] In 2017, above-normal temperatures in late summer and fall delayed the harvest of berries and medicinal plants.[126]

Northern Great Plains rangeland productivity may see less harm from climate change than other livestock-producing regions.[127,128] Rising temperatures and elevated carbon dioxide levels are projected to increase growing-season length and carbon assimilation by plants, thus increasing aboveground net primary productivity (atmospheric carbon converted into aboveground plant matter)[129,130,131] but decreasing nutritional quality.[132,133] However, drought-induced water limitation would produce the opposite response by reducing biomass production, concentrating nutrients, and enhancing forage quality.[134] While the northern part of the region could see more frequent forage surpluses under both intermediate (RCP4.5) and very high (RCP8.5) scenarios, the southern part of the region (e.g., Nebraska) may experience more frequent forage deficits.[1] Drought years have had a smaller impact on cattle numbers in the Northern Great Plains than in other regions,[135] and single-year droughts have only minimally impacted management or livelihoods.[136] However, ranchers face increasing challenges managing livestock health due to heat stress, parasites, and pathogens, as well as managing shifts in forage species, including invasive weeds.[137,138] Tribal producers may be more vulnerable to these stresses, as they tend to operate smaller farms and ranches on lands that have highly fractionated ownership, compared to non-Indigenous producers.[139] While cattle production has moved northward overall,[1] additional stressors to rangeland-based livelihoods exist in the region, including conversion to cropland,[140] rising land prices, and land ownership concentration trends.[141,142,143]

Geography of Land Use and Social Vulnerability



The Northern Great Plains region shows wide geographical variations in land use and social vulnerability.

Figure 25.8. The figure shows the geography of resource- and land-based livelihoods and vulnerabilities. Tribal reservation and trust lands are outlined on all maps. Panel (**a**) displays the predominant use of each county's agricultural land as either pasture or cropland. Pasture is common throughout much of the region, with cropland prev-

alent in the eastern portion of the region. Panel (**b**) shows federally owned public lands, including lands managed by the National Park Service, Bureau of Land Management, Bureau of Reclamation, US Forest Service, US Fish and Wildlife Service, Department of Defense, Department of Energy, and other federal agencies. In addition to public lands, private protected areas voluntarily provided to the database are also included but make up a very small minority of the overall public and other protected land area. The amount of federally owned public land increases in the more arid western portion of the region. Panel (**c**) displays locations of major energy sources in the region. Surface coal mines, oil and gas wells, and wind turbine installations are located throughout the region. Panel (**d**) shows county-level Social Vulnerability Index (SoVI) scores, with higher scores closer to 1 indicating higher levels of social vulnerability to environmental hazards.[144] Capital letters in panel (d) display locations of recent extreme climate events highlighted in the "Community Infrastructure and Quality of Life" section below (A, D, and E highlight examples of flood impacts, B highlights storm damage, and C provides an example of drought impacts). Figure credit: University of Nebraska, USDA Forest Service, NOAA NCEI, and CISESS NC.

Tourism and Recreation

The region's public and private lands provide tourism revenue, as well as benefits to residents' quality of life (Figure 25.8b).[145,146] Climate-related trends and extremes are expected to affect ecosystem services, wildlife, and tourism, with associated economic impacts.[147,148] Higher temperatures in the Yellowstone River in August 2016 are blamed for a fish kill that triggered the closure of the river to fishing and other uses, decreasing income for local and regional businesses.[149] Water-based activities are particularly vulnerable to drought and face increased conflicts with other water uses.[150] In 2017, Montana lost approximately 800,000 visitors and $289 million (in 2022 dollars) of tourism- and recreation- related income due to drought.[151] Visitors also shortened their stays due to smoke and fires.[150] Warmer winter temperatures in recent decades are correlated with mountain pine beetle outbreaks in western Montana but were not significantly correlated with mountain pine beetle outbreaks in other forests within the region, such as the Black Hills.[152] A 2017 drought decreased pheasant populations, affecting tourism income; its impact on wildlife populations also reduced Tribal-guided hunting opportunities and may have affected the competitiveness of culturally significant plants.[126] The length of winter sports seasons is expected to decrease[153] and thus negatively affect recreation economies in Montana, Wyoming, and South Dakota.[154] However, there may be improved opportunities for spring and autumn "shoulder season" recreation and both positive and negative effects on wildlife-based activities.[150]

Energy

Energy revenue in the region supports local services, infrastructure, and income that includes per capita payments for some Tribal members.[155] Energy revenue can also create risks in the region stemming from short-term revenue volatility and long-term dependence.[156] The region has an extensive number of oil and gas wells, numerous surface coal mines, and increasing wind turbine installations (Figure 25.8c). The region's share of employees working in fossil fuel extraction is four times greater (1.8% of all jobs) than in the Nation as a whole (0.4% of all jobs).[5] Energy-related livelihoods are affected by climate change due to changes in power generation, transmission, and consumption, as well as shifts in demands for particular types of energy sources.

Climate change impacts and mitigation efforts are expected to change energy demand in the Northern Great Plains seasonally. Higher summer temperatures and heatwaves are expected to increase energy demand in the Northern Great Plains and throughout the country, while in the region, higher winter temperatures and fewer cold snaps are expected to reduce energy demand for heating (Ch. 5).[157,158] Increased energy demands from outside the region will place increased demands on regional energy resources and electricity supply.[159] Lower winter electricity demands may potentially lower annual household energy costs in this region,[157] but increased electrification of the grid may increase costs to utility ratepayers as natural gas utilization declines.[160] Finally, climate change, especially climate extremes, may also stress energy infrastructure (e.g. rail, pipelines, distribution lines, transmission lines; Ch. 5).[161,162]

Energy-related livelihoods are also affected by shifts in the type of energy harvested. Energy extraction and generation in the region respond to external market and policy drivers.[163,164,165] For example, coal extraction has declined since 2011 due to air quality regulations, competition with lower-cost natural gas and renewables, and climate policy in states and utilities outside the region.[155] Tribal and other rural communities dependent on coal extraction for revenue and jobs have experienced losses to both as markets shift away from these resources.[166] Energy transition policy is heterogenous at the state level, and states in the region have pursued efforts to protect coal assets rather than help communities transition from coal.[155,167,168] In response to the demand for oil and gas, communities engaged in oil and natural gas extraction in the Northern Great Plains region grew faster than the regional average (14% compared to 6%),[8] and oil and natural gas extraction is expected to remain at or near current levels through 2030.[169] Renewable energy production is on the rise in the Northern Great Plains, with the region supplying 12% of the total US electricity generation from wind, biomass, and solar sources.[163,170] Wind electricity generation tripled in the region between 2011 and 2021 and was often co-located alongside row crop agriculture (Figure 25.8).[159,170] A growing number of Tribal entities are leading the Nation's renewable energy transition by installing renewable energy projects, including the Pine Ridge Indian Reservation in South Dakota (solar), the Oceti Sakowin Power Authority (wind), and the Confederated Salish and Kootenai Tribes in Montana (hydroelectric).[171,172,173] The Inflation Reduction Act of 2022 (IRA) is expected to accelerate deployment of renewable energy sources,[169] and the region may benefit from investments in hydrogen hubs; carbon capture, utilization, and storage; and advanced nuclear reactors (Ch. 5).[174] Without the IRA and other climate mitigation policies, additional energy produced by new renewable energy sources is expected to only meet the increased energy demand by 2050 rather than replace the current usage levels of petroleum and natural gas.[163]

Community Infrastructure and Quality of Life

Tribal lands, governments, and peoples are integral to the energy, agriculture, and recreation sectors. Immigrant populations are tied to agriculture in the region through their role in meatpacking, dairy, and other key industries. These communities face social vulnerability to harm from environmental hazards (Figure 25.8d). Communities across the region have experienced damages to infrastructure, businesses, homes, and livelihoods due to extreme events, including drought (2017, 2021), hailstorms (2018), flooding (2019, 2022), and wildfire (2021).[41] For example, after the 2019 Nebraska floods, community-level impacts included damage to homes, lack of water and sanitation services, and increased levels of anxiety and stress.[175] The effect of floods on the Santee Sioux Tribe included interruptions to power and drinking water supplies, wastewater backups, and destruction of many bridges and buildings (Figure 25.8d, point A).[176]

Future extreme events will disproportionately affect communities in the Northern Great Plains region that have greater exposure and sensitivity to hazards and fewer resources to prepare, respond, and adapt compared to larger cities.[12] For example, two storms damaged nearly 600 homes on the Pine Ridge Indian Reservation in July 2018, half of which were not repaired one year later (Figure 25.8d, point B). In 2019, the region experienced widespread flooding and damaged roads,[177] stranding many residents without access to basic needs. Many communities were disconnected from major highways, and infrastructure repairs are still underway. In drought years, communities dependent on surface water, such as those across the Crow Reservation, are seeing water resources and adaptation options become increasingly scarce (Figure 25.8d, point C).[166]

The lack of resilient infrastructure combined with regional climate impacts has created extreme water insecurity for Indigenous communities.[178] In the region, $159 million (in 2022 dollars) would be needed to bring either sewer or water access to 175 Tribal communities. Further, there are upwards of 18,000 homes within the region in need of sanitation (water and sewer) repair.[179]

Finally, regional residents living in housing or locations that are vulnerable face potential harms due to climate change. States in the region have a higher percentage of mobile and manufactured homes (e.g., 12.3% in Wyoming and 10.4% in Montana) compared to the US average (5.5%).[8] Mobile and manufactured homes are physically more vulnerable to extreme heat, flooding, and wildfires, exacerbating impacts from disasters.[180] Homes in floodplains are disproportionately occupied by renters and non-White populations. In Nebraska, Hispanic residents are overrepresented in floodplain areas (18% compared to 9% of residents in non-floodplain areas),[181] which resulted in disproportionate impacts to their housing security during the 2019 flooding in areas like Fremont and Grand Island, Nebraska (Figure 25.8d, points D and E).

Key Message 25.4

Climate Response Involves Navigating Complex Trade-Offs and Tensions

Climate change is creating new, and exacerbating existing, tensions and trade-offs between land use, water availability, ecosystem services, and other considerations in the region, leading to decisions that are expected to benefit some and set back others (*very high confidence*). Decision-makers are navigating a complicated landscape of shifting demographics, policy and regulatory tensions, and barriers to action (*high confidence*). Changes in temperature and precipitation averages, extremes, and seasonality will alter the productivity of working lands, resulting in land-use shifts to alternative crops or conversion to grasslands (*likely*, *medium confidence*). Shifts in energy demand, production, and policy will change land-use needs for energy infrastructure (*likely*, *medium confidence*).

Communities across the Northern Great Plains region experience complex tensions and trade-offs between land use, water availability, ecosystem services, and other factors, all exacerbated by the impacts of climate change. For example, higher temperatures and a longer growing season make the region attractive for climate-driven human migration[9] and increased forage production,[1] which in turn increase the demand for water resources. However, shifts in precipitation and reductions in snowpack will alter the quantity and timing of available water.[60] These tensions culminate in difficult decisions about how best to manage water quantity and quality and balance trade-offs between consumptive and ecological uses. Chapter 18 highlights frameworks for understanding complex systems, cascading effects, and decision-making under uncertainty.

Tensions: Navigating Barriers to Mitigation and Adaptation

Decision-makers are increasingly aware of current and projected climate change impacts, and communities are trying to adapt and mitigate. However, there are cultural, structural, and institutional barriers that prevent effective action in the Northern Great Plains region. States within the region currently rely on fossil fuel economies, creating resistance to energy transition and economic diversification.[155,156,182] For example, Wyoming has passed legislation designed to hamper the retirement of coal plants and to ensure a continued market for coal generation.[167] Other examples of barriers include less research funding than other regions;[183] lowered capacity to adapt (Box 25.1); varying perceptions of climate change;[184] and a confusing, and occasionally contradictory, set of water regulations and rights around surface water storage (e.g., implementation of artificial beaver dams to retain water on the landscape).[185,186] These factors limit transition planning and undermine community-level resilience.[168]

Integration of climate change into K–12 science education standards in the Northern Great Plains region varies greatly, with several states in the region failing to link human activities to climate change.[187] Acceptance of the human link to climate change is lower than the national average among adults in the

Northern Great Plains region, with particularly low acceptance among agricultural producers and agricultural interest groups.[188,189] This lack of acceptance highlights barriers to collective understanding and climate change response in the region and is matched by a stronger evidence base for actions that emphasize adaptation and resilience rather than mitigation (KM 25.5).

The employment, income, and public revenue impacts of the transition away from fossil fuels will vary by geography.[190,191] Declines in coal demand have, and will continue to have, negative effects on rural coal-dependent states and communities, such as Rosebud and Big Horn Counties in Montana.[155,156,192] The public revenue gains from renewable energy could be substantial but uneven, reflecting both the impact of facility siting on regional economic opportunity and the impacts of tax policy on the ability of state and local governments to capture and retain tax revenue.[155,193,194] Specifically, state taxation and expenditure limits preempt governments from generating revenue from diversified economic growth,[195] including from renewable energy, and tax incentives designed to lower costs for renewable energy projects can undermine the revenue benefits of an energy transition.[196] Tribal communities in this region also face barriers to developing and benefiting from renewable energy on Tribal lands, including a dependence on federal agencies for permitting, limited access to private finance, and an inability to access federal incentives, which makes private investment on Tribal lands less attractive.[197,198] Decision-makers and communities in the region have increased efforts to incorporate multiple values and ways of knowing (e.g., Indigenous Knowledge, local experience, and empirical science) into planning and action (KM 25.5).

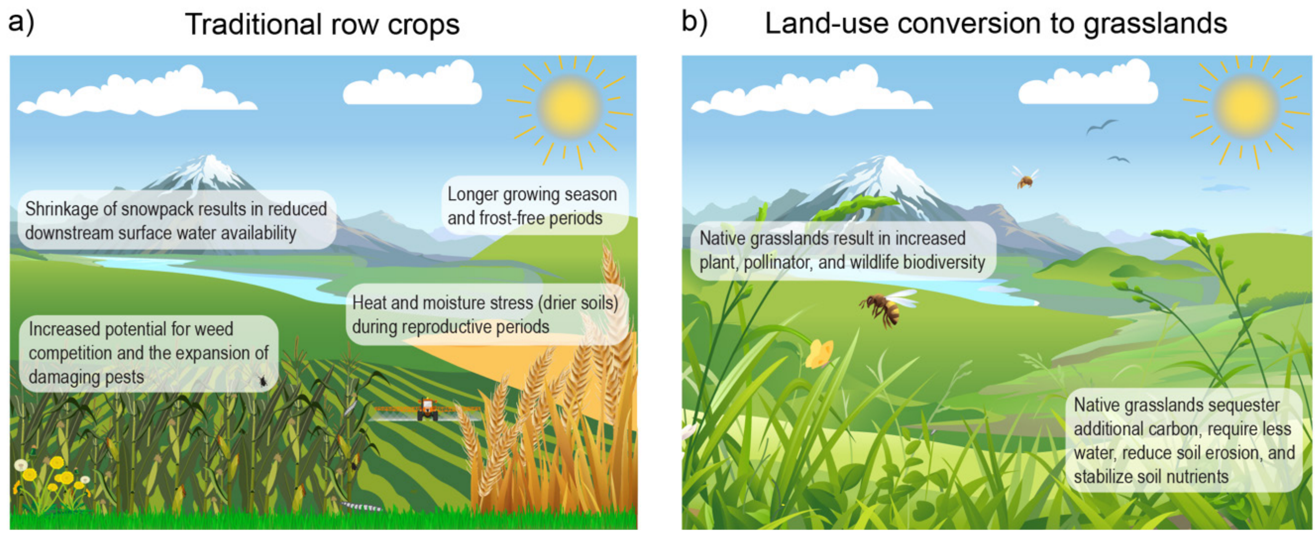
Box 25.1. Rural Capacity and Funding

With $1.28 trillion (in 2022 dollars) in funding, the Infrastructure Investment and Jobs Act is one of the largest investments in infrastructure, community resilience, and climate response in US history.[199] To successfully plan for and finance climate mitigation and adaptation projects, communities require capacity, staffing, resources, and expertise to apply for funding; fulfill reporting requirements; and design, build, and maintain infrastructure projects over the long term.[200] States where capacity to support these efforts is limited receive fewer federal resilience grants, and federal programs that create a need for capacity to apply for and manage grants can erode local capacity that could be utilized for other purposes, thereby discouraging participation.[201] Federal funding agencies can utilize maps of capacity at the local-government level to identify and support communities that lack staff and expertise to compete for climate mitigation and adaptation, community resilience, and economic development resources. Montana, Nebraska, North Dakota, and South Dakota rank among the 10 states where the greatest share of communities have a Rural Capacity Index lower than the national medium.[202] Key Message 20.3 further describes the role of governance and policy in risk, adaptation, and equity.

Trade-Offs: Land-Use Conversion

To counterbalance the potentially negative effects of a warmer future climate and drier soils, a shift to more water-conservative and nutrient-retentive land cover may be needed, such as from row crops to grassland (Figure 25.9). This would enhance ecosystem services such as wildlife, flood retention, nutrient stabilization, and carbon sequestration.[203,204] While this would increase resilience, it would also require many social and infrastructure adjustments and investments, including identifying seed sources for native species. Crops and services produced would shift from grain to forage, animal products, native plant seed, biofuel from grass, increased hunting on private land, and carbon credits. This would disadvantage companies that currently serve the high-input needs of conventional farmers but result in smaller loans for grassland producers due to less costly equipment, smaller seed purchases, and less grain shipped overseas.

Land-Use Conversion as a Strategy for Climate Adaptation



Land-use conversion offers one strategy for adapting to climate change.

Figure 25.9. Climate stressors interact with regional land-use decisions in complex ways. Recent and historical land-use decisions (**left**) are altering the productivity of working lands. Potential alternative land-use decisions (**right**) have the potential to increase resilience against climate change. By converting agriculture to grassland in areas that will become marginal for production, landowners and resource managers can conserve water and enhance ecosystem services. Figure credit: USGS.

Transitioning away from fossil fuel energy systems is expected to result in the abandonment or reduction of fossil fuel energy infrastructure (e.g., pump jacks, well bores), siting of new wind energy generation (e.g., wind turbines), construction of linear transmission CO_2 pipelines, and continued land conversion to biofuels.[165,205] Because renewable energy sources are expected to require larger land areas (3 to 25 times larger) to produce similar amounts of energy as nonrenewables,[206,207] a trade-off exists between providing energy and conserving the few remaining intact grassland tracts in the world.[208,209] Fragmentation of these tracts by energy infrastructure involved in harvesting and transmitting energy can reduce wildlife populations and provide conduits for invasive species.[159] Siting of energy infrastructure on areas already disturbed by row-crop agriculture or other activities may help prevent further fragmentation in some areas but may not be a possibility in the more intact grasslands of the Northern Great Plains that are relatively undisturbed.[159,209,210] Water-use trade-offs are another concern with energy development. Water law can influence the ability of industry to access water rights in low-flow years.[211] For instance, state and federal environmental policy may limit options to generate power from fossil fuel plants that require water for cooling during low-water years, which are projected to become more frequent (KM 25.1). Additionally, legal challenges related to water quantity and quality for endangered fish set up trade-offs between energy, wildlife, and recreation.[212,213]

Another adaptation action, piloted locally on less productive farmland with promising regional mitigation potential, is planting low-input, productive tall grasses, such as switchgrass, as dedicated biofuel energy crops (Figure 25.10).[214] This approach sequesters carbon from the atmosphere,[215,216] and marketing this alternative crop for forage, seed, or biofuels could generate income equal to or exceeding current income.[217] Switchgrass is a native plant that requires little fertilization and is especially resilient to drought. Biofuel feedstocks could be burned to generate electricity or converted to ethanol or bio-oil, syngas, and biochar. Planting grasses would store more carbon in the soil, require fewer inputs of fossil fuel compared to the annual planting of conventional crops, and improve other components of soil health.[218] However, large-scale land-use conversion to biofuel energy crops could disrupt food production processes, reduce biodiversity, and drive water competition.[219]

Marginal Farmland Planted to Switchgrass

Conversion of cropland to production of biofuels such as switchgrass is being piloted in the region as a climate adaptation action.

Figure 25.10. Switchgrass is a highly productive native prairie perennial that is the most promising species for future commercial growth as biofuel (for use as liquid transportation fuels and in electricity production). Photo was taken in 2021 at an experimental farm near South Shore, South Dakota, following two summers of drought, when production of switchgrass hay was 5 tons per acre and was more profitable than the production of corn. Photo credit: ©Arvid Boe, South Dakota State University.

Key Message 25.5

Communities Are Building the Capacity to Adapt and Transform

Adaptation is underway in the Northern Great Plains to address the effects of climate change. Agricultural communities are shifting toward climate adaptation measures such as innovative soil practices, new drought-management tools, and water-use partnerships (*medium confidence*). Several Tribal Nations are leading efforts to incorporate Traditional Knowledge and governance into their adaptation plans (*high confidence*). Resource managers are increasingly relying on tools such as scenario planning to improve the adaptive capacity of natural ecosystems (*medium confidence*).

Effective adaptation accounts for climate change uncertainty as well as the complex interactions and trade-offs within and between ecological and social systems (Ch. 31).[220,221] The failure to carefully navigate the full suite of adaptation options and the consequences of those options can result in maladaptation—increased vulnerability to climate change due to poor or misguided action (Box 25.2)[222] or inequitable distribution of outcomes. Despite these challenges and risks, climate adaptation planning also presents opportunities to build collaborative partnerships and steward ecosystems.[223] The communities, economic sectors, and natural resource practitioners in this region are advancing adaptation solutions (Box 25.3).

Box 25.2. Prairie Pothole Wetlands and Climate Adaptation Challenges

In the eastern Prairie Pothole Region of Minnesota, North Dakota, South Dakota, and Iowa, an increase in rainfall in the spring season has exacerbated problems with excess shallow groundwater in farm fields. Farmers have responded by draining this water with perforated plastic pipes (known as tiles; Figure 25.11)[224,225] buried at the rooting depth of mature corn plants, a practice that improves crop yield.[226] Tiling has increased rapidly in eastern North and South Dakota, particularly in the Red River valley.[227,228,229,230] To date, approximately half of the wetlands in the Northern Great Plains have been drained, disrupting their ecosystem services, such as flood protection, carbon sequestration, and forage and water for livestock.[231,232] Drainage transforms the hydrology of downslope ecosystems, contributing to the widening and sedimentation of rivers,[224,233,234,235] and promotes toxic algal blooms in aquatic systems through transport of nutrients (especially phosphorus and nitrate).[236,237] Additionally, improper placement of tiles may drain water from nearby wetlands.[226] Adaptation actions to regain wetland benefits and respond to climate change include restoring grassland and drained wetlands, redoubling the protection of wetlands with easements, revising vegetation management of wetland watersheds, and discouraging tile drainage in farm fields with wetlands present.[238,239,240,241]

Pattern Field Tiling

Draining agricultural fields through tiling improves crop yields but can harm ecosystems.

Figure 25.11. Pattern field tiling in the Prairie Pothole Region is designed to drain low, wet ground to provide soil space for roots of crops, which can increase yields. Tiling can inadvertently drain wetlands if placed too close to or below the elevation of the wetland bottom. Plastic pipe is buried at each black line visible in the photograph. Photo credit: USFWS.

Box 25.3. Climate Adaptation Successes

Climate adaptation happening in the Northern Great Plains region includes farmers in Nebraska testing new methods to improve soil structure and hydrologic function, Indigenous communities returning buffalo to their lands, ranchers returning less productive farmland to grassland for forage production, and local communities responding to flooding and working to improve flood readiness.

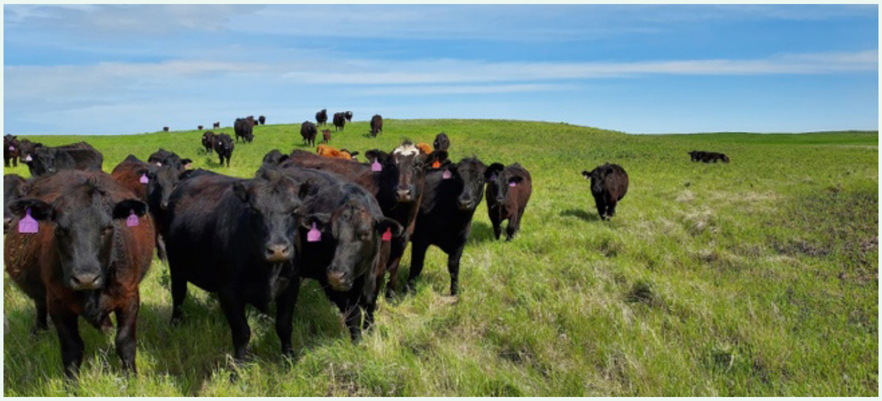
Adaptation Through Soil Health

Restoring soil structure and hydrologic function is a critical adaptation strategy in the Northern Great Plains region. In Nebraska, the Natural Resources Conservation Service has used federal conservation program dollars to support farmers testing soil health management practices, such as incorporating cover crops into annual crop rotations. Partnerships that leverage on-farm trials with outreach and research contribute to growing both the knowledge base and the execution of crop and livestock management practices that support improved soil function. Benefits include water-related outcomes such as increased infiltration and reduced runoff. Photo credit: USDA

Bringing Back the Buffalo

Bringing back the buffalo has been a regional resilience-building strategy for ranchers, Tribal Nations, and others who understand the role it plays in the ecosystem. The buffalo has deep cultural and spiritual significance for Tribal Nations in the region and beyond. The Tanka Fund has been pivotal in this regional effort by connecting ranchers to technical support and resources to increase herd sizes. Similarly, the InterTribal Buffalo Council helps Tribal Nations develop and maintain their own herds. These two entities connect resources to people and Tribal Nations looking to restore the buffalo as the keystone species of grassland ecosystems. Photo credit: NPS

Restoring Native Perennial Land Cover



As climate changes, it may be beneficial to return less productive cropland to native perennial cover that can provide multiple ecosystem services, including climate mitigation through carbon storage, pollinator benefits, and forage production for livestock. Audubon Great Plains, in partnership with government organizations and other nonprofits, is leading a new Conservation Forage Program in North Dakota to help producers achieve this shift in land use to benefit both producer operations and natural resources. Programs such as these that provide technical and financial assistance to producers while also helping to establish the necessary infrastructure for grazing (e.g., fencing, water access) and allow livestock use after vegetation establishment will allow farmers and ranchers flexibility in their operations. Photo credit: ©Reese Lausen

Responding to Increases in River Flooding

Flooding along major rivers is an increasing challenge for rural and Indigenous communities in this region. In March 2019, a 64-unit Tribal housing community with more than 300 Yankton Sioux members on the edge of the Lake Andes National Wildlife Refuge was inundated with floodwaters and cut off from the town of Lake Andes. Subsequent heavy rain events flooded basements and made the road inaccessible until the water over the highway froze in December. On August 12, 2019, the Tribe released a statement: "Our community is literally drowning."[242] The White Swan Recovery Group was created to provide resources for impacted community members and advocate for long-term solutions. The group received training to provide local lead and mold remediation and housing repairs. They continue to explore long-term solutions as the area is subject to frequent flooding; these efforts include advocacy to elevate the highway to protect housing, as well as conversations regarding relocating the community. Photo credit: Marcie Hebert, USFWS

Adaptations in Agriculture

The agricultural community in the Northern Great Plains region is developing innovative climate adaptation solutions to support livelihoods in the region (e.g., Johnson and Knight 2022[243]), many of which also support mitigation by sequestering carbon (Ch. 11). Stakeholders recognize that soil improvements increase flood and drought resilience.[244] Growing evidence from working farms and ranches in the region demonstrates how diversification strategies—such as reduced soil disturbance, increased crop residue, plant cover, and livestock and crop diversity (sometimes referred to as soil health or regenerative practices)—improve soil properties and processes, including water-holding capacity and infiltration, and provide many potential public and private co-benefits, including carbon sequestration.[245,246,247] These properties and processes produce enhanced carbon and nitrogen cycling and soil structure,[240] increased soil microbial communities, and lower pest communities while reducing nutrient inputs and leading to greater yields and profitability.[248,249,250,251,252] There is strong demand for, and proven efficacy around, producer knowledge networks to support transitioning to soil health practices.[253,254] Additionally, reintegrating row crop and livestock production systems could diversify income, increase operation resilience,[246] and restore ecosystem services, including sequestering more carbon in soil; retaining nutrients, especially nitrate; and supporting biodiversity.[108,217,255]

In arid parts of the region, adaptive solutions for irrigated agriculture will be critical. The majority of the region's states assign water rights based on prior appropriation, under which the first person to put water to beneficial use has the right to continue to use that water as long as the water is being used for the same beneficial use. This can slow the ability to acquire new water rights that may be necessary to address climate impacts.[256] The Upper Colorado River Commission (UCRC), as part of the 2019 Drought Contingency Plan,[25] is investigating the feasibility of implementing a demand-management program in the Upper Division states of the basin, including Wyoming. Under this program, water users would be compensated for voluntarily reducing consumptive uses. The conserved or imported water would be stored in federal reservoirs and released when needed to ensure compact compliance under a decision of the UCRC. On a smaller scale, many watershed and irrigation groups are investigating collaborative and shared water management strategies to manage scarce water resources to meet agricultural and ecological water needs, including the Brush Creek Irrigation District[257] and the Popo Agie Watershed Healthy Rivers Initiative[258] in Wyoming, as well as some Montana Tribes.[259] Instead of directly following the prior appropriation doctrines, different approaches to collaboratively manage water resources to meet agriculture and instream needs are being implemented. All of these efforts include and rely on improved hydrologic monitoring and data collection, as well as strong communication and buy-in from stakeholders.

Ranchers are also exploring adaptation strategies that increase livestock production by adjusting range management for a warmer climate.[260] One strategy to improve ranch resilience is through the use of drought planning.[261,262] Drought plans focus on identifying critical time periods for monitoring conditions and making decisions.[263] A planned drought response may involve adjusting the number of cattle, the season of grazing, the length of grazing time in pastures based on precipitation and vegetation growth,[264] or holistic planned grazing strategies that manage for ecosystem health by adapting to changing conditions.[265] A 2017 study found that nearly 60% of ranchers in the region had some type of drought contingency plan;[261] however, adoption of weather and climate data into management decisions has been slow.[136,266] The development of new grassland productivity forecasts may increase adoption by translating climate outlooks into usable information for ranchers.[267] Unique multistakeholder groups are also exploring collaborative adaptive management to understand and reconcile stakeholder experiences and ways of knowing about complex rangeland systems on public lands.[264]

Adaptation to Flooding

In response to significant flooding in 2011 and 2019 in the upper Missouri River basin (UMRB), improved monitoring was implemented to inform water management decisions. Frozen and saturated soil and significant snowpack in the UMRB were major contributors to flooding in those two years. Additionally, the drought west of the Missouri River in 2016–2017 highlighted the problem of sparse soil moisture data inhibiting accurate drought monitoring. As a result, the US Army Corps of Engineers, in collaboration with the state climate offices, is establishing a soil moisture and snowpack monitoring network.[268,269] A total of 529 stations are scheduled for installation between 2021 and 2027 on a 25-square-mile grid at elevations below 5,500 feet. The data from these stations, which include multiple soil moisture and temperature depths, as well as snow depths, will be directly available to NOAA to track and forecast flooding, drought, and other climatic and weather events.

With increased spring precipitation across much of the region, rural and Indigenous communities are adapting to more frequent flooding. Adaptation responses range from individual-scale approaches, such as elevating homes, to policy changes, including changing building codes and zoning regulations. Nebraska's unique river-basin Natural Resources District structure has enabled watershed-scale approaches that bring together multiple jurisdictions and stakeholders to decrease flood risk.[270] More drastic responses considered by some communities include relocating altogether. One increasingly successful adaptation strategy for responding to flood and natural disasters is the grassroots formation of local groups and coalitions to assist communities with disaster recovery and long-term adaptation (e.g., Sioux Empire Community Organizations Active in Disaster in South Dakota, Midwest Housing Resource Network in Nebraska). These groups are a mechanism for local communities to come together in mutual aid to plan for and support each other in response to flooding.

Adaptations in Indigenous Communities

Indigenous Peoples have called the Northern Great Plains region home for centuries, and today several regional Tribal Nations are leading the way in climate adaptation and implementation.[271,272,273] Several other Tribal Nations are leading the effort in water resilience and proactively addressing drought.[274,275,276,277] Indigenous approaches to adaptation combine traditional and contemporary management practices often grounded in spirituality and cultural traditions.[278] The key issues for Tribal climate adaptation in the region are capacity, sustainability, and sovereignty.[197]

The Rosebud Sioux Tribe has several initiatives in progress to build resilience to climate change.[279,280] The Sicangu Climate Crisis Working Group developed a Tribal climate adaptation plan that covers 20 Tribal communities across more than a million acres of Tribal land. The plan incorporates Lakota philosophy and Traditional Knowledge, including historical migrations, astronomy, origin stories, and the Tribes' special relationship with the buffalo. The plan prioritizes data sovereignty, interdepartmental collaboration, and directly supporting Tribal households to prepare for the impacts of climate change.[273] Additionally, the Rosebud Sioux Tribal Water Department has developed a drought adaptation plan and extensive real-time monitoring that enables the management of stream flow and groundwater sources, including the Ogallala Aquifer.[276] One of the major challenges has been the enforcement of the Rosebud water code to address neighboring farmers pumping Tribal-managed groundwater. However, with the removal of the moratorium on Tribal water codes, the Rosebud Sioux Tribe may now have the ability to manage its water as a sovereign nation.[281]

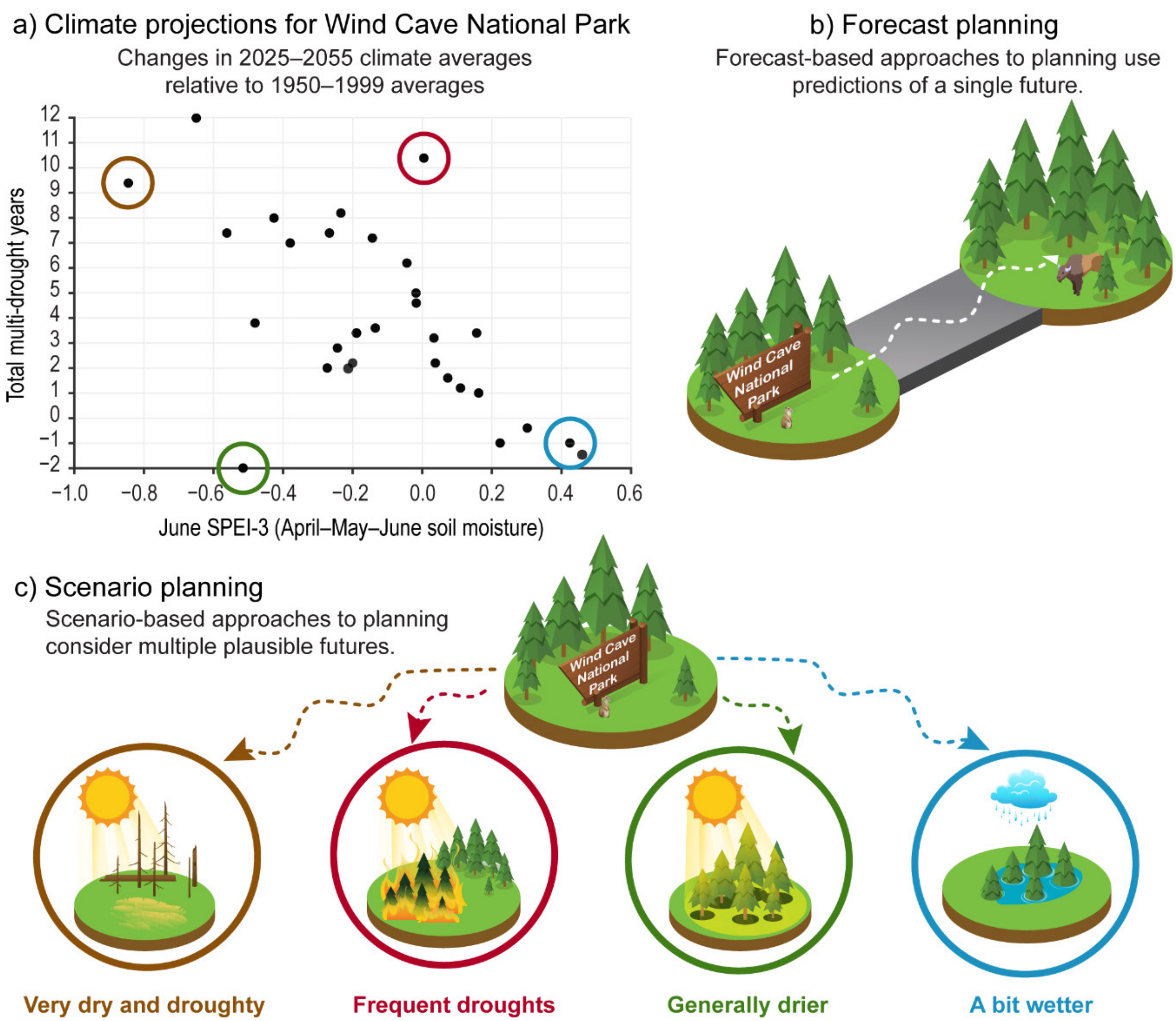
In 2018, the Blackfeet Nation completed a climate adaptation plan, which includes all of the natural resource departments across the Tribal government.[271] This inclusive approach takes more time and coordination but also creates collaborative opportunities by breaking down silos, minimizing redundancy, and maximizing scarce resources. For many Tribal Nations, sustainability is a key issue. This was especially true during the COVID-19 pandemic and continues to be the reality in rural agricultural regions with smaller tax bases and higher turnover rates in staffing. Implementation includes the Ksik Stakii Project, which aims to protect beaver, restore rivers, and increase natural water storage to reduce vulnerability to drought and flooding.[271,282] A notable capacity-building strategy at Blackfeet is for Tribal resource departments to partner directly with Blackfeet Community College students on research projects. This type of a partnership is particularly important in the Northern Great Plains region, which has the highest concentration of Tribal colleges in the country.

Public Land Adaptation

The National Park Service (NPS) and partners have adapted scenario-based planning to help natural and cultural resource managers and others work with uncertainty and address the ways change might plausibly occur (Ch. 8).[283,284] Adaptation action on public lands in this region is challenged not only by the region's inherent climatic variability but also by the uncertainty in how resources, lifeways, or livelihoods might be affected by climate change and which adaptation responses might be effective (Figure 25.12).

Adaptation of scenario-based planning for public resource stewardship has focused on NPS units within the region—including Knife River Indian Villages National Historic Site, Badlands National Park, Wind Cave National Park, and Devils Tower National Monument.[283,285,286,287,288,289,290,291] This work has increased scenario plausibility and relevance and improved facilitation and efficiency of climate adaptation decision-making.[283] It has also clarified the importance of distinguishing climate futures (i.e., climate scenarios) from climate-resource scenarios (i.e., scenarios of both changes in climate and associated changes in resource condition).[289,292] Importantly, this work has created a model to support climate adaptation for natural resource decision-making in the face of climate uncertainty.

Adaptation Planning



Scenario-based planning accounts for uncertainty by considering a range of ways in which change might occur.

Figure 25.12. Forecast-based planning uses predictions of a single future (**b**), whereas scenario-based planning works with a set of plausible futures that capture a broad range of potential future conditions, providing a framework to support decisions under conditions that are uncertain and uncontrollable. Scenario-based planning at Wind Cave National Park identified four potential outcomes (**a**, **c**) for grassland and pine forest vegetation, surface water availability, and American bison (*Bison bison*) and prairie dog colonies under different climate futures—very dry and droughty (brown), frequent droughts (red), generally drier (green), and a bit wetter (blue)—all of which have different management implications for the natural and cultural resources in the park. Each dot in the graph represents a climate projection, and the set of four circled projections collectively encompasses most of the range of ways in which drought and springtime moisture levels could change by midcentury. SPEI—the Standardized Precipitation–Evaporation Index—is a multi-scalar drought index, based on precipitation and potential evapotranspiration, that is used to identify wet and dry periods in a given location.[293] A zero value indicates average moisture balance, positive values signify above-average wetness, and negative values represent drier-than-average conditions. SPEI-3 is a three-monthly SPEI calculation, and this figure shows values for April–June. Adapted from Schuurman et al. 2022[294] and Runyon et al. 2021.[289]

Rural Community Adaptation

Rural communities have two key needs to foster climate adaptation (KM 11.3). The first is economic diversification to create more resilient economies (e.g., broadband connectivity, restoration activities that create jobs and restore ecological function, and conservation that improves access and opportunity in recreation-based economies). The second is the need for a new social contract around resource extraction, especially for communities that will remain rural, isolated, and resource-dependent.[295] Major investments in community services, infrastructure, and economic development led by rural communities require long-term and sustainable funding to build capacity and resilience (Box 25.1).[194,200] Barriers to building adaptive capacity include a lack of coordinated federal assistance programs.[296] The region also has the potential for population growth in communities currently facing out-migration driven by favorable changes in climate coupled with a robust recreation economy, particularly in the intermountain West.[297,298]

Traceable Accounts

Process Description

The chapter lead authors were identified in the summer of 2021. This team compiled a list of nominated and Fourth National Climate Assessment (NCA4) authors as a pool of possible contributors. Additions to this list came from professional networks, research into priority departments at key regional institutions, and searches on several databases of experts from historically marginalized populations. The lead authors defined potential themes for the region based on team expertise and a review of literature published since the release of NCA4 and then narrowed the list of potential authors based on their ability to address these themes and a desire for diversity.

Candidates were selected based on a mix of expertise, regional distribution, career stage, age, gender, sector, discipline, and race and ethnicity. After preliminary research on potential contributors, introductory conversations were pursued to gauge interest and answer questions. The majority of the chapter team was recruited in September and October 2021, although as gaps were identified, other authors were added. Weekly all-author meetings started in September 2021 to craft the Zero Order Draft, with subgroup meetings held when needed to work out details. Once key topics were identified in December 2021, authors were divided into Key Message teams, based on interest and relevant knowledge. Virtual all-author meetings continued weekly, with Key Message teams meeting approximately every other week and more frequently before submitting the Zero Order Draft.

Key topics were identified through discussion, relevant literature, and knowledge of the region. Authors held two virtual engagement meetings, one during the day and one in the evening, to provide options for participants. Engagement events were promoted by the US Global Change Research Program through author networks, on social media, and with personal invitations to individuals whose voices the author team wanted to be represented. Feedback from engagement aligned well with the draft structure, but some of the emphases were adjusted based on stakeholder feedback. The author team incorporated inputs received in a public call for the technical material and relevant scientific publications and added several key technical contributors to bring other types of knowledge (e.g., Indigenous and experiential) that would provide a more complete assessment. Key Message teams discussed and came to consensus about Key Messages proposed in the First Order Draft and revised and came to consensus on Key Messages for the Second and Third Order Drafts. Key Messages were further iterated in the Fourth and Fifth Order Drafts to respond to comments from the public, National Academies, and agency technical review.

Key Message 25.1

Climate Change Is Compounding the Impacts of Extreme Events

Description of Evidence Base

The role of climate variability in the region has been well established.[39,42,299] The added effect of climate change is still emerging. NOAA State Climate Summaries document long-term increases in temperature in the region and varying changes in precipitation across the region.[14,15,16,17,18] Recent USGS trend and attribution efforts reflect the trends in flooding presented here, and the majority of attributions for those changes are related to changes in precipitation, with some also related to changes in temperature.[43]

The upper Missouri River basin combines the varying effects of east–west and north–south gradients in precipitation and temperature, respectively, for the Northern Great Plains. However, the Key Message team wants to acknowledge that the Northern Great Plains region also includes parts of the Columbia, Colorado, Souris, Red, and Minnesota River basins.

Multiple independent scientific assessments and analyses of climate change effects on drought occurrence in the region are reaching similar conclusions across multiple climate change scenarios.[22,26,45,48,51] The study showing increased wildfire activity in the Northern Great Plains is based on satellite data, which adds credibility, because the use of the same methodology to assess wildfire across the region eliminates discrepancies caused by differences in how local governments record wildfire occurrence.[57]

Major Uncertainties and Research Gaps

Given the high degree of natural climate variability in the region, predicting future hydroclimatic and ecological conditions at specific locations is a major challenge. Climate change predictions of increased drought occurrence vary spatially and temporally. Complex interactions among temperature, precipitation, evapotranspiration, and moisture storage also create uncertainty for future conditions and agricultural production in this region (KM 3.4). As many of the projections of soil moisture predict close to no net change and the region already has a low effective precipitation that has high interannual variability, projected changes in soil moisture vacillate between overall net positive and negative changes.[47,48,49] Better understanding of how climate change affects soil moisture will require a greater assessment of the variability in soil moisture among global climate models and the incorporation of other factors such as soil type and plant species–specific responses at the local scale.[117,118]

Lack of long-term observations for small-scale and rare hail events and shortcomings in high-resolution models create uncertainty for predicting future events in specific areas,[28,29] so the models rely on trends in favorable hail environments.[30,31,32,33,34,35,300] Projections of severe convection in current research have largely focused on a very high scenario (RCP8.5).

Although drought frequency and severity are expected to increase, changes in multiyear drought occurrence due to climate change are relatively unknown.[45,52,53] Research on wildfires in the region has not addressed how human presence has influenced wildfire activity in the grasslands but has covered it in the forests.[58]

Description of Confidence and Likelihood

The coauthors of this section discussed the initial levels of confidence and likelihood, weighing the literature, observational data, and collective subject-matter expertise. The authors assigned a *likely* estimate with *high confidence* for an increase in severe droughts because of the pervasive evidence that increasing summer temperatures will increase evaporative demand, while changes in precipitation patterns lean toward increasingly dry summers. The authors assigned a *medium* confidence and no likelihood estimate for increasing hail frequency and size because the literature is still emergent and precludes a likelihood estimate but does present evidence that suggest increasing hail frequency and size in the High Plains area under at least some climate change scenarios. The authors assigned a *very likely* estimate with *high confidence* for changes in flood potential because research and observations strongly support both an increase of snowmelt runoff and flood potential in the eastern half of this region and respective decreases in the west. NOAA State Climate Summaries cited predict increases in extreme precipitation, which are expected to increase flood risk, even in areas with declines in overall precipitation. The authors assigned a *likely* estimate with *high confidence* for increased wildfire risk because the increase in evaporative demand and precipitation variability that favors drought also favors increased numbers of wildfires. Research indicating shorter duration of snowpack coverage also favors longer wildfire seasons. The authors assigned a *very likely* estimate with *very high confidence* for increases in evapotranspiration because multiple sources and subject-matter experts agree that the increasing warm-season temperatures will increase evaporative demand. The authors assigned a *very likely* estimate with *high confidence* for greater precipitation variability because of the depth of both observational and model-based studies and consensus among subject-matter experts for current and future trends toward increased variability.

Key Message 25.2

Human and Ecological Health Face Rising Threats from Climate-Related Hazards

Description of Evidence Base

Climate trends from NOAA State Climate Summaries,[14,15,16,17,18] individual state-level climate assessments, USGS studies,[43] and demographic data from the 2020 US Census Bureau provided information to help characterize the region in terms of ecological conditions[99,100,101] and human populations.[61] CDC databases were also used extensively for health-related statistics. Multiple recent peer-reviewed studies of the impacts of specific aspects of climate change on human health were reviewed and included in the assessment. With relatively few region-specific studies of the health impacts of climate change, analyses based on areas with more concentrated populations provided valuable insights that are applicable to the Northern Great Plains. Several studies related to mental health have addressed the impacts on ranchers and farmers, rural residents, and Indigenous populations and are included in this assessment.[73,75,76] Many studies predict water quality changes in response to climate change; fewer studies have identified such changes.[90] Land-use change was predicted to be a larger driver of changes in water quality than climate change, and, along with management practices, land-use change appears to be the major driver in many cases;[90,91] however, the interaction of land use, management practices, and climate extremes is an important area for future research and potential harm reduction.[93,94,95]

Major Uncertainties and Research Gaps

The complex interactions among climate-related indicators themselves, with even more variability contributed by the considerable east–west geographical expanse of the region, lead to notable uncertainties for future climate conditions and the interactions between those climate conditions and local populations. The overall low population and population density across the region make data collection relative to health-related impacts difficult, adding to even more uncertainty in projections for impacts on individuals or locales. Research gaps include limited studies relating to health impacts specific to the region. In addition to the demographic barriers noted above, many areas within the region have limited sensors for measuring local conditions related to air quality, temperature, water quality, and air and soil moisture. The paucity of sensors, most notable in nonurban areas of the region, for these conditions introduces uncertainty when focusing on specific locations. The need for location-specific data is particularly important when addressing adaptive measures, since some conditions, such as air quality and temperature, can vary dramatically within small geographical areas.

Climate impacts on the ecology of the Northern Great Plains are difficult to generalize because individual species are expected to respond very differently to changes in climate. While declines have been observed and are projected for some taxa,[104,106] there are knowledge gaps around what those impacts might be for many taxa, species, and culturally significant plants and animals. Climate impacts will interact with and are expected to compound many other anthropogenic stressors, such as invasive species and conversion of natural ecosystems to row crop agriculture, and it is unknown which taxa are most vulnerable to climate change and what the magnitude of these impacts could be.

While the authors understand water-quality and physical processes related to climate, many management activities designed to reduce nutrients are taking place on the landscape, along with changing agricultural nutrient requirements. Therefore, it can be difficult to find the climate signal in trends related to surface water quality, apart from the signal related to other important factors, such as land use, agricultural practices, and wastewater treatment.[90,94] The problem of attribution is further confounded by the complex effects of reaction-transport lags between any climate or landscape-scale driver and detectable changes in nutrients in surface or groundwater.[90,91] Recent findings based on observational data[90,91] support past predictions that land-use changes would have comparable or greater effects on water quality than climate changes.

Climate change has long been hypothesized as a driver of harmful algal blooms. Warming water temperature, higher carbon dioxide levels, and increases in heavy precipitation can create preferential conditions for algae. Blue-green algae can thrive in warming, slow-moving water; high carbon dioxide levels can result in rapid algae growth; and heavy precipitation can result in more nutrient runoff.[96] Unfortunately, supporting these hypotheses with observations has been challenging because of gaps in monitoring, lack of long-term algae data, and changes in laboratory and remote-sensing methods.[97,98]

Description of Confidence and Likelihood

Likelihood and confidence statements for climate change impacts on the health of residents of the region (*virtually certain*, *high confidence*) and on the region's ecology (*very likely*, *medium confidence*) are based on literature, some of which is cited in Key Message 25.2, observational data, and collective subject-matter expertise. The *very likely* rating for the region's ecology in both likelihood statements was based on the information that impacts are already being observed, and the *medium confidence* rating for both confidence statements was assigned because data or projections of impacts exist for some taxa but not all. Impacts to some aspects of the region's ecology are unclear or unknown. The research gaps and uncertainties listed in the preceding section limit the ability to project impacts for specific locations but do not lessen the confidence regarding current impacts on the various aspects of human health in the region as a whole, assertions strongly supported by an increasing number of studies (Ch. 15).[301] Levels of confidence and likelihood have been discussed in an ongoing fashion among the coauthors of the section, who weighed the overall literature and personal expertise to reach consensus for the stated levels.

Key Message 25.3

Resource- and Land-Based Livelihoods Are at Risk

Description of Evidence Base

Multiple national government economic reports provide the background for population growth and the importance of the agricultural and energy sectors to livelihoods in the Northern Great Plains. The most recent comprehensive syntheses of crop and climate impacts,[3,114,119] the most recent publications focused on Indigenous communities,[126] and the most recent foundational publications on crop physiology impacts of climate change at a broader scale than the region[120] support the projected negative impacts that rising temperatures would have on crop and culturally significant plant yields and timing. The net effect of climate change on agricultural livelihoods is uncertain due to the unresolved interacting effects of temperature, soil moisture, and carbon dioxide levels, as well as the degree of climate adaptations that may occur.[120,122] Projected aboveground net primary productivity increases and effects of drought are well documented across multiple scientific papers,[129,130,131] with recent papers supporting older papers from the literature and reinforcing the expected outcomes. The current resilience of rangeland-based livelihoods[135,136] and their future challenges[137,138] are well documented and in agreement. Although extensive peer-reviewed literature does not exist for climate effects on tourism and recreation, a few peer-reviewed literature examples documented climate change impacts on water-based, hunting, winter, and sightseeing recreational activities.[150,151,153] The scientific literature on projected changes in electricity use within the region in response to climate change is readily available and in agreement (Ch. 5),[157,158] but literature on energy resource and electricity demands on the region from outside the region is limited and lacks specificity.[155,159] Examples of increasing and shifting types of energy demands on the region are well documented in both peer-reviewed scientific literature as well as government reports,[163,165,169,170] but comprehensive literature reviews providing overviews of how all energy shifts are occurring in relation to one another and in response to climate change and climate change policy are lacking. Literature on the effects of current and projected energy demand and shifts among types of energy sources on the livelihoods within the region is less available, and information is gleaned from government reports.[8] The impact of climate extremes on energy infrastructure is general in nature (Ch. 5)[161] and does not cover climatic variability and extremes unique to the region for all the energy infrastructure types found in the region.[162] Peer-reviewed literature on climate change impacts to livelihoods in the region does not fully address recent extreme events, so agency reports (e.g., FEMA 2019[177]) and Tribal documents (e.g., Blackfeet Nation 2022[139]) are used to document examples of impacts. This is also the case with Tribal infrastructure, where critical information on infrastructure was pulled from Indian Health Service and Bureau of Indian Affairs reports. Impacts are also identified by a technical contributor (Cullen) who works directly with communities affected by disasters in the region.

Major Uncertainties and Research Gaps

As stated in the text of the Key Message, the net effect of climate change on specific crop yields is uncertain, and multiple interacting effects would benefit from further study to fully grasp how climate change will comprehensively impact the agricultural industry, especially as it develops cultivars and management practices that adapt to the changing environment.

The net impact on forage quantity and quality in the region remains to be further explored. Productivity responses of Northern Great Plains rangelands to climate change have a degree of uncertainty, as the response of the vegetation to climate change may vary between the two dominant plant functional groups (C_3 and C_4). Scaling up the climate change responses of individual species and functional groups and how they contribute to larger ecosystem processes and properties, such as evapotranspiration or productivity, is important for improving the forecasting of climate change impacts to grasslands and shrublands in the region; this is a research gap. There is also uncertainty about how the negative impact of drought, which is expected to increase under climate change, will impact the expected positive gains on forage quantity and quality due to rising temperatures and elevated carbon dioxide.

Comprehensive studies of how climate change will affect tourism and recreation in the region are missing from the literature. Climate change impacts on tourism livelihoods are often limited to case studies and would benefit from more directed scientific study. Although some climate change models predict changes in insect outbreaks, which can lead to large impacts on recreational areas, correlations between outbreaks and climate change (e.g., mountain pine beetle) were not widespread, indicating a research gap in understanding all the interactions contributing to the relationship of observed outbreaks and climate change (e.g., Weed et al. 2015[152]).

Further studies detailing how increased national energy demand impacts regional energy harvest would provide a deeper understanding of the economic connections that in turn greatly affect regional communities. Strategic planning for the development of new oil and gas resources while transitioning to other energy resources in the region could benefit the grassland resource as a whole. Carbon capture, utilization, and storage (CCUS) in the region may play a role in mitigating US emissions. However, little carbon is currently being sequestered, and documentation of the costs and benefits for the region, as well as its many barriers and uncertainty, is a major research gap. It would be helpful to gather more information on these topics before CCUS technology is deployed at scale in the region. Specific research examining how energy infrastructure in our region would respond to climate extremes is another research gap.

The effects of extreme events on agricultural, energy, and recreation-based livelihoods are often investigated more by the general media than by scientific studies and are therefore insufficiently covered in the research literature. This is also apparent when trying to evaluate the impact of climate change and climate extreme events on socially vulnerable communities. Peer-reviewed literature focused on climate change effects on rural and Indigenous communities in the region is a research gap.

Description of Confidence and Likelihood

The coauthors of this section discussed the initial levels of confidence and likelihood, weighing the literature, observational data, and collective subject-matter expertise. The authors assigned a *likely* estimate with *medium confidence* for agriculture and recreation seeing some positive but primarily negative effects of changing temperature and precipitation regimes on livelihoods. The *medium confidence* level was assigned because regional-specific agricultural literature is limited and requires multiple sources to be pieced together to evaluate the likelihood and confidence of changes in agriculture, and because recreation and tourism literature was limited to case studies often focused on extreme climate events that could increase with climate change. The authors assigned a *likely* estimate with *high confidence* to the statement that energy-sector livelihoods would be affected by shifts away from fossil fuel sources driven by emissions-reductions policies; this is because the coal industry has declined undeniably due to market competition, air-quality regulations, non-regulatory decisions made by public and private power utilities, and state and federal climate rules and renewable energy investments. Demand for oil and gas remains stable. The authors assigned a *likely* estimate and *medium confidence* to the statement that climate change will test the adaptive resilience of the region's socially vulnerable residents. This statement is assigned that particular likelihood and confidence because of instances in which recent extreme events have set back rural, Indigenous, and low-income communities, although there is a lack of extensive documentation or literature addressing this risk.

Key Message 25.4

Climate Response Involves Navigating Complex Trade-Offs and Tensions

Description of Evidence Base

The evidence that climate change is creating new and exacerbating existing tensions and trade-offs relies heavily on peer-reviewed literature cited throughout the chapter. There is increasing evidence and examples of how climate change is impacting, and will continue to impact, human communities and natural resources in the Northern Great Plains in complex and interacting ways.[167,219] The region is expected to see higher temperatures, a longer growing season, and shifts in water availability (KM 25.1) that will have impacts on livelihoods, land use, and water quantity and quality (KM 25.3). Climate change may also impact regional demographics over time, driving population growth of urban and amenity communities[9] and the continuing depopulation of rural communities.[5]

The evidence in the peer-reviewed literature indicates that when these impacts are combined, adaptation and mitigation decisions will result in benefits to some individuals and communities and have negative impacts for others. For example, as climate change alters the productivity of existing farmland, some producers are choosing to adapt by planting biofuel energy crops, such as switchgrass (Figure 25.10).[214] The peer-reviewed evidence identifies many benefits for such an action, including sequestration of carbon from the atmosphere,[215,216] sales that exceed current income,[217] and enhanced soil health and resilience to drought.[218] However, peer-reviewed evidence also indicates that some communities may experience negative impacts, such as the disruption of food production processes, reduced biodiversity, and water competition.[219] Evidence for how decision-makers are navigating these trade-offs is emergent and highly dependent on local context.

Evidence has been well established in the peer-reviewed literature that individual and community knowledge and culture determines how climate change is experienced and managed (KM 20.2). Within this region, the acceptance of human-caused climate change is lower than the national average.[188,189] In a recent nationwide assessment,[187] several states in the region (Wyoming, Colorado, and North Dakota) had curricula that supported the notion that climate change is real and human-caused and can be mitigated, despite reliance on fossil fuel. Lower-scoring states (Montana and Nebraska) failed to link human activities to climate change or stated that climate change is controversial and that educating students about climate change should be the responsibility of parents (South Dakota). As a result of low acceptance and varied educational efforts, discourse in the region focuses on the adaptation and resilience effects of climate action rather than the mitigation effects (KM 25.5). These factors provide evidence of the complicated and shifting landscape for decision-making.

Peer-reviewed demographic and economic literature describes how the regional economy is reliant on agriculture and resource-based sectors (KM 25.3), so adaptation conversations have focused on land-use shifts to alternative crops (Figure 25.10),[214] conversion to grasslands (Figure 25.9),[203,204] and changes in energy infrastructure.[165,205] Many factors complicate the ability of communities in the region to adapt to climate change, but recent peer-reviewed data and literature highlight the high degree of rurality (Figure 25.1) and low capacity to compete for and utilize federal funds (Box 25.1) as particularly inhibiting.

Major Uncertainties and Research Gaps

Major uncertainties surround the choices that decision-makers and communities will make regarding the management and allocation of resources within the region and the impacts of those choices. There are additional gaps in understanding. For example, increased renewable energy in the region will impact labor opportunities in the region, but little is known on the labor effects of increased renewable energy. Estimates on land area that is required by different energy resources (e.g., wind versus oil) to produce similar amounts of energy are variable. Planning for minimizing grassland fragmentation while developing renewable resources with larger footprints could benefit from more accurate estimates.

Description of Confidence and Likelihood

Likelihood and confidence statements are based on literature cited in the narrative text, observational data, and collective subject-matter expertise. Confidence for the statement that climate change is leading to decisions that are expected to benefit some and set back others (*very high confidence*) was assigned based on the strong evidence of positive and negative effects of land-use change between agriculture, grassland, and energy in response to changes in climate (e.g., possible negative effects of large-scale conversion to biofuels).[219] Confidence for the statement that decision-makers are navigating a complicated landscape of shifting demographics, policy and regulatory tensions, and barriers to action (*high confidence*) was assigned based on the evidence of policy and decision-making around trade-offs in energy investment and infrastructure development (e.g., state legislation compelling, easing, or resisting energy transition),[167] although it's unclear how widespread such action is. Likelihood was not assigned to these two statements, as the uncertainty associated with human decision- and policymaking is difficult to quantify and is context dependent. For the statement that changes in temperature and precipitation averages, extremes, and seasonality will alter the productivity of working lands, resulting in land-use shifts to alternative crops or conversion to grasslands (*likely*, *medium confidence*), confidence and likelihood were assigned based on evidence of benefits from pilot actions in the region (Figure 25.10), although the scalability of these actions to large geographies is still an area of study. For the statement that shifts in energy demand, production, and policy will change land-use needs for energy infrastructure (*likely*, *medium confidence*), confidence and likelihood were assigned based on evidence from the literature regarding the transition away from fossil fuel energy systems and its impact on abandonment of infrastructure[165,205] and possible fragmentation of existing grasslands due to new infrastructure.[159]

Key Message 25.5

Communities Are Building the Capacity to Adapt and Transform

Description of Evidence Base

Recent peer-reviewed literature provided the evidence base for adaptation actions being taken around soil health practices in the Northern Great Plains.[245,247] This literature has expanded significantly in recent years; the cited literature describes not only scientific understanding of soil changes and its related adaptive benefits but also research on farmer knowledge networks specific to this region. The evidence base for drought planning also draws from recent peer-reviewed literature and is growing.[261,262] The evidence base for diversification of grass-based livelihoods draws on a more limited peer-reviewed literature base and is more case specific.[217,246] Recent reports and planning efforts provide the evidence base for the newly implemented flood monitoring system in the upper Missouri River basin.[268,269] Reports, planning documents, limited peer-reviewed literature, and conversations with Tribal members provided the evidence for adaptation actions and challenges in rural and Indigenous communities.[271,272,273] A rapidly growing body of peer-reviewed literature provided the evidence for recent advances in ecosystem-based adaptation and scenario planning in the region (Ch. 8).[283,284]

Major Uncertainties and Research Gaps

Given the already high degree of climatic variability in the region and uncertainty in predicting future conditions, climate adaptation planning is a challenge. Despite these challenges, the evidence base shows that many climate adaptation actions are being tried across the region. In the process of implementing these adaptation actions, one of the major uncertainties is whether planned or implemented actions will ultimately be successful at helping communities or ecosystems adapt to climate change. There is a lack of research evaluating the success of climate adaptation actions, possibly due to insufficient time to judge success or a lack of robust monitoring and evaluation of outcomes. Furthermore, many climate adaptation actions are implemented in very context-dependent situations; therefore, it is uncertain how generalizable some adaptation actions or strategies may be.

Description of Confidence and Likelihood

It is difficult to quantify adaptation responses and to estimate their numerical variability. Therefore, the authors have not assigned any likelihood estimates to this Key Message. The authors assigned a *medium confidence* rating to the statement about adaptation actions in agricultural communities because there is evidence that a shift toward soil health and other adaptation practices is starting (e.g., Brown 2018;[245] Zilverberg et al. 2018[247]), but widespread adoption of these practices is not yet a reality. The authors assigned a *high confidence* rating to the third statement because there is good evidence that several Tribal Nations are leading efforts to incorporate Traditional Knowledge and governance into their adaptation plans (e.g., Blackfeet Nation 2018;[271] CSKT 2016;[272] Sicangu Climate Crisis Working Group 2022[273]). The statement about adaptation planning for natural resource managers is assigned a *medium confidence* rating because scenario planning is a well-developed tool and gaining traction in the National Park Service (e.g., Ch. 8),[283,284] but it is not yet being used widely outside of the National Park Service.

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