19. Great Plains

Convening Lead Authors
Dennis Ojima, Colorado State University
Mark Shafer, Oklahoma Climatological Survey

Lead Authors
John M. Antle, Oregon State University
Doug Kluck, National Oceanic and Atmospheric Administration
Renee A. McPherson, University of Oklahoma
Sascha Petersen, Adaptation International
Bridget Scanlon, University of Texas
Kathleen Sherman, Colorado State University

Key Messages

1. **Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.**
2. **Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events are already observed; as these trends continue, they will require new agriculture and livestock management practices.**
3. **Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.**
4. **Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.**
5. **The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.**

Introduction

The Great Plains is a diverse region where climate and water are woven into the fabric of life. Day-to-day, month-to-month, and year-to-year changes in the weather can be dramatic and challenging. The region experiences multiple climate and weather hazards, including floods, droughts, severe storms, tornadoes, hurricanes, and winter storms. In much of the Great Plains, too little precipitation falls to replace that needed by humans, plants, and animals. Climate variability already stresses communities and causes billions of dollars in damage; climate change will add to both stress and costs.

The people of the Great Plains historically have adapted to this challenging climate. Although trends and projections suggest more frequent and more intense droughts, severe rainfall events, and heat waves, communities and individuals can reduce vulnerabilities through the use of new technologies, community-driven policies, and the judicious use of resources. Adaptation (means of coping with changed conditions) and mitigation (reducing emissions of heat-trapping gases to reduce the speed and amount of climate change) choices can be locally driven, cost effective, and beneficial for local economies and ecosystem services.

Significant climate-related challenges are expected to involve: 1) resolving increasing competition among land, water, and energy resources; 2) developing and maintaining sustainable agricultural systems; 3) conserving vibrant and diverse ecological systems; and 4) enhancing the livelihoods of the region's people. These growing challenges will unfold against a changing backdrop that includes a growing urban population and declining rural population, new economic factors that drive incentives for crop and energy production, advances in technology, and shifting policies such as those related to farm and energy subsidies.

The Great Plains region features relatively flat plains that increase in elevation from sea level to more than 5,000 feet at the base of mountain ranges along the continental divide. Forested mountains cover western Montana and Wyoming, extensive rangelands spread throughout the Plains, marshes extend along Texas' Gulf Coast, and desert landscapes distinguish far west Texas (Omernik 1987). A highly diverse climate results from the region's large north-south extent and change of elevation. This regional diversity also means that climate change impacts will vary across the region.

Great Plains residents already must contend with weather challenges from winter storms, extreme heat and cold, severe thunderstorms, drought, and flood-producing rainfall. Texas' Gulf Coast averages about three tropical storms or hurricanes every four years (Roth 1997), generating coastal storm surge and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland.

Annual average temperatures range from less than 40ºF in the mountains of Wyoming and Montana to more than 70ºF in south Texas, with extremes ranging from –70ºF in Montana to 121ºF in North Dakota and Kansas (NCDC 2012). Summers are long and hot in the south; winters are long and often severe in the north. North Dakota's increase in annual average temperature is the fastest in the contiguous U.S and is mainly driven by warming winters.

Temperature and Precipitation Distribution in the Great Plains

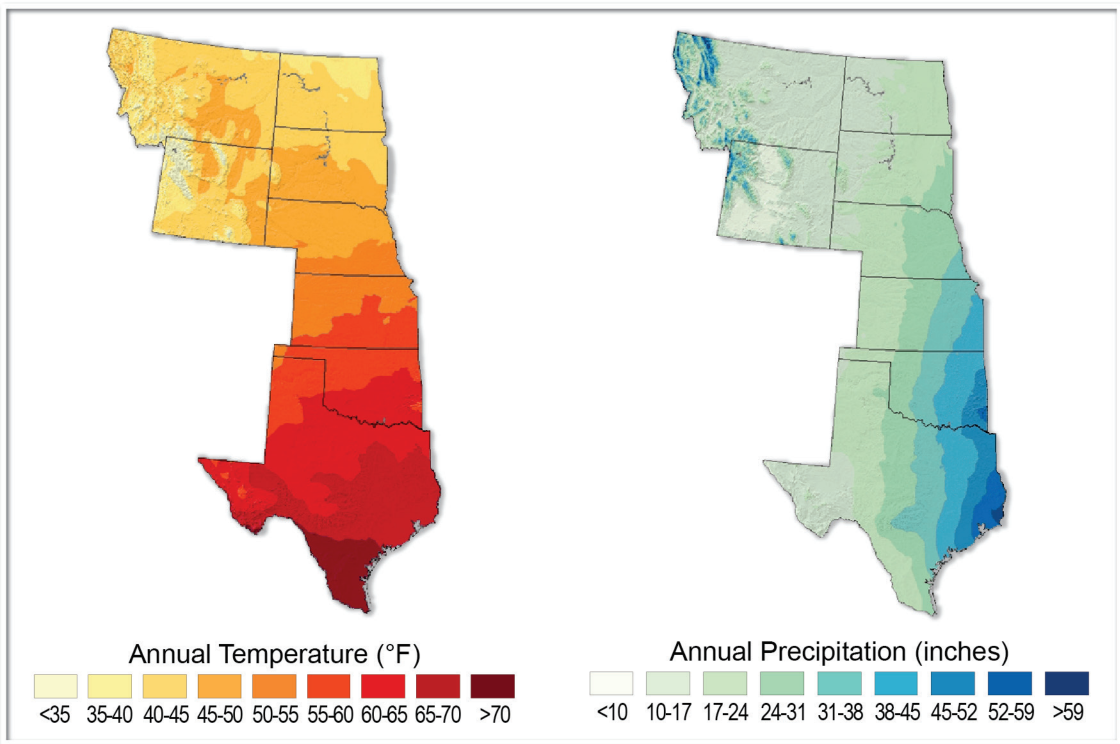

Figure 19.1: Temperature and Precipitation Distribution in the Great Plains

Caption: The region has a distinct north-south gradient in average temperature patterns, with a hotter south and colder north. For precipitation, the regional gradient runs east-west, with a wetter east and a much drier west. (Source: Kunkel et al. 2012b)

Average annual precipitation greater than 50 inches supports lush vegetation in eastern Texas and Oklahoma. For most places, however, average rainfall is less than 30 inches, with some of Montana, Wyoming, and far west Texas receiving less than 15 inches a year. Across much of the region, annual water loss from transpiration by plants and evaporation is higher than annual precipitation, making these areas particularly susceptible to droughts.

Projected Climate Change

For an average of 7 days per year, maximum temperatures reach more than 100ºF in the Southern Plains and about 95ºF in the Northern Plains. These high temperatures are projected to occur much more frequently, even under a scenario of substantial reductions in heat-trapping gas (also called greenhouse gas) emissions (B1), with days over 100ºF projected to double in number in the north and quadruple in the south by mid-century (Kunkel et al. 2012b; Ch. 2: Our Changing Climate; Key Message 7). Similar increases are expected in the number of days with minimum temperatures higher than 80ºF in the south and 60˚F in the north (cooler in mountain regions). These increases in extreme heat will have many negative consequences, including increases in surface water losses, heat stress days, and demand for air conditioning (Ojima et al. 2012). These negative consequences will more than offset the benefits of warmer winters, such as lower winter heating demand, less cold stress on humans and animals, and a longer growing season, which will be extended by an average of 24 days by mid-century (Kunkel et al. 2012b; Ojima et al. 2012; Ch. 2: Our Changing Climate, Key Message 4). More overwintering insect populations are also expected.

There is a projected trend toward increased precipitation in the north and decreased precipitation in the south by the end of this century under a scenario of continued high emissions (A2). In central areas, changes are projected to be small, though the precise location of this transition zone between wetter and drier conditions is not well known, as precipitation projections are less certain than for those for temperature (Kunkel et al. 2012b). The number of days with heavy precipitation (at least one inch) is expected to increase by mid-century, especially in the north. Days with little or no precipitation will also be less common in the north, with projections of up to 5 fewer such days. By contrast, large parts of Texas and Oklahoma are projected to see more days with no precipitation (up to 5 more days with little or no precipitation) in the same timeframe (Kunkel et al. 2012b; Ch. 2: Our Changing Climate; Key Messages 5 & 6).

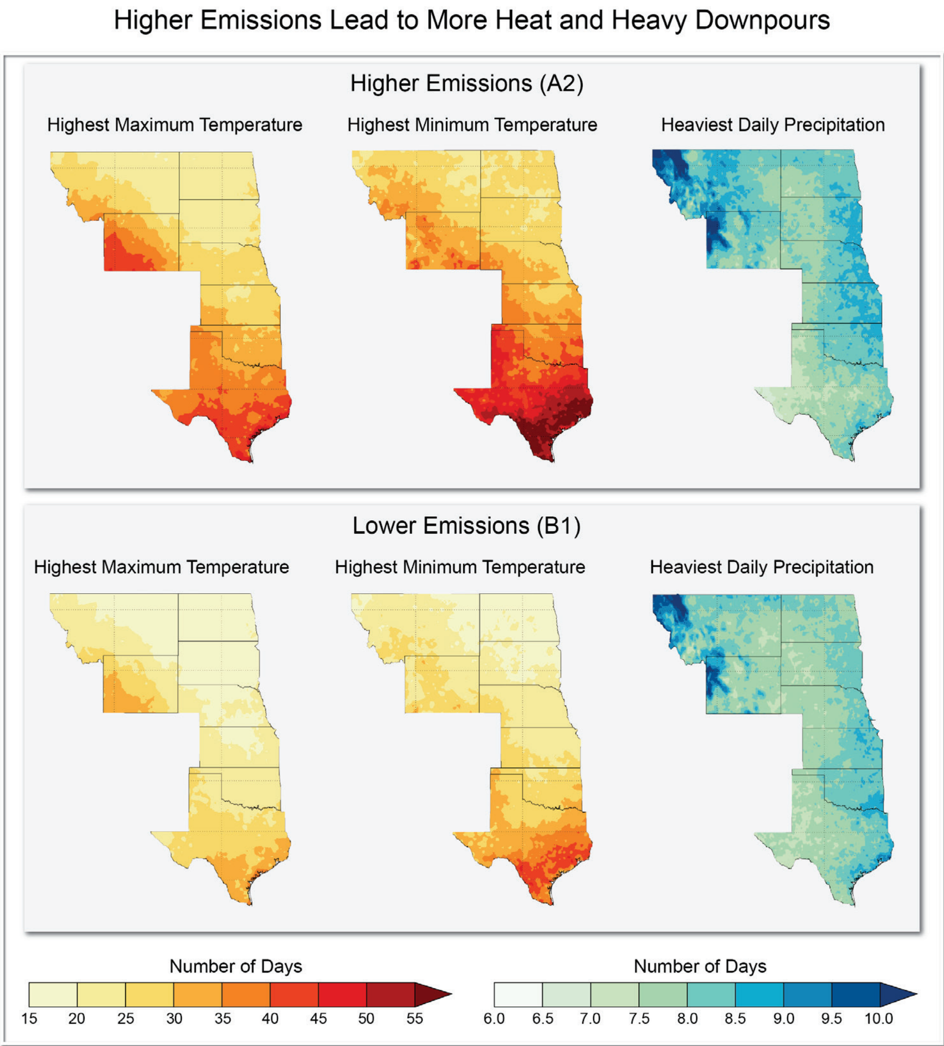

Figure 19.2: Higher Emissions Lead to More Heat and Heavy Downpours

Caption: Maps show projections (for 2041-2070) of the number of days in which highest maximum temperature (left), highest minimum temperature (middle), and heaviest daily precipitation (right) is projected to exceed what was observed between 1971 and 2000 on just 2% of the days in each year, which is about 7 days per year. The top three maps show projected changes if emissions of heat-trapping gases continue to rise (higher emissions, A2), and the bottom three maps show projections with substantial reductions in emissions (lower emissions, B1). (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Multi-model Mean.)

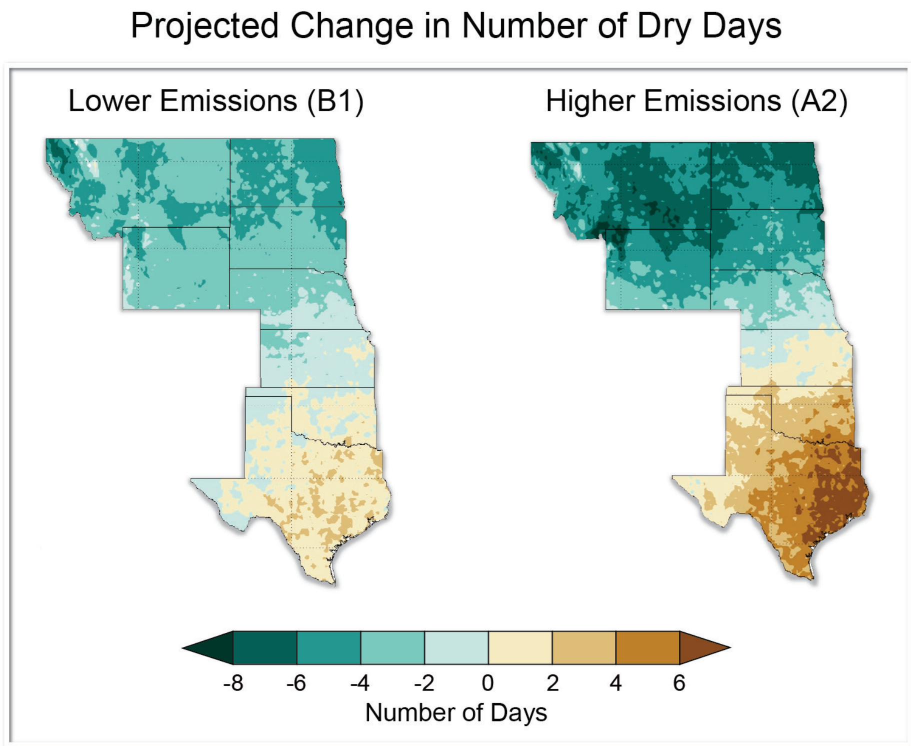

Figure 19.3: Projected Change in the Number of Dry Days, 2071-2099

Caption: Current regional trends of a drier south and a wetter north are projected to become more pronounced, compared to observed 1971 to 2000 averages. Maps show projected changes in the number of days with less than 0.1 inches of precipitation, assuming substantial reductions in emissions (lower emissions, B1) and if emissions continue to rise (higher emissions, A2). (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Multi-model mean.)

Water, Energy and Land Use

Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.

Water, energy, and land use are inherently interconnected (Barry 1983), and climate change is creating a new set of challenges for these critical sectors (Averyt et al. 2011; Ojima et al. 2002). The Great Plains is rich with energy resources, primarily from coal, oil, and natural gas, with growing wind and biofuel industries (Brekke 2009; Morgan et al. 2008). Texas produces 16% of U.S. energy (mostly from crude oil and natural gas), and Wyoming provides an additional 14% (mostly from coal). North Dakota is the second largest producer of oil in the Great Plains, behind Texas. Nebraska and South Dakota rank third and fifth in biofuel production, and 8 of the top 10 producers of wind energy are from the Great Plains, with Texas topping the list. More than 80% of the region's land area is used for agriculture, primarily cropland, pastures, and rangeland.

Other land uses include forests, urban and rural development, transportation, conservation, and industry.

Significant amounts of water are used to produce energy (Averyt et al. 2011; Foti et al. 2011) and to cool power plants (Barber 2009; Kenny et al. 2009). Electricity is consumed to collect, purify, and pump water. Although hydraulic fracturing to release oil and natural gas is a small component of total water use (Nicot and Scanlon 2012), it can be a significant proportion of water use in local and rural groundwater systems. Energy facilities, transmission lines, and wind turbines can fragment both natural habitats and agriculture lands (Ojima et al. 2002; Ch. 10: Water, Energy & Land).

The trend toward more dry days and higher temperatures across the south will increase evaporation, decrease water supplies, reduce electricity transmission capacity, and increase cooling demands. These changes will add stress to limited water resources and affect management choices related to irrigation, municipal use, and energy generation. In the Northern Plains, warmer winters will reduce heating demand, though hotter summers will increase demand for air conditioning, with the summer increase in demand outweighing the winter decrease (Ch. 4: Energy Supply and Use, Key Message 2).

Changing extremes in precipitation are projected across all seasons, including higher likelihoods of both increasing heavy rain and snow events and more droughts (Kunkel et al. 2012b). Increased runoff and flooding will reduce water quality and erode soils. Increased snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods, as is already common along the Red River of the North. More intense rains will contribute to urban flooding.

Increased drought frequency and intensity can turn marginal lands into deserts. Reduced per capita water storage will continue to increase vulnerability to water shortages (Texas Water Development Board 2012). Legal requirements mandating water allocations for ecosystems and endangered species add further competition for water resources.

Diminishing water supplies and rapid population growth are critical issues in Texas. Because reservoirs are limited and have high evaporation rates, San Antonio has turned to the Edwards Aquifer as a major source of groundwater storage. Nineteen water districts joined to form a Regional Water Alliance for sustainable water development through 2060. The alliance creates a competitive market for buying and selling water rights and simplifies transfer of water rights.

Sustaining Agriculture

Changes to agricultural production systems due to warming winters and changes in the timing and magnitude of rainfall events are already observed; as these trends continue, they will require new agriculture and livestock management practices

The important agricultural sector in the Great Plains, with a total market value of about $92 billion (split almost equally between crops, at 43%, and livestock, at 46%) (USDA 2012), already contends with significant climate variability (Ch 6: Agriculture). Projected changes in climate, and human responses to it, will affect aspects of the region's agriculture, from the many crops that rely solely on rainfall, to the water and land required for increased energy production from plants, such as fuels made from corn or switchgrass (see Ch. 10: Water, Energy, and Land Use).

Water is central to the region's productivity. The High Plains Aquifer, including the Ogallala, is a primary source for irrigation (Maupin and Barber 2005). In the Northern Plains, rain recharges this aquifer quickly, but little recharge occurs in the Southern Plains.

Projected increases in precipitation in the Northern Plains will benefit agricultural productivity by increasing water availability and reducing reliance on irrigation. Rising temperatures will lengthen the growing season, possibly allowing a second annual crop in some places. But warmer winters also pose challenges (Dunnell and Travers 2011; Hu et al. 2005; Wu et al. 2012). Some pests and invasive weeds will be able to survive the warmer winters (Nardone et al. 2010; Van Dijk et al. 2010). Winter crops that leave dormancy earlier are susceptible to spring freezes (NOAA and USDA 2008). Rainfall events already have become more intense (Groisman et al. 2004), increasing erosion and nutrient runoff, and projections are that the frequency and severity of these heavy rainfall events will increase (Karl 2009; NOAA and USDA 2008).

In the Southern Plains, projected declines in precipitation and greater evaporation due to higher temperatures will increase irrigation demand and exacerbate current stresses on agricultural productivity. Increased water withdrawals from the High Plains Aquifer would accelerate depletion of the aquifer and limit the ability to irrigate (Konikow 2011; Scanlon et al. 2010). Shifting from irrigated to dryland agriculture would reduce crop yields by about a factor of two (Colaizzi et al. 2009).

The projected increase in high temperature extremes and heat waves will negatively affect livestock and concentrated animal feeding operations (Hahn et al. 2009; Mader et al. 2009). Shortened dormancy periods for winter wheat will lessen an important source of feed for the livestock industry. Climate change may thus result in a northward shift of crop and livestock production in the region. In areas projected to be hotter and drier in the future, maintaining agriculture on marginal lands may become too costly.

Adding to climate change related stresses, growing water demands from large urban areas are also placing stresses on limited water supplies. Options considered in some areas include groundwater development and purchasing water rights from agricultural areas for transfer to cities (Grafton et al. 2011).

During the drought of 2011 and 2012, ranchers liquidated large herds due to lack of food and water. Many cattle were sold to slaughterhouses; others were relocated to other pastures through sale or lease. As herds are being rebuilt, there is an opportunity to improve genetic stock, as those least adapted to the drought conditions were the first to be sold or relocated. Some ranchers also used the drought as an opportunity to diversify their portfolio, managing herds in both Texas and Montana.

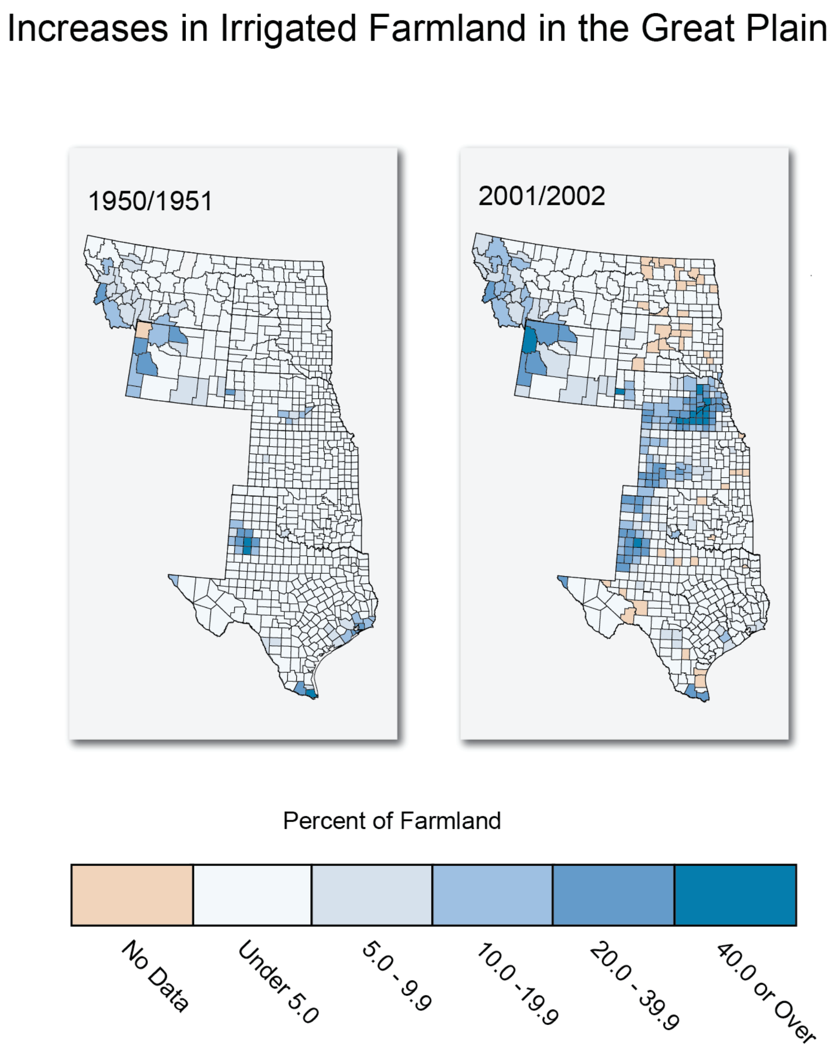

Figure 19.4: Increases in Irrigated Farmland in the Great Plains

Caption: Irrigation in western Kansas, Oklahoma, and Texas supports crop development in semi-arid areas. Declining aquifer levels threaten the ability to maintain production. Some aquifer-dependent regions, like south-eastern Nebraska, have seen steep rises in irrigated farmland, from around 5% to more than 40%, during the period shown. (Source: Atlas of the Great Plains 2011).

Conservation and Adaptation

Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.

Development of lands for energy production, land transformations on the fringes of urban areas, and economic pressures to remove lands from conservation easements pose threats to natural systems in the Great Plains. Habitat fragmentation is already a serious issue that inhibits the ability of species to migrate as climate variability and change alter local habitats (Becker et al. 2007; Gray et al. 2004). Lands that do remain out of production are susceptible to invasion from non-native plant species.

Many plant and animal species are responding to rising temperatures by shifting their distributions at increasingly greater rates (Chen et al. 2011; Parmesan 2007). The historic bison herds migrated to adapt to climate, disturbance, and associated habitat variability (Samson et al. 2004), but modern land-use patterns, roads, agriculture, and structures inhibit similar large-scale migration (H. John Heinz III Center for Science Energy and the Environment 2008; Kostyack et al. 2011). In the Southern Plains, agriculture practices have modified more than 70% of seasonal lakes larger than 10 acres (Guthery and Bryant 1982; Matthews 2008), affecting bird populations (Peterson 2003) and fish populations in the region (Poff et al. 2002; Snodgrass et al. 2001).

Observed climate-induced changes have been linked to changing timing of flowering, increases in wildfire activity and pest outbreaks, shifts in species distributions, declines in the abundance of native species, and the spread of invasive species (Ch 8: Ecosystems & Biodiversity). From Texas to Montana, altered flowering patterns because of more frost-free days have increased the length of pollen season for ragweed by as many as 16 days (Ziska 2011). Earlier snowmelt in Wyoming (Hendricks 2003) has been related to the American pipit songbird laying eggs about 5 days earlier. During the past 70 years, observations indicate that winter wheat is flowering 6 to 10 days earlier as spring temperatures have risen (Hu et al. 2005). Some species may be less sensitive to changes in temperature and precipitation, causing first flowering dates to change for some species but not for others (Dunnell and Travers 2011). Even small shifts in timing, however, can disrupt the integrated balance of ecosystem functions like predator-prey relationships, mating behavior, or food availability for migrating birds.

Box: Climate and Conservation

The interaction of climate and land-use changes across the Great Plains promises to be challenging and contentious. Opportunities for conservation of native grasslands, including species and processes, depend primarily and most immediately on managing a fragmented network of untilled prairie. Restoration of natural processes, conservation of remnant species and habitats, and consolidation/connection of fragmented areas will facilitate conservation of species and ecosystem services across the Great Plains. However, climate change will complicate current conservation efforts as land fragmentation continues to reduce habitat connectivity, as seen in this example of sage grouse habitat.

Energy-releated Habitat Fragmentation and Sage Grouse Decline

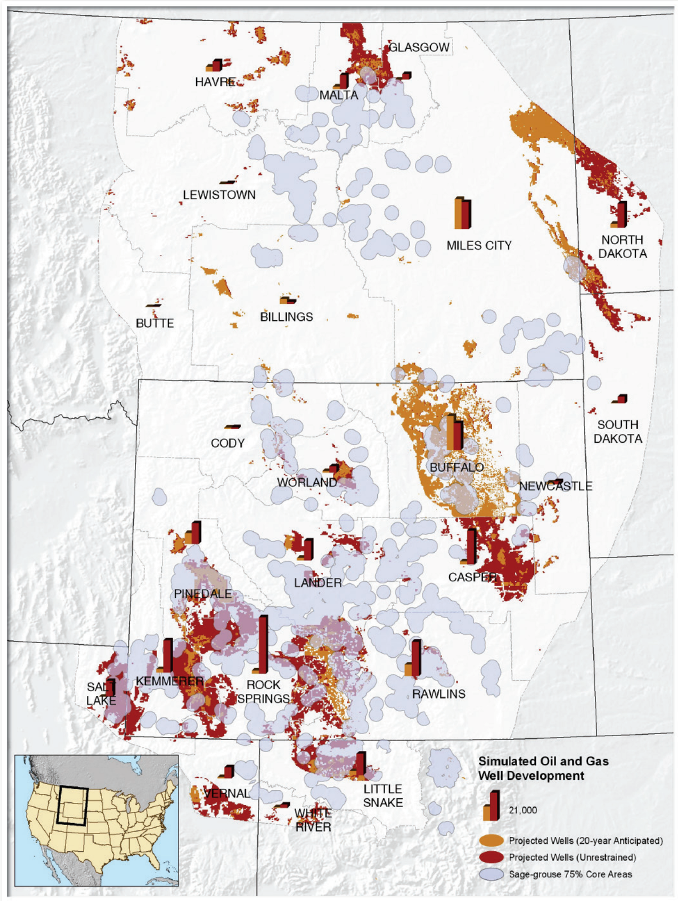

Figure 19.5: Energy-related Habitat Fragmentation and Sage Grouse Decline

Caption: Habitat fragmentation inhibits the ability of species such as Sage Grouse to migrate in response to climate change. Map illustrates the location and extent of expected future oil and gas development in two projected build-out cases. The first utilizes 20-year development projections from the federal Bureau of Land Management, which issues permits for energy development on these lands (orange), and the second assumes unrestrained growth in oil and gas development (red). Blue areas indicate core sage grouse habitat (Doherty 2008) to highlight expected areas of future conflict. Analysis suggests a 7% to 19% population decline in sage grouse populations depending on the build-out scenario. The Greater Sage Grouse is a candidate for Endangered Species Act protections, and its habitat is associated with other species' health as well. (Copeland et al. 2009)

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The complicated mix of species range shifts, changing plant cycles, and other climate-related effects make it difficult to project all of the interactions among the vegetative species of the

Great Plains. In general, plants will benefit from higher temperatures, carbon dioxide enrichment, and increases in precipitation, but those benefits will be limited by availability of water in the soil and other factors. The net effect of this set of factors on natural areas of the region is still difficult to project. However, the implementation of ecosystem adaptive management approaches provides robust options for multiple situations.

Vulnerable Communities

Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.

The Great Plains is home to a geographically, economically, and culturally diverse population. For rural and tribal communities, their remote locations, sparse development, limited local services, and language barriers present greater challenges in responding to climate extremes. Working-age people are moving to urban areas, leaving a growing percentage of elderly people in rural communities (See also Ch. 13: Rural Communities).

Overall population throughout the region is stable or declining, with the exception of substantial increases in urban Texas and in tribal communities (Parton et al. 2007). Growing urban areas require more water, expand into forests and cropland, fragment habitat, and are at a greater risk of wildfire – all factors that interplay with climate.

Populations such as the elderly, low-income, and non-native English speakers face heightened climate vulnerability. Public health resources, basic infrastructure, adequate housing, and effective communication systems are often lacking in communities that are geographically, politically, and economically isolated (Singer 2009). Elderly people are more vulnerable to extreme heat, especially in warmer cities and communities with minimal air conditioning or sub-standard housing (Longstreth 1999). Language barriers for Hispanics may impede their ability to plan for, adapt to, and respond to climate-related risks (Johnson and Lichter 2008; Kandel and Parrado 2005; Vazquez-Leon 2009).

The 70 federally recognized tribes in the Great Plains are diverse in their land use, with some located on lands reserved from their traditional homelands, and others residing within territories designated for their relocation, as in Oklahoma. While tribal communities have adapted to climate change for centuries, they are now constrained by physical and political boundaries (Therrell and Trotter 2011; Tsosie 2007). Traditional ecosystems and native resources no longer provide the support they used to (Cook 2008; Tsosie 2009). Tribal members have reported the decline or disappearance of culturally important animal species like bison, changes in the timing of cultural ceremonies due to earlier onset of spring, and the inability to locate certain types of ceremonial wild plants (Riley 2011; Ch. 12: Tribal Lands & Resources).

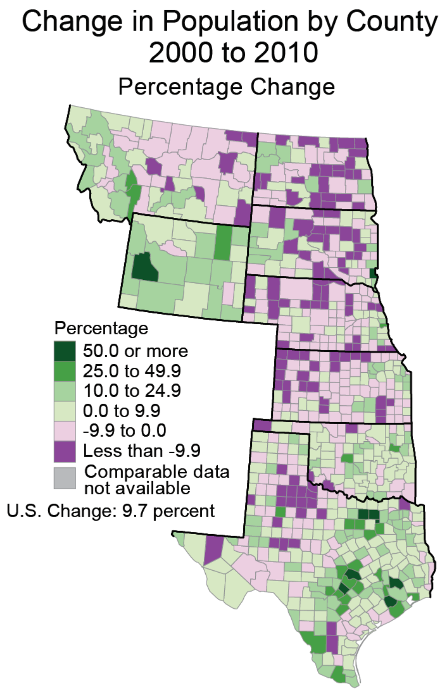

Figure 19.6: Population Change in the Great Plains, 2000-2010.

Caption: Demographic shifts continue to reshape communities in the Great Plains, with many central Great Plains communities losing residents. Rural and tribal communities will face additional challenges in dealing with climate change impacts due to demographic changes in the region. Green areas are increasing in population, while purple areas are decreasing in population. (U.S. Census Bureau 2010b)

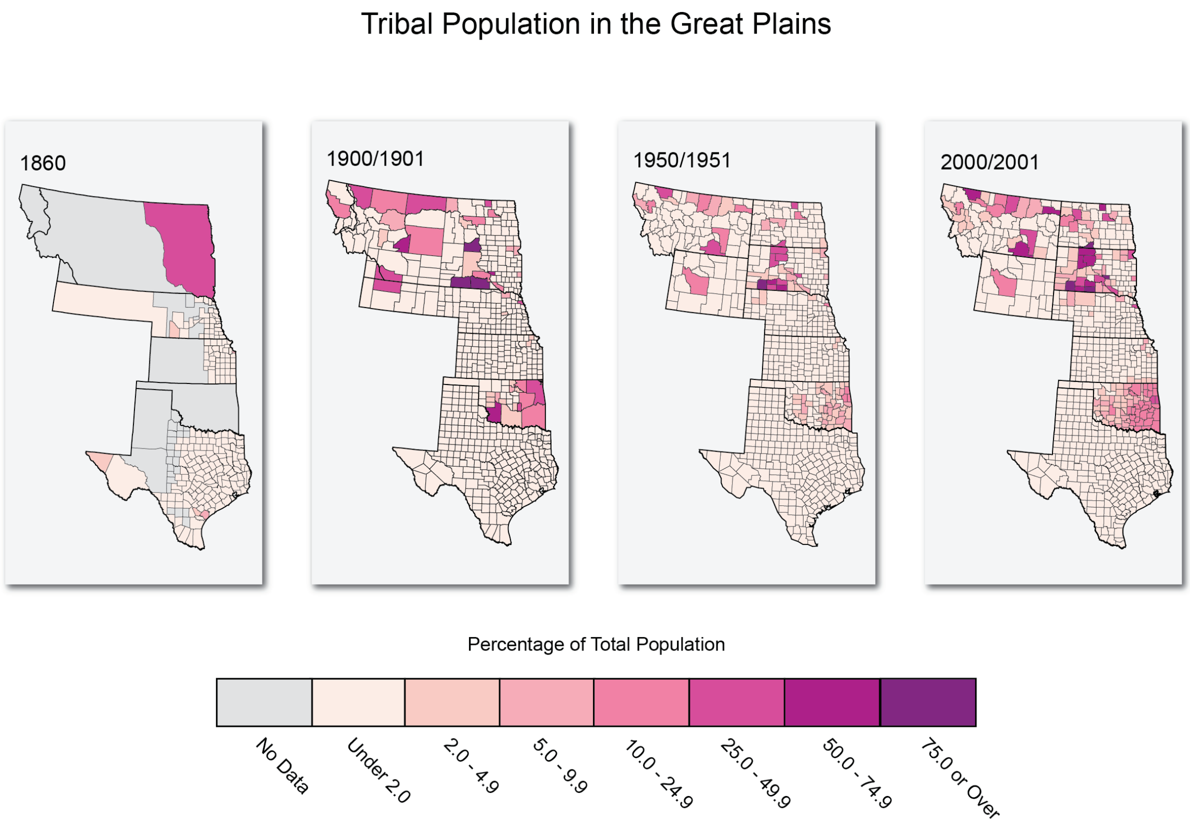

Figure 19.7: Tribal Population in the Great Plains

Caption: Tribal population in the Great Plains is concentrated near large reservations, like the Hopi and Navajo lands in Northern New Mexico; Cherokee, Chickasaw, Choctaw, and other tribal lands in Oklahoma; various Sioux tribes in South Dakota; and Blackfeet and Crow reservations in Montana. (Source: Atlas of the Great Plains2011)

Box: Oglala Lakota Respond to Climate Change

The Oglala Lakota tribe in South Dakota is incorporating climate change adaptation and mitigation planning as they consider long-term sustainable development planning. Their *Oyate Omniciye* plan is a partnership built around six livability principles related to transportation, housing, economic competitiveness, existing communities, federal investments, and local values. Interwoven with this is a vision that incorporates plans to reduce future climate change and adapt to future climate change, while protecting cultural resources (Oyate Omniciye 2011).

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Opportunities to Build Resilience

The magnitude of expected changes will exceed those previously experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

The Great Plains is an integrated system. Changes in one part, whether driven by climate or by human decisions, affect other parts. Some of these changes are already underway, and many pieces of independent evidence project that ongoing climate-related changes will ripple throughout the region.

Many of these challenges will cut across sectors: water, land use, agriculture, energy, conservation, and livelihoods. Competition for water resources will increase within already-stressed human and ecological systems, particularly in the Southern Plains, affecting crops, energy production, and how well people, animals, and plants can thrive. The region's ecosystems, economies, and communities will be further strained by increasing intensity and frequency of floods, droughts, and heat waves that will penetrate into the lives and livelihoods of Great Plains residents. Although some communities and states have made efforts to plan for these projected changes, the magnitude of the adaptation and planning efforts do not match the magnitude of the expected changes.

Successful adaptation of human and natural systems to climate change will require:

- recognition and commitment to addressing these challenges;
- regional-scale planning and local-to-regional implementation (Adger et al. 2011; Joyce et al. 2009; Ojima et al. 2002);
- renewed emphasis on restoration of ecological systems and processes (Eriksen and Brown 2011a; Eriksen 2011b; Eriksen and O'Brien 2007; McNeeley 2011; O'Brien and Leichenko 2008);
- recognition of the value of natural systems to sustaining life (Berkes and Folke 1998; Gunderson and Holling 2002; Tschakert et al. 2007; Walker and Meyers 2004);
- sharing information between decision-makers; and
- enhanced alignment of social and ecological goals (Lyytimäki and Hildén 2007).

Communities already face tradeoffs in efforts to make efficient and sustainable use of their resources. Jobs, infrastructure, and tax dollars that come with fossil fuel extraction or renewable energy production are important, especially for rural communities. There is also economic value in the conversion of native grasslands to agriculture. Yet the tradeoffs between this development, the increased pressure on water resources, and the effects on conservation need to be considered if the region is to develop climate-resilient communities.

Untilled prairies used for livestock grazing provide excellent targets for native grassland conservation. Partnerships among many different tribal, federal, state, local, and private landowners can decrease landscape fragmentation and help manage the connection between agriculture and native habitats. Soil and wetland restoration enhances soil stability and health, water conservation, aquifer recharge, and food sources for wildlife and cattle. Healthy species and ecosystem services support social and economic systems where local products, tourism, and culturally significant species accompany large-scale agriculture, industry, and international trade as fundamental components of society.

There is tremendous adaptive potential among the diverse communities of the Great Plains. Positive steps toward greater community resilience have been achieved through local and regional collaboration and increased two-way communication between scientists and local decision-makers. Climate-related challenges can be addressed with creative local engagement and prudent use of community assets (Ostrom 1990). These assets include social networks, social capital, indigenous and local knowledge, and informal institutions.

Box: The Summer of 2011

Future climate change projections include more precipitation in the northern Great Plains and less in the southern Great Plains. In 2011, such a pattern was strongly manifest, with exceptional drought and recording-setting temperatures in Texas and Oklahoma and flooding in the northern Great Plains. Many locations in Texas and Oklahoma experienced more than 100 days over 100ºF. Both states set new records for the hottest summer since record keeping began in 1895. Rates of water loss were double the long-term average. The heat and drought depleted water resources and contributed to more than $10 billion in direct losses to agriculture alone. The community of Spicewood, Texas ran dry.

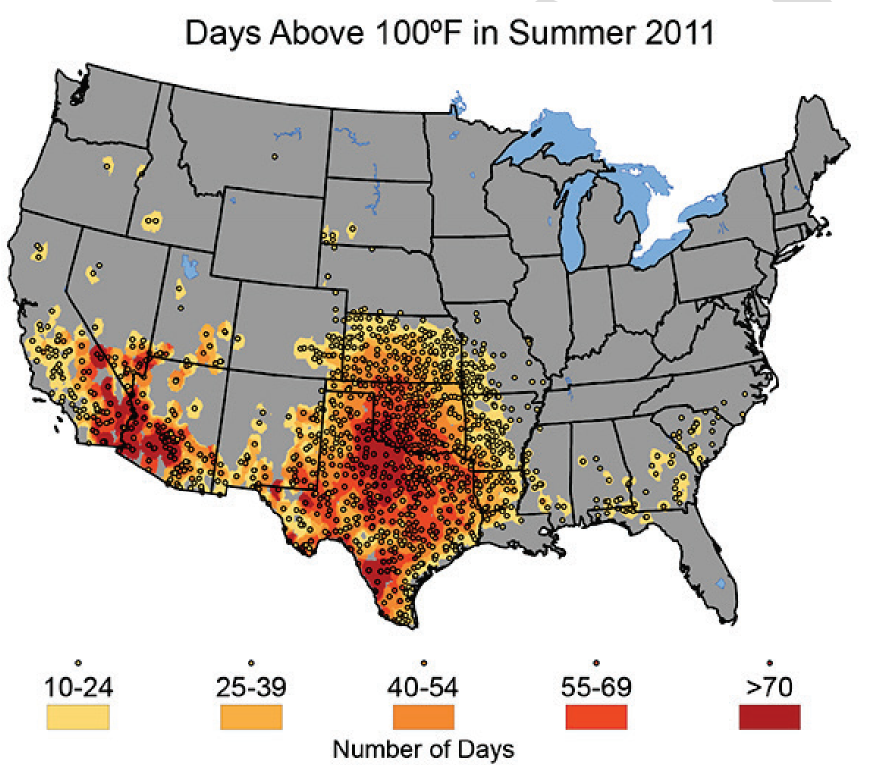

Figure 19.8: Days Above 100ºF in Summer 2011

Caption: In 2011, cities including Houston, Dallas, Austin, Oklahoma City, and Wichita, among others, all set records for the highest number of days recording temperatures of 100ºF or higher in those cities' recorded history. The black circles denote the location of observing stations used in the analysis (those recording 100ºF days) (Source: NCDC 2012)

By contrast, the Northern Plains were exceptionally wet, with Montana and Wyoming recording all-time wettest springs and the Dakotas and Nebraska not far behind. Record rainfall and snowmelt combined to push the Missouri River beyond its banks and leave much of the Crow Reservation in Montana underwater. The Souris River near Minot, North Dakota crested at four feet above its previous record, with a flow five times greater than any in the past 30 years. Losses from the flooding were estimated at $2 billion.

Although there is large natural variability, these recent temperature extremes were attributable in part to human-induced climate change (approximately 20% of the heat wave magnitude and a doubling of the chance that it would occur)(Hoerling et al. 2012a). In the future, average temperatures in this region are expected to increase (Ch. 2: Our Changing Climate, Key Message 8) and will continue to contribute to the intensity of heat waves.

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Traceable Accounts

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Key Message Process: A central component of the assessment process was the Great Plains Regional Climate assessment workshop that was held in August, 2011 in Denver, CO with approximately 40 attendees; it began the process leading to a foundational TIR report, the Great Plains Regional Climate Assessment Technical Report (Ojima et al. 2012). The report consists of 18 chapters assembled by 37 authors representing a wide range of inputs including governmental agencies, NGOs, tribes and other entities.

The chapter author team engaged in multiple technical discussions via regular teleconferences. These included careful review of the foundational TIR (Ojima et al. 2002) and of approximately 50 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. These discussions were followed by expert deliberation of draft key messages by the authors during an in-person meeting in Kansas City in April 2012 wherein each message was defended before the entire author team before this key message was selected for inclusion in the Report; these discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define “key vulnerabilities”.

Key message #1/5	**Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Technical Input (Ojima et al. 2012). Technical Input reports (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Evidence for rising temperatures across the U.S. are discussed in Ch. 2: Our Changing Climate, Key message 4 and its Traceable Accounts. Specific details for the Great Plains are detailed in the NCA Climate Trends and Outlooks (Kunkel et al. 2012b) references. The impact of rising temperatures on energy and water is also explored in depth in Ch.10: Water, Energy, and Land, as well as Ch. 4: Energy Supply and Use. Cited publications have explored the projected increase in water competition and stress for natural resources (Averyt et al. 2011; Barber 2009; Kenny et al. 2009; Nicot and Scanlon 2012; Texas Water Development Board 2012) and the fragmentation of natural habitats and agricultural lands (Ojima et al. 2002), providing numerous references that were drawn from to lead to this conclusion.
New information and remaining uncertainties	A key uncertainty is the exact rate and magnitude of the projected changes in precipitation since high inter-annual variability may either obscure or highlight the long-term trends over the next few years. Also unknown is ecological demand for water. Water use by native and invasive species under current climate needs to be quantified so that it can be modeled under future scenarios to map out potential impact envelopes. There is also uncertainty over the projections of changes to precipitation due to model’s difficulty with projections of convective precipitation, which is the primary source of water for most of the Great Plains.
Assessment of confidence based on evidence	**Very High** for all aspects of the key message. The relationship between increased temperatures and higher evapotranspiration is well-established. Model projections of higher temperatures are robust. Confidence is highest for the Southern Plains where competition between sectors, cities and states for future supply is already readily apparent and where population growth (demand-side) and projected

	increases in precipitation deficits is greatest.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #2/5	**Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events are already observed; as these trends continue they will require new agriculture and livestock management practices.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Great Plains Technical Input (Ojima et al. 2012). Technical Input reports (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Evidence for altered precipitation across the U.S. are discussed in Ch. 2: Our Changing Climate, Key message 5 & 6 and its Traceable Accounts. Specific details for the Great Plains, such as warming winters and altered rainfall events are detailed in the NCA Climate Trends and Outlooks (Kunkel et al. 2012b) with its references. Limitations of irrigation options in the High Plains aquifer are detailed in Scanlon et al. (2010). The impacts of shifting from irrigated to rain-fed agriculture are detailed in Colaizzi et al.(2009).
New information and remaining uncertainties	A key issue (uncertainty) is rainfall patterns. Although models show a general increase in the northern plains and a decrease in the southern plains, the diffuse gradient between the two leaves the location of greatest impacts on the hydrologic cycle uncertain. Timing of precipitation is critical to crop planting, development and harvesting; shifts in seasonality of precipitation need to be quantified.
Assessment of confidence based on evidence	The general pattern of precipitation changes and overall increases in temperature are robust. However, trying to assess changes in more specific locations is more uncertain, but the implications of these changes are enormous. Our assessment of high is based on the projections and known relationships to crops (e.g. corn not being able to 'rest' at night due to high minimum temperatures), but pinpointing where these will occur is difficult. Additionally, other factors that influence productivity, such as genetics, technological change, economic incentives, and federal and state policies, can alter or accelerate the impacts, which leads to an overall confidence of **high**.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #3/5	**Landscape fragmentation is increasing, for example, in the context of energy development activities. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Great Plains Technical Input (Ojima et al. 2012). Technical Input reports (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. A number of publications have explored the change in habitat composition (Guthery and Bryant 1982), plant distribution and development cycles (Dunnell and Travers 2011; Hu et al. 2005; Ziska 2011) and animal distributions (Chen et al. 2011; H. John Heinz III Center for Science Energy and the Environment 2008; Hendricks 2003; Kostyack et al. 2011; Parmesan 2007).
New information and remaining uncertainties	In general, the anticipated carbon dioxide enrichment, warming, and increase in precipitation variability influence vegetation primarily by affecting soil-water availability to plants, especially given the current east-to-west difference in precipitation and the vegetation it supports. These effects are evident in experiments with each of the individual aspects of climate change. It is difficult to project, however, all of the interactions with all of the vegetative species of the Great Plains so as to better manage ecosystems. Several native species have been in decline due to habitat fragmentation, including quail, ocelots and lesser prairie chickens. Traditional adaptation methods of migration common to the Great Plains, such as bison herds had historically done, are less of an option as animals are confined to particular locations. As the content of habitats change due to invasive species of plant and animals and viability of native vegetation as climate changes, the current landscapes may be incapable of supporting these populations.
Assessment of confidence based on evidence	**High**. The effects of carbon dioxide and water availability are well known on individual species, but less published research exists on the interaction between different species.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #4/5	**Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Technical Input (Ojima et al. 2012). Technical Input reports (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Extreme events are documented in Key Message 7 from the "Our Changing Climate" chapter (Ch. 2) for the Nation, and in Kunkel et al. (2012b) for specific outlooks and trends for this region. There are a few studies documenting the vulnerability of communities in remote locations with sparse infrastructure, limited local services, and aging population (Singer 2009) with some areas inhibited by language barriers (Johnson and Lichter 2008; Kandel and Parrado 2005; Vazquez-Leon 2009). Changes in the tribal communities have been documented on a number of issues (Cook 2008; Oyate Omniciye 2011; Riley 2011; Therrell and Trotter 2011; Tsosie 2007, 2009).
New information and remaining uncertainties	A key issue (uncertainty) is how limited financial resources will be dedicated to adaptation actions and the amount of will and attention that will be paid to decreasing vulnerability and increasing resilience throughout the region. Should the awareness of damage grow great enough, it may overcome the economic incentives for development and change perspectives allowing for increased adaptive response but if current trends continue more vulnerable lands may be lost; thus the outcome on rural and vulnerable populations is largely unknown.
Assessment of confidence based on evidence	**High**. Extensive literature exists on vulnerable populations, limited resources and ability to respond to change. Because the expected magnitude of changes is beyond previous experience, societal response is unknown.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #5/5	**The magnitude of expected changes will exceed those previously experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the Great Plains Technical Input (Ojima et al. 2012). Technical Input reports (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. A number of publications have looked at the requirements for adaptation of human and natural systems to climate change concerning the need for large and small scale planning (Adger et al. 2011; Berkes and Folke 1998; Joyce et al. 2009; Ojima et al. 2002), emphasis on restoring ecological systems and processes (Eriksen and Brown 2011a; Eriksen 2011b; Eriksen and O'Brien 2007; McNeeley 2011; O'Brien and Leichenko 2008), realizing the importance of natural systems (Berkes and Folke 1998; Gunderson and Holling 2002; Tschakert et al. 2007; Walker and Meyers 2004), and aligning the social and ecological goals (Lyytimäki and Hildén 2007). The short-term nature of many planning activities is described in Riley et al. (2012).
New information and remaining uncertainties	No clear catalog of ongoing adaptation activities exists for the Great Plains region. Initial steps have been supported by the National Climate Assessment in association with NOAA's Regional Integrated Sciences and Assessments teams. Until a systematic assessment is conducted, most examples of adaptation are anecdotal. However, stresses in physical and social systems are readily apparent as described in the other key messages. How communities, economic sectors, and social groups will respond to these stresses needs further study.
Assessment of confidence based on evidence	**Medium**. Due to the nature of the challenges, the risks of delaying response are tremendous. While systematic evidence is currently lacking, emerging studies point toward a proclivity toward short-term planning and incremental adjustment rather than long-term strategies for evolving agricultural production systems, habitat management, water resources and societal changes.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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