CHAPTER 7

Managing Effects of Drought in the Great Plains

Brice Hanberry, Matt C. Reeves, Andrew Brischke, Mike Hannemann, Tipton Hudson, Richard Mayberry, Dennis Ojima, Holly R. Prendeville, and Imtiaz Rangwala

B. Hanberry is a Research Ecologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Rapid City, SD 57702.

M.C. Reeves is a Research Ecologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Human Dimensions Program, Missoula, MT 59801.

A. Brischke is an Area Assistant Agent, University of Arizona, Mohave and Coconino Counties Cooperative Extension, Kingman, AZ 86401.

M. Hannemann is a Stewardship Staff Officer, U.S. Department of Agriculture, Forest Service, Southwestern Region, Williams, AZ 86046.

T. Hudson is an Associate Professor, Washington State University Extension, Rangeland & Livestock Management, Pullman, WA 99163.

R. Mayberry is a Rangeland Management Specialist, U.S. Department of the Interior, Bureau of Land Management, Division of Forest, Range, Riparian and Plant Conservation, Washington, DC 20240.

D. Ojima is a Senior Research Scientist, Colorado State University, Natural Resource Ecology Laboratory, and University Director, North Central Climate Science Center, Fort Collins, CO 80523.

H.R. Prendeville is a Northwest Climate Hub Coordinator, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory, Corvallis, OR 97331.

I. Rangwala is a Research Scientist, Cooperative Institute for Research in Environmental Sciences and North Central Climate Adaptation Science Center, University of Colorado-Boulder, Boulder, CO 80303.

INTRODUCTION

The Great Plains region of the United States is semiarid and frequently has water deficits that result in changes in natural resources, economic losses, and reduced ability of people to maintain their livelihoods. Drought occurs due to periods of low precipitation or extended elevated temperatures, or a combination of these weather conditions. Drought can directly affect soil characteristics, land use and land cover, productivity, abundance and composition of plants, animals, and soil organisms. Drought also affects social-ecological systems, particularly management of livestock, which is an important economic sector across the Great Plains.

In general, economic, social, and ecological systems in the Great Plains (box 7.1) are resistant and resilient to drought within the normal range of variability (Kopp et al. 2014). Drought occurred 43 percent of the time in the Southwestern United States and 27 percent in the northern Great Plains during 1944–1984 (Holechek et al. 1989), and tree-ring records have shown that 20th-century droughts were shorter in duration than past Great Plains megadroughts (during 1000–1300; Cook et al. 2007). The 2012 drought and associated dust storms revived interest in the Dust Bowl era. Although dust storms during drought were not new, the consequences of an inadequate management response to extended severe drought were demonstrated in the Great Plains during the 1930s. Farming arid land, plowing native grass, overgrazing, and lack of vegetation resulted in topsoil erosion that still persists in some locations (Hornbeck 2012). Instead of changes in agricultural land use, adjustment occurred through land abandonment and migration of drought "refugees." Communities and local governments destabilized due to population collapse and debt, without drought relief programs. Management changes were slow, despite recommendations by Federal and State agencies, including agricultural experiment stations and extension services (Hornbeck 2012).

Although past events have had significant impacts, recent drought events yield insight on what can be expected in the future (box 7.2). These include the 2002 and 2012 droughts, and more recently the 2017 drought in the northern Great Plains. Recent droughts have led to severe and transformative ecosystem impacts (Breshears et al. 2016). For example, high temperature and severe droughts during 2002 and 2012 have caused a decline in several perennial grassland species, particularly blue grama (*Bouteloua gracilis*), in the eastern plains of Colorado (Rondeau et al. 2018). This opportunity allowed less valued forage species to proliferate, thereby reducing the quality of rangeland grasses, which has implications for livestock grazing and use by wildlife (Rondeau et al. 2018). Extreme drought may cause aboveground net primary productivity to decrease to historically low levels, primarily due to decreases in dominant forbs; however, C4 grasses may compensate for reduced productivity by recovering quickly after drought (Hoover et al. 2014).

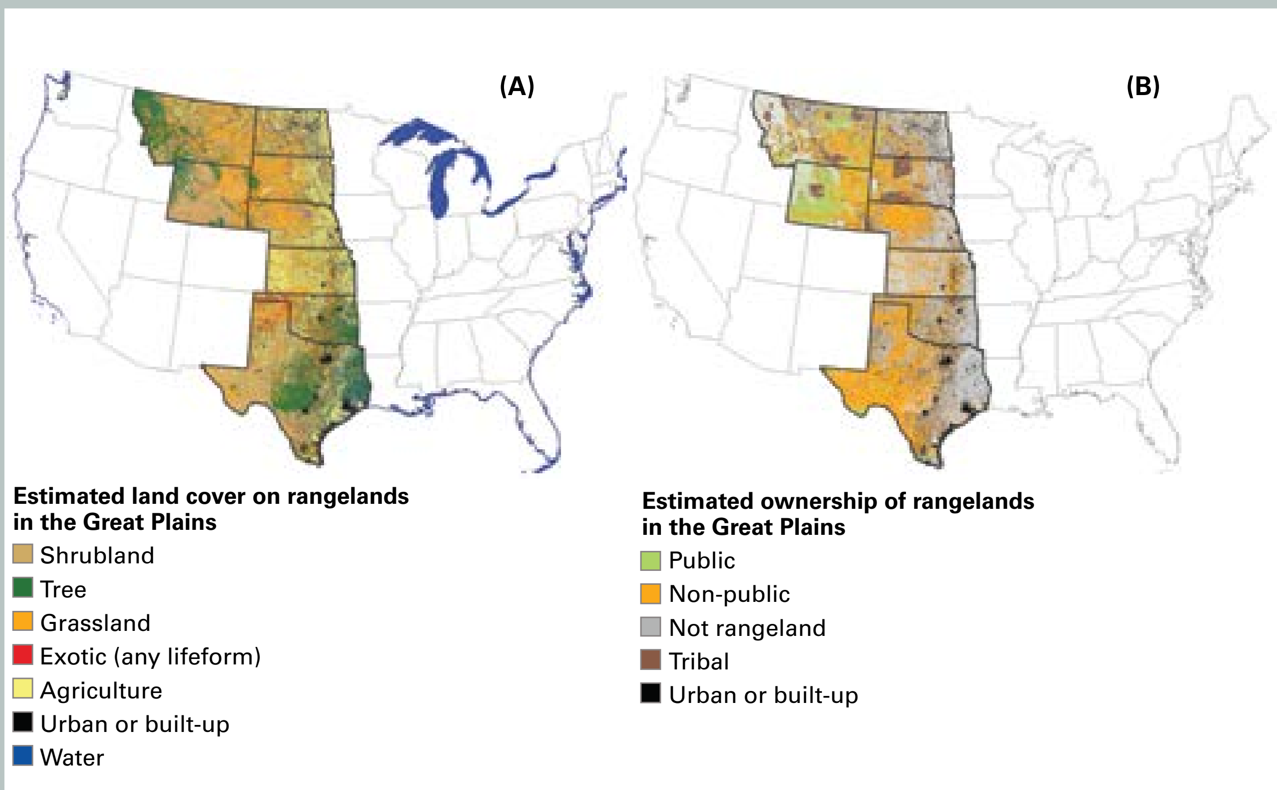
Approximately 75 percent of cattle were in an area of drought during 2012 in the United States (USDA NASS 2018). Drought during the previous year had already caused producers to reduce livestock inventories in Texas and Oklahoma (Rippey 2015). Drought-motivated increases in slaughter depressed cattle prices during 2012, although cattle and retail beef prices remained at or near-record high levels (USDA ERS 2018). Corn prices were also high, so removing lighter weight cattle from pastures and placing them in feedlots was not profitable (USDA ERS 2018). During 2017 in Montana and the Dakotas, drought caused ranchers to cull herds (USDA ERS 2018). Wildfire burned an area of 1.2 million acres, much of which was targeted for livestock grazing, exacerbating loss of forage in Montana.

Insights from both climate models and observations suggest increases in variability during recent decades and into the 21st century, resulting in relatively quick transitions (e.g., seasonal timescales) from anomalously wet to dry conditions (Collins et al. 2013, Heim 2017). Recent literature characterizes these events as "flash droughts," a rapid intensification to drier conditions over a period of weeks to months (Otkin et al. 2018). During the 2015 growing season, the Wind River Indian Reservation in west-central Wyoming experienced near-record high precipitation in May. However, the anomalous wet conditions in the early part of the summer quickly dissipated by the latter half of the growing season, causing severe drought conditions by September. Evaporative Demand Drought Index (EDDI), one measure of water stress, was the lowest 1-month EDDI (i.e., low water stress) on record (since 1979), whereas September 2015 experienced the highest EDDI value (i.e., high water stress) (McNeeley et al. 2017).

The Great Plains are particularly prone to flash droughts from episodic precipitation deficits (Mo and Lettenmaier 2015, 2016). One example occurred in the northern Great Plains during the summer of 2017 when a severe flash drought developed because of near-record low precipitation in late spring and early

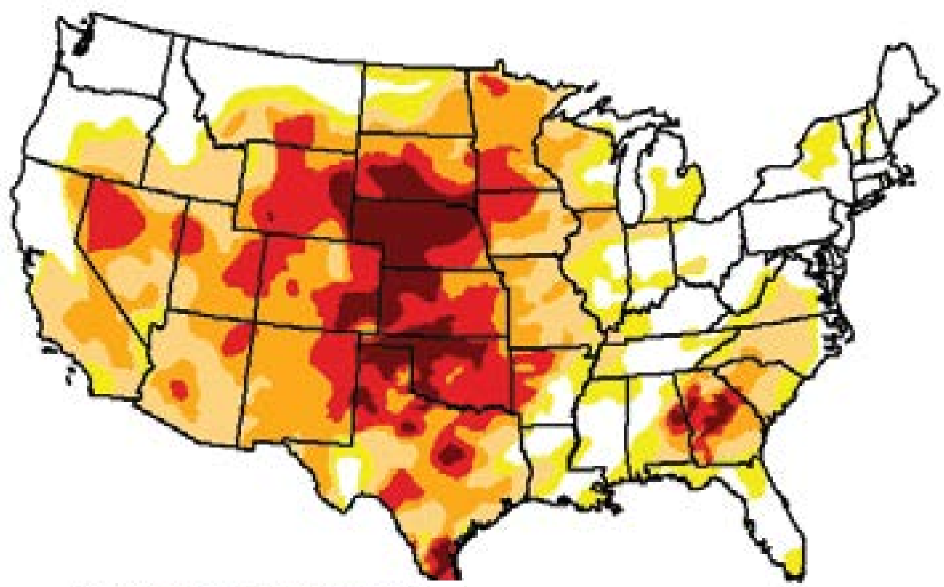
BOX 7.1
Geographic Scope and Climate

As defined by the National Climate Assessment, the Great Plains region comprises eight States: Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming ([Shafer et al. 2014] estimated land cover from the LANDFIRE project, https://www.landfire.gov [panel A] and ownership from the Protected Areas Database of the United States [PAD-US], U.S. Geological Survey version 1.4 [panel B]). The climate of the Great Plains is diverse due in part to the large latitudinal range from the Canadian to the Mexican borders. Statewide mean annual temperatures range from 40.5 °F to 64.8 °F in North Dakota and Texas, respectively. Statewide annual precipitation ranges from 12.9 to 36.5 inches, generally following a west to east gradient. The region is also marked with extreme intra-annual temperature differences, in some cases exceeding 100 °F.



BOX 7.2
Drought Displayed at the U.S. Drought Monitor

Widespread drought in the Great Plains is shown here for the year 2012, although drought varies in extent and location. Many drought indices exist, including the SPEI, SPI, PDSI, Self-calibrated PDSI, and the newer EDDI. The U.S. Drought Monitor is a widely used drought resource (https://droughtmonitor.unl.edu), jointly produced by the National Drought Mitigation Center at the University of Nebraska, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Administration. The U.S. Drought Monitor is used to trigger disaster relief payments which total billions every year. U.S. Drought Monitor maps show drought intensities ranging from D0 (abnormally dry) to D4 (exceptional drought), as well as associated impacts.



Drought conditions (percent area)

	None	D0–D4	D1–D4	D2–D4	D3–D4	D4
Current	26.16	73.84	61.82	42.45	21.60	6.73
Last week 12/18/2012	26.21	73.79	61.79	42.51	21.67	6.64
3 months ago 9/25/2012	23.41	76.59	65.45	42.12	21.48	6.12
Start of calendar year 1/3/2012	50.41	49.59	31.90	18.63	10.18	3.32
Start of water year 9/25/2012	23.41	76.59	65.45	42.12	21.48	6.12
1 year ago 12/27/2011	50.89	49.11	28.49	18.95	10.01	3.31

December 25, 2012
(Released Thursday, Dec. 27, 2012)
Valid 7 a.m. EST

Intensity
- D0 Abnormally dry
- D1 Moderate drought
- D2 Severe drought
- D3 Extreme drought
- D4 Exceptional drought

(Richard Heim, NCEI/NOAA)

SPEI = Standardized Precipitation-Evapotranspiration Index
SPI = Standardized Precipitation Index
PDSI = Palmer Drought Severity Index
EDDI = Evaporative Demand Drought Index.

summer when the region normally receives a large share of its precipitation. This drought, which caused widespread impacts to agriculture and ecosystems, emerged at the end of the wettest decade (2007–2016) on record for the region (Hoell and Rangwala 2018). Climate change is expected to increase the occurrence of flash droughts during the 21st century (Trenberth et al. 2014).

Water availability is expected to decrease in the future because of shortages arising from decreased water supplies and/or increased water demand. In the Western United States, 90 percent of water consumption is for irrigated agriculture (USDA ERS 2019). Depletion of aquifers and aboveground water bodies will reduce these water supplements. Well depths may no longer be adequate on public and private lands, resulting in inadequate water infrastructure to meet demand. Land parcels with extensive infrastructure including pipelines and pumping stations for water supply have high exposure to drought risk. In addition, with increased drought and demand for water from other resource sectors, transfer of water rights may occur from agriculture to urban centers or for multiple objectives, such as maintenance of minimum stream flows for protection of aquatic species, recreation, better water quality, and riparian and wetland restoration.

New management practices to minimize vulnerability and maximize water efficiencies will be necessary to maintain resilience of rangelands under long-term and spatially extensive drought. Social and ecological resilience to drought depends on adaptive capacity and strategies at many spatial scales (Joyce et al. 2013, McNeeley et al. 2016). That is, even robust agricultural technologies and data-driven management strategies may be ineffective in the absence of social capital. Social capital is a way to understand the benefits of relationship networks, reciprocity, trust, and cooperation for individuals, communities, and organizations who make natural resource decisions (Adger 2003). Trust, mutual respect, and proactive communication set the stage for learning and teamwork across fence lines and regions (Adger 2003, Muro and Jeffrey 2008, Rasmussen and Brunson 1996). These processes in turn enable managers to act in ways that lead to more resilient ecological outcomes. Processes linking social capital and natural capital, such as soil development, nutrient and water cycling, vegetation production, and land use, are key to understanding how drought affects the socio-ecological system in this region (fig. 7.1).

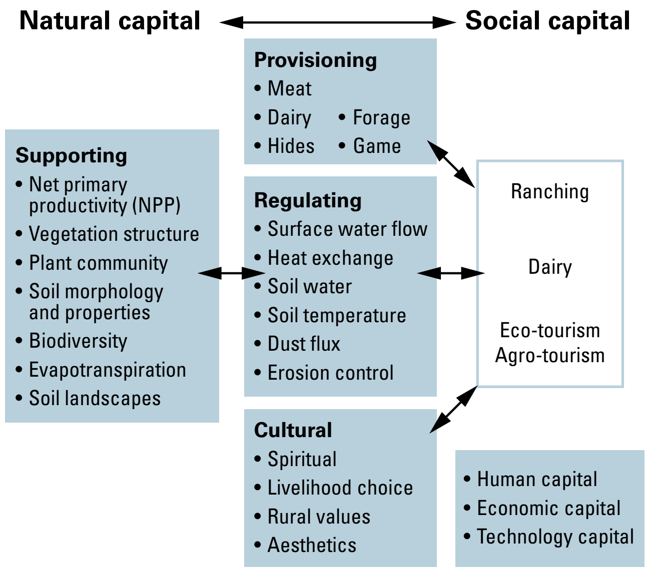


Figure 7.1—Understanding processes linking social capital and natural capital, such as land use, nutrient cycling, water cycling, vegetation production, and soil development, is key to understanding how drought affects different representations of the social-ecological system. These factors include forage production (vegetation productivity) and forage quality (e.g., nitrogen content) and are affected by land use and climatic factors such as precipitation and temperature. Drought has a profound impact on livestock numbers, with major reductions during periods of prolonged episodes of low precipitation. In addition, socio-economic trends affect livestock numbers due to market pressures and cultural value changes.

Here, we describe the need to track drought conditions, the prospect of future drought, and drought effects on rangeland resources. We provide drought-wise best management practices (BMPs), including both U.S. Department of Agriculture, Forest Service (USFS) and U.S. Department of the Interior, Bureau of Land Management (BLM) guidelines, to manage rangelands for increased drought resilience. We emphasize planning and collaboration that will help incorporate drought into management of natural resource systems. Although our focus is the Great Plains region, which is variously defined, concepts and management techniques are applicable to rangelands in general, where agriculture and livestock sectors are the dominant land uses.

CHARACTERIZING DROUGHT AND CLIMATE

Defining Drought

Following the preceding science synthesis of drought (Luce et al. 2016), drought is lack of water or precipitation levels lower than the annual average resulting from various factors including warmer temperatures and reduced precipitation (see chapter 1).

Drought metrics for the 20th century are a subset of the historical range of variability. Long-term reconstructions indicate more severe and longer lasting droughts over previous centuries (Cook et al. 2007, Finch et al. 2016, Luce et al. 2016).

Drought Monitoring

In recent years, there has been an upsurge in the availability of high-resolution (<0.6–6 miles) and near real-time weather information, which includes a better assessment of ecological water stress (i.e., anomalies in evaporative stress, evapotranspiration, soil moisture, and snow; see chapter 2) and higher confidence in near-term (1–2 weeks) weather forecasts. Weather involves shorter intervals than climate, which typically consists of 30-year averages. This information identifies regions with high risk for a drought emergence or intensification. Appropriate understanding and use of this information is often lacking among managers and can be greatly enhanced to inform their short-term preparedness (4–6 months). Beyond the short term, managers can develop a risk-based planning approach to prepare for a seasonal drought or longer term timeframe. Managers are encouraged to use a variety of drought monitoring and assessment tools, including those found at the U.S. Drought Portal (https://drought.gov), the National Drought Mitigation Center (https://drought.unl.edu), and the U.S. Drought Monitor (https://droughtmonitor.unl.edu) (box 7.2). Additional information may be found at the National Oceanic and Atmospheric Administration (NOAA) climate portal (https://www.climate.gov) and NOAA National Weather Service website (https://www.weather.gov).

Future Projections

Climate change is expected to increase the frequency and severity of drought episodes in the Great Plains because of increases in evaporative demand (Trenberth et al. 2014), greater proportion of precipitation occurring in high-intensity events, increases in number of dry days, and reduced snowpack (Easterling et al. 2017, Wuebbles et al. 2014). Future scenarios for the region generally project that elevated temperatures drive greater decreases in soil moisture, particularly in the latter half of the growing season, because of greater increases in evapotranspiration relative to precipitation (Hoell et al. 2018). Climate change is expected to intensify the hydrological cycle so the likelihood for both more severe droughts and flooding will increase; that is, more intense spring flooding may occur in the same year with more intense summer and autumn droughts. Larger and more extreme events will result in greater interannual and intra-annual variability in precipitation. In general, climate change during the 21st century will broaden the summer season with more extreme hot days than previously experienced; conversely, the winter season will shrink with fewer extreme cold days (Hansen et al. 2012, Meehl et al. 2009). Rangeland health may be particularly sensitive to the changing patterns of climate, especially a longer growing season, late growing season soil moisture deficits, and more water stress between rains.

For the Central and Western United States, there is a considerable range in global climate model projections for both temperature and precipitation during the 21st century. For example, by mid-21st century, this region may warm 3 to 8 °F (fig. 7.2), and precipitation change may vary anywhere from -20 to +20 percent (fig. 7.3). Severity and specificity (i.e., exact nature of ecological response) of climate change-induced effects on rangeland ecosystems will vary accordingly. Despite recent advances in climate modeling, uncertainty in regional projections remains high (Knutti and Sedláček 2013). As a result, innovative methods to incorporate uncertainty in planning are needed to ensure a foundation for decision making (Maier et al. 2016, Rowland et al. 2014, Sofaer et al. 2016).

In general, projections suggest increases in precipitation in the northern Great Plains and decreases in the southern Great Plains. The physical mechanisms driving this pattern are generally well understood, but the degree of change is largely controlled by variability of the climate system. The northern Great Plains has experienced a 12-percent increase in cold-season (October–March) precipitation during 1975–2014 compared to 1895–1974 (Livneh et al. 2016). Model projections also indicate a greater proportion of future moisture supply will occur via intense precipitation events (Easterling et al. 2017). These trends are being observed across much of the continental United States, including the Great Plains, in recent decades (Easterling et al. 2017, Livneh et al. 2016). Extreme precipitation will result in increased surface runoff and erosion potential, and comparatively less infiltration of water to deeper soil layers.

Soil moisture and vegetation will be affected significantly by altered snowpack, including total area under snow, depth, and duration of snow-covered ground. More precipitation will fall as rain rather than snow because of a warmer atmosphere. Warming will lead to earlier evapotranspiration and an earlier growing

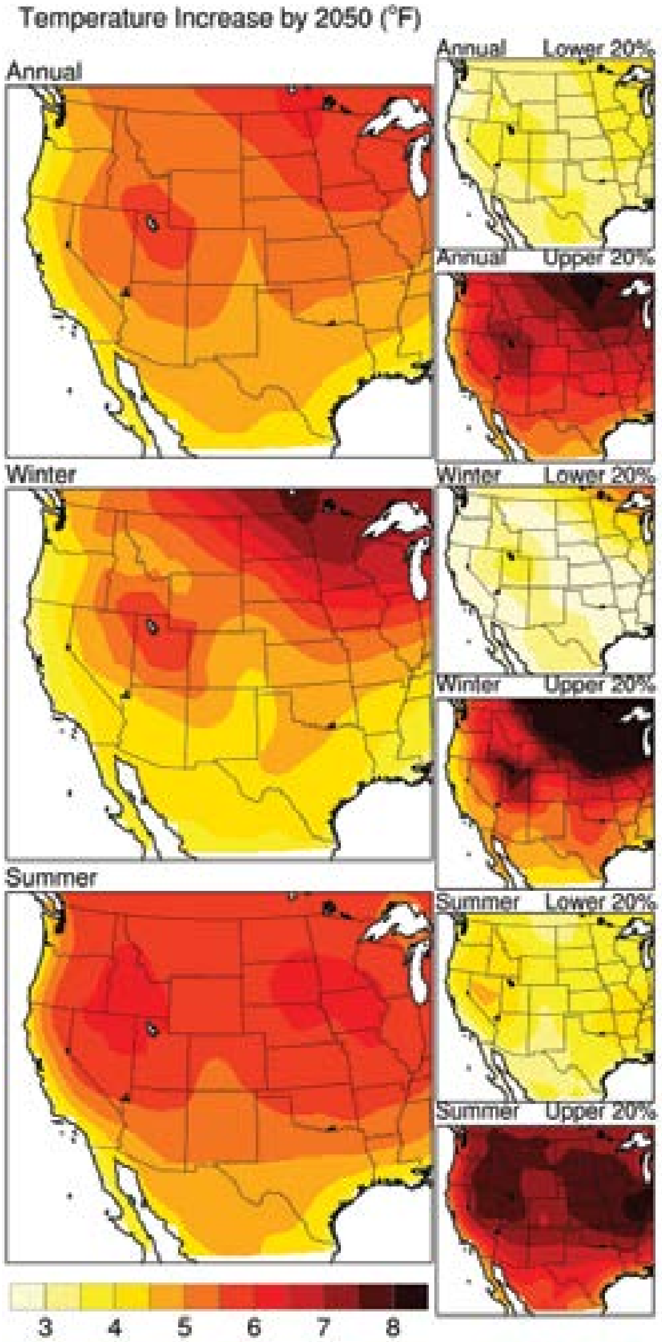


Figure 7.2—Projected changes in annual, winter (DJF), and summer (JJA) temperature by 2050 (2035–2064 relative to 1971–2000) over the Western United States from an ensemble of 34 climate models under Relative Concentration Pathway (RCP) 8.5. The large maps show the average change for all models; the small maps show the average changes of the highest 20 percent and lowest 20 percent of the models rank-based on change for the Great Plains. (Data source: CMIP5 projections re-gridded to 1-degree grid [Reclamation 2013; https://gdo-dcp.ucllnl.org]).

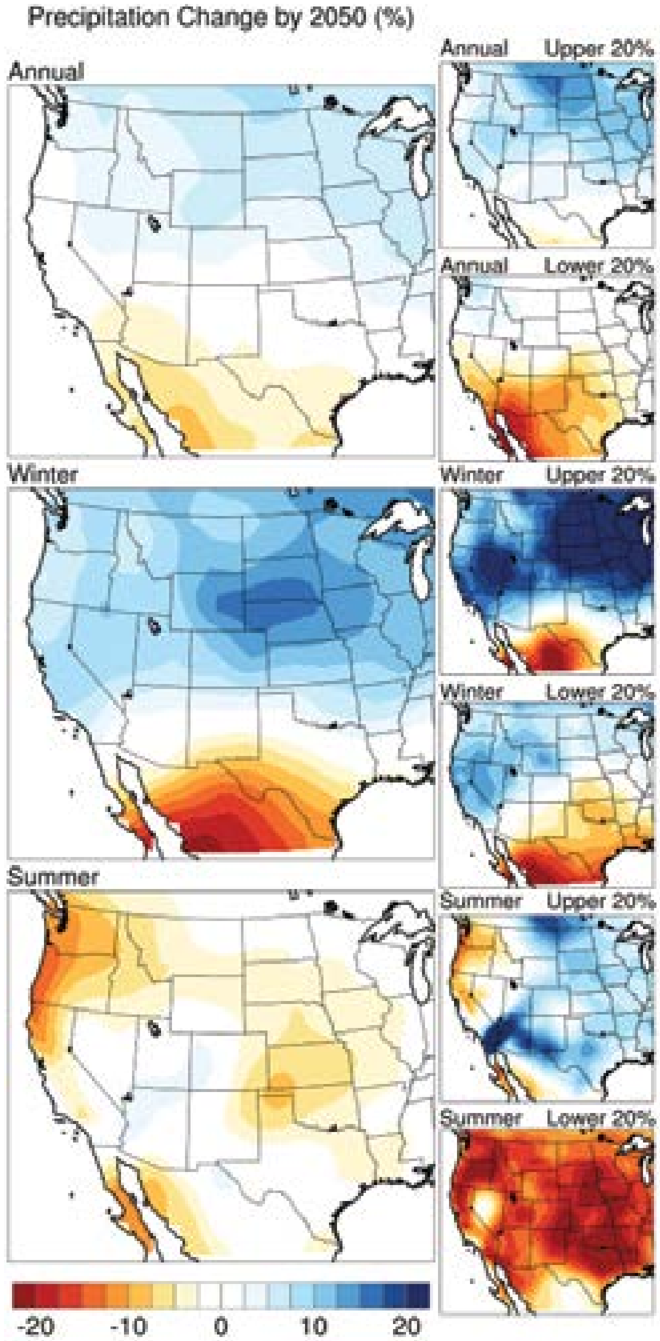


Figure 7.3—Projected changes in annual, winter (DJF), and summer (JJA) precipitation by 2050 (2035–2064 relative to 1971–2000) over the Western United States from an ensemble of 34 climate models under RCP 8.5. The large maps show the average change for all of the models; the small maps show the average changes of the wettest 20 percent and driest 20 percent of the models rank-based on the change for the Great Plains. (Data source: CMIP5 projections re-gridded to 1-degree grid [Reclamation 2013; https://gdo-dcp.ucllnl.org]).

season, as a result of shallow snow depth, rain-on-snow events, and earlier snowmelt. Warming and longer duration of evapotranspiration will also cause longer duration of depleted soil moisture, in some cases driving aridification in the American West (Cook et al. 2015, Mankin et al. 2017).

Climate models suggest that one of earliest signals of warming will be a reduced ratio of snowfall to rainfall (Pierce and Cayan 2013), a phenomenon that may already be occurring in the American West (Harpold et al. 2017, McNeeley et al. 2017).

For much of the Great Plains, climate models project increasing deficits in near-surface and deeper layer soil moisture during the latter half of the growing season (fig. 7.4). The anticipated decrease in soil moisture is due to continued climate warming during the 21st century (Cook et al. 2015, Walsh et al. 2014, Wehner et al. 2017), although such a risk appears to be greater for the southern plains as compared to the northern plains (Reeves et al. 2017), where most models project higher annual precipitation (Easterling et al. 2017, Walsh et al. 2014) (figs. 7.2, 7.4). However, there are many environmental factors that govern soil moisture loss through evapotranspiration, and there is uncertainty in our understanding of model accuracy (Ainsworth and Rogers 2007, Mankin et al. 2017). These factors include (1) increased water-use efficiency by plants because of elevated CO_2 levels, (2) increased transpiration rates from higher leaf area index (greening), and (3) evapotranspiration in response to increased leaf temperature and altered vapor pressure deficit. Warming may favor warm-season C4 grasses, whereas increased CO_2 may favor cool-season C3 plants. Combined warming and CO_2 enrichment may favor C4 grasses when soil moisture limits plant productivity (Morgan et al. 2011).

EFFECTS OF DROUGHT ON RANGELAND SYSTEMS

Soil Moisture

Soil moisture depends on the influences of precipitation, temperature, and wind on evaporation and transpiration by plants. Soil attributes such as infiltration, porosity, texture, and depth also affect available water capacity. Soil organic matter binds soil particles together into stable aggregates, improving water infiltration and porosity. Greater infiltration and pore space allow retention of more soil moisture during rain and prevent evaporation,

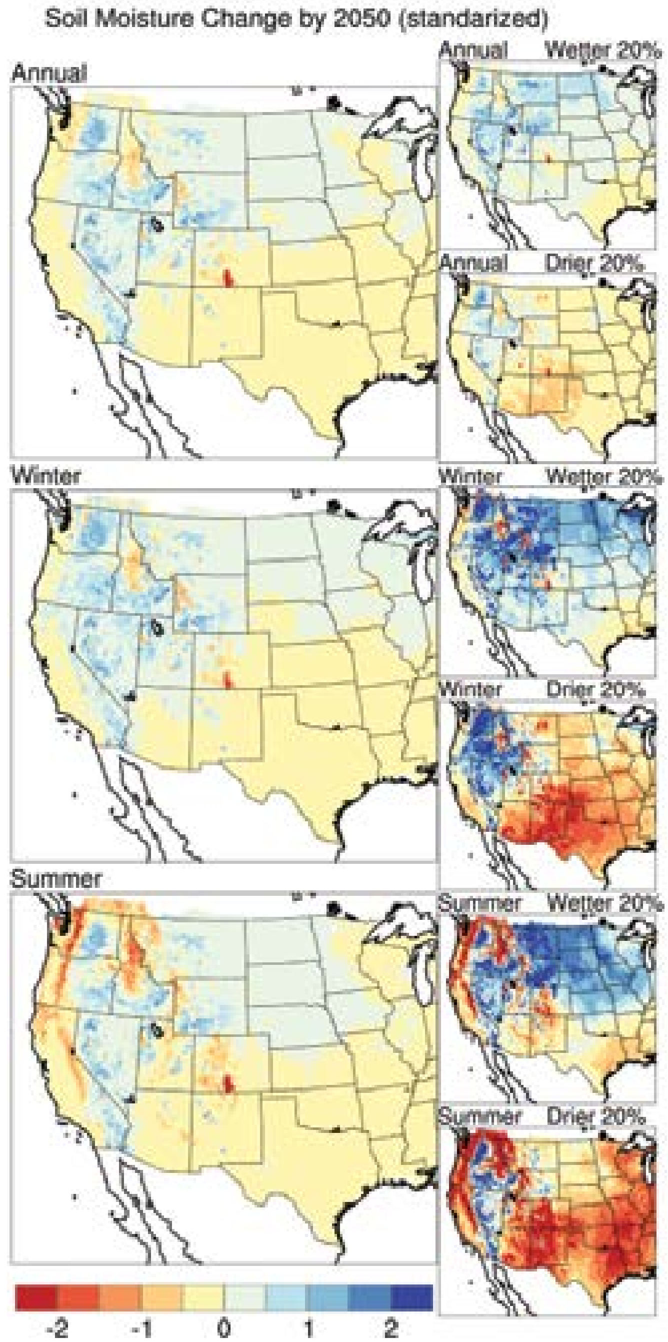


Figure 7.4—Projected changes in annual, winter (DJF), and summer (JJA) soil moisture by 2050 (2035–2064 relative to 1971–2000) over the Western United States from an ensemble of 29 climate models (all models that projected soil moisture) under RCP 8.5. The large maps show the average change for all of the models; the small maps show the average changes of the wettest 20 percent and driest 20 percent of the models rank-based on the change for the Great Plains. (Data source: 1/8th degree Variable Infiltration Capacity hydrological projections based on bias-corrected CMIP5 data [Reclamation 2014; https://gdo-dcp.ucllnl.org]).

reducing drought impacts and increasing productivity. A 1-percent increase in organic matter can triple water-holding capacity, equivalent to an additional 25,000 gallons of available water per acre and the equivalent of 3 inches of rain (Steiner et al. 2015). In addition, a 1-percent increase in organic matter adds up to $700 worth of additional nutrients per acre (Steiner et al. 2015).

Soil attributes can be mismanaged, particularly the amount of soil organic matter that controls infiltration and porosity. Land use may result in insufficient vegetative cover to protect soil from wind and water erosion. Typical erosion rates may be up to 0.04 inches per year, whereas topsoil replenishes at a rate of less than 0.004 inches per year (Thurow and Taylor 1999). Reduced productivity can result in reduced production of organic matter. Because most annual production occurs below the soil surface, roots are a primary contributor of organic matter in grasslands.

Vegetation

Water deficits limit vegetation growth, reproduction, and survival, indicated by reduced aboveground height and root length, limited seed development, dormancy during the growing season, and senescence. Deficits in water availability during the growing season will affect plants more than when plants are dormant. Vegetation cover, which may already be sparse due to aridity and use, will be reduced during drought, increasing soil vulnerability to wind and water erosion. Reduced vegetation cover also reduces water infiltration into soil, further exacerbating water loss to runoff and soil erosion. In addition, vegetation loss contributes to decreased soil organic matter critical to maintaining water holding capacity.

Each plant species has a different response to timing of rain events, drought, and drought combined with grazing and/or fire. After drought ends, loss of aboveground vegetation increases light and reduces competition. Therefore, plants may grow to above-average height and reproduce prolifically. Moran et al. (2014) showed that aboveground net primary production of Great Plains grasslands was correlated with total annual precipitation and aboveground net primary production of the previous year, even under chronic drought. Dominant vegetation assemblages have the capacity to physiologically adjust to climatic variability and may shift in composition, ensuring regenerative capacity following disturbance (Moran et al. 2014).

Invasive Species

Drought and changing seasonality of precipitation may be an inciting factor that facilitates invasion of plant species during dormancy of native plants. Alternatively, invasive species may be less drought resistant and establish during wetter winters; annual grasses in particular may not have deep roots. Invasive nonnative species remove or displace native species, which have been exposed to Great Plains conditions for thousands of years. Invasive grasses include species such as smooth bromegrass (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), Timothy-grass (*Phleum pratense*), and crested wheatgrass (*Agropyron cristatum*) that are planted for forage, as well as cheatgrass (*B. tectorum*), red brome (*B. madritensis*), and medusahead (*Taeniatherum caput-medusae*) that spread aggressively on their own. Annual bromes and cheatgrass are present on about 30 percent and 22 percent, respectively, of pasturelands in the northern plains (includes Colorado and excludes Oklahoma and Texas) (USDA NRCS 2016). One species in particular that is changing ecological conditions in the eastern regions of the Great Plains is eastern redcedar (*Juniperus virginiana*), a tree species native to the Eastern United States. Drought and excessive grazing can influence the extent and magnitude of all of the species mentioned above, and must be considered in management plans (Davies et al. 2011).

The presence of invasive species affects ecosystem health by decreasing native forb and grass species diversity (Cully et al. 2003, DeKeyser et al. 2009, Miles and Knops 2009, Pritekel et al. 2006), affecting quality and abundance of forage, and disrupting nitrogen and soil organic carbon dynamics (Hendrickson et al. 2001; Wedin and Pastor 1993; Wedin and Tilman 1990, 1996). Therefore, invasive species can alter water infiltration into soils (Harivandi 1984, Hurto et al. 1980, Taylor and Blake 1982) and natural disturbance regimes, especially for wildfire. Shallow-rooted annual species may not produce as much organic matter as native vegetation (Rau et al. 2011), particularly during drought. Though crested wheatgrass is frequently seeded following wildfires, and both crested wheatgrass and Kentucky bluegrass reduce soil erosion, tolerate grazing, establish well, and are resistant to drought and cold (Hansen and Wilson 2006, Monsen et al. 2004), crested wheatgrass and Kentucky bluegrass hinder native plant recruitment and growth and are difficult to remove (Henderson and Naeth 2005, Marlette and Anderson 1986).

Wildfire

Wildfire requires vegetation as a fuel source and dry conditions for ignition. Seasonal rain provides moisture for vegetation growth followed by summers that dry vegetation and decrease humidity. Drought increases the length of time when humidity is low and vegetation is dry and susceptible to fire. Other factors increase fire frequency, such as presence of nonnative species (especially cheatgrass in Montana and Wyoming) that contain less moisture early in the summer compared to native species. Conversely, drought combined with overgrazing of vegetation will reduce availability of fuels for fire. Minimal fine fuels, active fire suppression, and fragmentation of vegetation may decrease fire frequency and allow an increase in woody vegetation.

Grasslands are typically fire-dependent ecosystems, and frequent fire is needed to maintain ecosystem structure and function (Limb et al. 2016). Without fire, woody vegetation will replace herbaceous vegetation. Trees and shrubs may establish during wetter conditions and spread in the absence of control by fire, in some cases becoming dense enough to shade out herbaceous vegetation. For example, without fire, eastern redcedar is spreading north through the Great Plains. Currently, eastern redcedar is sold commercially, including by USFS nurseries, and planted for windbreaks. Within 35–40 years, tree densities can be high enough to replace rangelands (Limb et al. 2014).

Drier rangelands, where both fire and woody vegetation are limited by aridity, are less dependent on fire. Although fire suppression may allow invasion by species with low fire tolerance, nonnative annual grasses tend to increase fire frequency, subsequently spreading post-fire while reducing habitat suitability for native species (Havill et al. 2015). Cheatgrass influences fire regimes through positive feedbacks in drier grasslands where fire is less frequent (e.g., Wyoming and Montana). Annual grasses have greater flammability than native perennial grasses due in part to low moisture content (Neibergs et al. 2018). Native grasses retain moisture in plant tissue into August, even when no longer actively growing (Neibergs et al. 2018). Where invasive annuals dominate, dry fuels may be available in June, lengthening the duration of flammable conditions (Neibergs et al. 2018). Cheatgrass life history varies from year to year. As a winter annual, its abundance is driven primarily by available moisture during autumn when it germinates, and during spring when seedlings initiate growth prior to native or naturalized perennial grasses (Knapp 1998). This is consistent with other findings that showed that above-average precipitation in autumn and winter before fire season (analysis for 1977–2003) was better correlated with larger and more numerous wildfires than were common drought measures such as low precipitation or high temperature (Littell et al. 2009).

DROUGHT MANAGEMENT OPTIONS IN RANGELANDS

Soil Moisture

Management strategies that are likely to increase soil organic matter will also increase soil moisture. Strategies include promotion of (1) dense herbaceous vegetation cover, (2) deeply rooted, perennial herbaceous plants rather than shallow-rooted annuals, (3) drought-tolerant herbaceous plants, and (4) diverse native plants (Rau et al. 2011). Control of nonnative annual species that produce less soil organic matter is also needed. Plant diversity will ensure plant cover and activity under a variety of conditions throughout the year. Monitoring of grazing levels to ensure continuous vegetative cover under drought conditions, at least during most years at most locations, may be necessary. Careful consideration of cover thresholds and risk assessment is needed for allotment management plans. This is important because soil compaction from intensive grazing during drought may reduce water infiltration and increase surface erosion, which may lead to reduced vegetation growth and cover.

Vegetation and Restoration

Because vegetation protects soil and contributes to soil organic matter, proactive management strategies are the same for both soil and vegetation, namely promotion of (1) dense herbaceous vegetation cover, (2) deeply rooted, perennial herbaceous plants rather than shallow-rooted annuals, (3) drought-tolerant herbaceous plants, and (4) diverse native plants. A diversity of plants will possess different traits, such as drought tolerance strategies, root-to-shoot ratios, growth rates, rooting depths, and different growing seasons, allowing some species to be more successful under varying soil moisture regimes. Establishment of plants during drought is not likely to be as successful as during wetter conditions. Surviving aboveground plant shoots may have reduced crude protein and digestibility. Therefore, not only is there less vegetation, the available vegetation provides less nutritional value. Reduced nutritional value, in turn, may require adjustments in grazing regimes.

Ecological restoration aims to restore degraded landscapes to healthy ecosystems that are resilient to disturbances such as drought, fire, and flooding and provide various ecosystem functions such as water supply, flood control, and pollination. Part of the restoration process aimed at increasing resilience to drought may also include restoring critical ecological processes such as appropriate fire regimes and grazing strategies. More resilient landscapes tend to have more diverse communities (Peterson et al. 1998), so building and maintaining ecosystems that are resilient to drought help restore landscapes with a diversity of native plant species. Restoration in grasslands is more successful when plant material is diverse (Barr et al. 2016, Serajchi et al. 2017).

Successful restoration is challenging, and an integrated approach suited for specific sites and management goals is essential. Restoration during a drought is even more challenging with extended periods of little to no rain resulting in reduced soil moisture and vegetation growth, increased fire risk, and accelerated invasion of some invasive species (Finch et al. 2016). Using climate information (e.g., the National Weather Service Climate Prediction Center's 3-month outlook) to determine anticipated precipitation levels in upcoming months will help restoration planning relative to site preparation, invasive species control, seeding, and planting (Kimball et al. 2015). A decision-support tree has been developed to help guide restoration efforts in a cost-effective manner (Kimball et al. 2015).

With ample precipitation, efforts should focus on restoring diverse, native plant communities because seeding and planting in wet conditions improve restoration success and effectiveness (Bakker et al. 2003, Kimball et al. 2015), although continued control and removal of invasive species is still necessary. Seeding and planting during a drought are possible, although not optimal, but a variety of techniques are needed to improve plant establishment and survival such as seed pillows, seed coatings, irrigation, and transplanting seedlings (Finch et al. 2016). Seeding with mixes that contain multiple species and applying these mixes at high rates enhance restoration success, and increasing seed-mix diversity contributes to grassland restoration success (Barr et al. 2016). Incremental shifts in planting times should occur to coincide with precipitation. Dormant seeding may result in more successful germination. Examining and updating planting techniques to include climate information (Printz and Hendrickson 2015) will improve restoration success.

Seed transfer guidelines have been developed to help guide land managers in obtaining native seed that is adapted to specific environments (Johnson et al. 2004), although modified guidelines may be needed in a warmer climate. Provisional seed zones delineate areas of similar climate focusing on variables important to plant survival and growth: winter minimum temperature (cold hardiness) and aridity (the ratio of mean annual temperature and mean annual precipitation; Bower et al. 2014). Empirical seed zones have been developed for a number of species and delineate areas based on climatic variables and genetic information for wild populations (Erickson et al. 2004, Johnson et al. 2013). The genetic information is gathered in common garden experiments, focusing on plant traits that are important to survival and reproduction. The use of provisional or empirical seed zones may help to guide land managers on where to source plant material for restoration so that material is adapted to the local environment. This information, along with local expertise and projections of future climate and drought conditions, will aid in matching specific seeds with specific sites.

Restoration using native plant material is a directive or strongly encouraged in Federal agencies, but obstacles exist in using native plant material, such as expense of seed and lack of sufficient quantities. The National Seed Strategy for Rehabilitation and Restoration 2015–2020 was developed to encourage use of native plant materials in restoring plant communities and supporting healthy ecosystems. This strategy is generating a network of resource managers and restoration ecologists who have experience in selecting the right seed in the right place at the right time. In addition, the strategy is enhancing the capacity of native seed collectors, agricultural producers, nurseries, and seed storage facilities to provide adequate amounts of economical native plant material. The national Native Seed Network (http://nativeseednetwork.org) has an online database of native seed vendors throughout the United States.

A review of grazing studies on shrub-steppe rangeland concluded that bunchgrasses are more sensitive to defoliation during the growing season than to grazing after seed shatter and the cessation of active growth (Burkhardt and Sanders 2012). The authors recommended that native bunchgrasses, particularly jointed grasses, be allowed to produce seed approximately every other year. This can be accomplished by deferring all grazing in a given year until after plants have produced seed or by allowing a relatively short period of early spring grazing followed by rest until after seed shatter.

Invasive Species

A variety of treatments, alone or in combination, may be evaluated to reduce invasive species and restore native plant communities. During periods of drought, restoration efforts may focus primarily on removing invasive species that are moisture stressed, making removal treatments more effective (Bakker et al. 2003, Kimball et al. 2015). Control of invasive species is most effective during early stages of invasion to prevent spread, so monitoring to detect invasive species is critical. Combined damage and control efforts cost approximately $137 billion annually; for example, weed control, primarily by herbicides, costs about $11 billion per year (Kopp et al. 2014, Stitt et al. 2006).

During drought, dormancy in plants reduces uptake of herbicides, making chemical application ineffective. Biological control agents also may be less effective at controlling invasive species during drought. Mechanical treatments can reduce woody plant encroachment (Archer et al. 2011), but other methods result in less soil disturbance and erosion, which helps build or maintain drought-resilient ecosystems (Davies et al. 2013, Gifford 1982). Prescribed fire, during a drought year or in combination with herbicides, may control invasive species of cool-season grasses and woody plants and favor native species (DiTomaso et al. 2006, Ereth et al. 2017, Twidwell et al. 2016). Fire behavior during drought may be altered by lack of fine fuels to spread fire or by higher flammability.

Manipulation of grazing to focus on when invasive species are green and palatable and when native species have set seed may be another strategy, although determining the efficacy of this practice may take some time. Grazing to suppress cheatgrass, as an independent goal from altering fire behavior, must occur when the plant is palatable and when seed production can be interrupted or slowed (Mosley and Roselle 2006). This phenological stage is rather short in cheatgrass, but during this stage (roughly seedhead emergence through soft dough stage), cattle, sheep, and goats will readily consume it. After this stage, plants are unpalatable and livestock movements may serve only to assist in distributing and planting seed rather than consuming it.

Because of the additional effort in fencing and herding required to deliberately target cheatgrass, treating very large areas in a single year is infeasible. The BLM has initiated several targeted grazing projects to explore techniques, frequency of grazing, and capability (practicality) of permittees to manage livestock numbers and distribution, in order to achieve project objectives. The use of targeted grazing to improve rangeland resilience to drought represents an opportunity for managers to experiment with various species of animals. As a result, the BLM may authorize grazing specifically to target invasive plants during drought.

Effectiveness of this approach is not without dispute; research in Oregon evaluated cover and production of cheatgrass in grazed and ungrazed treatments and found no difference among grazed and non-use treatments (Bates and Davies 2014). A fuel-based restoration model for sagebrush-steppe has been proposed that incorporates pre-fire plant community composition, environmental factors, and ecological processes that control resistance and resilience (Hulet et al. 2015). This approach also identified 11 research objectives that require further exploration before reliable management planning and prescription can proceed.

Minimizing surface disturbance and scheduling grazing to maintain native community resilience are strategies for preventing introduction or establishment of invasive plants. Management options that can be used to prevent invasive plant establishment include:

- Refrain from grazing or moving cattle through populations of invasive plants while they are setting seed or when fruit is ripened.
- Purchase only certified weed-free seed for forage (required by many national forests year-round).
- Keep cattle and other livestock out of newly planted areas.
- Employ rotational grazing and other management strategies that minimize soil disturbance.
- Purge animals with weed-free feed for 5 days before moving them from infested to uninfested areas.
- Position activity boundaries to exclude areas infested with invasive species. If not possible, consider treating infested areas before other land-disturbing activities.
- Close or reroute public roads or trails in infested areas.

- Prevent pack animals from entering infested areas.
- Brush seeds off animals, equipment, shoes, and clothing.

Wildfire

Wildfire removes (at least in the short term) vegetation, exposing bare soil. In fire-adapted grasslands where fire may occur annually, few plants may die because perennial plants regrow aboveground vegetation (Gates et al. 2017). Fire removes dead plant material, allowing more light for new growth, and fire may be necessary for seed germination in some species, including grasses and forbs (Blank and Young 1998). Plants have higher forage quality following fire due to increased crude protein and decreased fiber content. For livestock, the benefit from burning can be comparable to that from supplemental feeding (Limb et al. 2016). Fire provides an opportunity to manage for varied disturbance and grazing intensity, rather than promotion of uniformity. If biomass has increased and ground cover is present, higher stocking during post-fire regrowth is an appropriate management response.

For post-fire restoration, a site should be evaluated prior to restoration efforts to determine if it is a reasonably intact, healthy ecosystem that may be resilient to disturbance, and has low density of invasive species (<15-percent cover). If so, then it may be best to wait a season to determine if revegetation will occur via the seed bank and remaining vegetation on site (Auffret and Cousins 2011, Farrell and Fehmi 2018, Lipoma et al. 2016). Natural revegetation through a seed bank is a viable option if the area has not experienced high disturbance (Farrell and Fehmi 2018). Delaying seeding a season for natural revegetation will maintain soil biocrusts, while ensuring persistence of plant material adapted to the local environment. The Burned Area Emergency Response (BAER) program used by the USFS uses various seed mixes and mulch for erosion control and installation of erosion control devices after fire. Seeded species must be able to establish and stabilize soil rapidly.

Federal agencies and managers may recommend resting burned areas for two grazing seasons to allow recovery of perennial plants and establishment of seeded species (Gates et al. 2017). The USFS does not have a national policy for rest after a fire. Instead, it is common practice to use a range-readiness evaluation to determine if the burned area can be grazed before the upcoming grazing season. Burned areas will recover at different rates depending on fire characteristics, weather, pre-burn vegetation, and other factors.

Vegetation regrowth in response to fire attracts more intensive grazing, resulting in a fire-grazing linkage that produces differential grazing intensity and heterogeneity across an area ("pyric herbivory"), in conjunction with other areas that are grazed lightly or not at all (Fuhlendorf and Engle 2009). Heterogeneous vegetation structure and plant diversity may be missing ecological attributes that are critical for declining animal species, such as grassland birds and pollinators. In contrast, unrelenting heavy grazing leads to a decrease in perennial grasses, an increase in invasive annual grasses, and a decrease in soil and fuel moisture. Under drought conditions or in arid regions (e.g., the Great Basin, where vegetation did not evolve under grazing pressure from American bison [*Bison bison*]), burned areas are likely to need protection from grazing. Vegetation may not recover well under limited water availability. In addition, fires that occur in winter expose soils for a long period of time before vegetation regrows, and potential soil damage through erosion may warrant protection from trampling and compaction.

Elevated risk of wildfire due to drought may increase expenditures on suppression, fuels management, and post-fire restoration. Fires force the closure of roads and recreation areas and destroy infrastructure, including fencing. Fires also cause financial losses due to reduced access for livestock grazing, and may damage infrastructure used for livestock management. Although the costs of conducting a prescribed burn on rangeland are relatively low, this option is financially risky for most private landowners due to laws in most States requiring reimbursement of fire suppression costs when a prescribed fire on private lands spreads onto public or adjacent private land.

Managed Herbivory

Livestock are a key economic driver in the Great Plains and are linked with drought and vegetation abundance. For example, the value of U.S. cattle production was $60 billion in 2015 and a record $82.1 billion in 2014 (USDA NASS 2018). Drought produces uneven livestock-based economic gains and losses in space and time. The 2014 Farm Bill authorized the Livestock Forage Disaster Program to provide compensation to eligible livestock producers for grazing losses due to a qualifying drought condition (this program was initially funded in 2008). Compensation is up to $30 per month for adult cattle for up to 5 months, depending on duration and severity of drought. Government payouts during 2014 were $4.4 billion, 84 percent of which were retroactive payments back to October 2011 (USDA ERS 2018) (box 7.3).

The southern Great Plains, which currently produces the most livestock in the Great Plains region, is more vulnerable to drought and loss of forage productivity than more northern locations. Texas has received the highest and second highest amount of supplemental and ad hoc disaster assistance payments between 2008 and 2016 (USDA ERS 2018). Ranchers in the southern Great Plains may need to rely on grazing management plans that vary with weather conditions, as well as consider using different livestock breeds. In the future, livestock production may shift northwards where water supplies and forage are more secure.

Stocking rates, timing, and location of livestock owned by grazing permittees may need to be adjusted in order to protect land and maintain vegetation for wildlife. A proactive strategy to manage rangelands before drought, in areas where forage species have evolved with grazing and fire, may be promotion of heterogeneity through a combination of fire and varying grazing intensities (Fuhlendorf and Engle 2001). Brief periods of heavy grazing combined with long intervals of low-intensity grazing may mimic historical disturbance. Reduced and deferred grazing during and after drought conditions allows for greater protection of a continuous vegetative layer. Resting rangelands for at least a season after drought may be necessary for recovery. Liquidating or relocating livestock is preferable to degrading rangeland and the cost of long-term loss of rangeland productivity. Stocking to 10–40 percent of historical levels during the past century has helped protect rangelands and provide other ecosystem services (Havstad et al. 2018, Wang et al. 2014), although some of this change has been offset by larger cattle size.

Decision making in the agricultural sector is complex, based on variability in weather patterns, along with shifts in market demands, consumer preferences, and State and Federal policies (Kopp et al. 2014). Ranchers may select conservative stocking as a long-term strategy or may stock more heavily and destock, with supplemental feeding and movement of cattle as additional actions in response to drought. Regular destocking and restocking due to forage insecurity is economically disadvantageous and risky (Neibergs et al. 2018), although flexible stocking and purchase of yearlings rather than maintenance of a base herd of cow-calf pairs may increase gains.

Maintaining a smaller core herd and incorporating yearling steers to economically increase stocking rates during drought years rather than merely having a conservatively sized constant herd may improve returns (Torell et al. 2010). In any case, aggressive destocking at the earliest detection of drought, when market prices are higher and cattle are heavier, may produce better economic outcomes while protecting natural resources and future productivity (Thurow and Taylor 1999). Measures that prolong predrought stocking rates, such as water availability and supplemental forage, may increase economic and ecological risk (Thurow and Taylor 1999). Managers may consider conservative constant rates versus flexible rates based on herd expansion with yearlings on public lands.

Flexibility in management prior to drought can be increased through the following actions:

- Maintain a reserve forage supply (e.g., stock conservatively, rest pastures, develop a grass bank).
- Improve infrastructure to allow pastures to be used in multiple seasons rather than just summer or just winter (e.g., water and shelter can be limiting factors).
- Ensure consistent water supply by installing wells and pipelines rather than relying solely on surface water; this will enable use of available forage if stock ponds go dry.
- Evaluate the potential for other forage sources, such as Conservation Reserve Program lands (if opened to grazing) or annual forages (cover crops).

Pasture recovery following drought can be enhanced through the following actions:

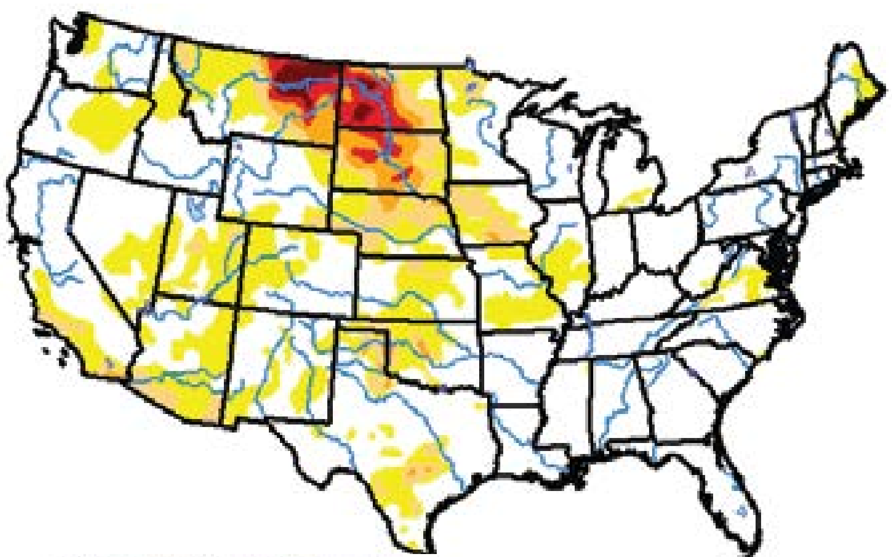
- Devote much of the year following drought to improving plant vigor and restoring protective residual vegetation and plant litter.
- Restore hydrological condition as a high priority for rangelands. The efficiency of precipitation is reduced until enough litter is accumulated to optimize infiltration and minimize evaporation. Delaying grazing when green-up occurs will allow this to occur faster.
- Restore plant vigor as the second highest priority by promoting rapid plant growth (which happens

BOX 7.3
Drought Intensity and Livestock Forage Program Payments

The U.S. Drought Monitor is used to trigger disaster relief payments for the Livestock Forage Program (LFP). A livestock producer is eligible if he or she owns or lease grazing land or pastureland physically located in a county rated by the U.S. Drought Monitor as having:

- D2 (severe drought) intensity in any area of the county for at least 8 consecutive weeks during the normal grazing period. The producer is eligible to receive assistance in an amount equal to one monthly payment.
- D3 (extreme drought) intensity in any area of the county at any time during the normal grazing period. The producer is eligible to receive assistance in an amount equal to three monthly payments.
- D3 (extreme drought) intensity in any area of the county for at least 4 weeks during the normal grazing period, or a D4 (exceptional drought) intensity at any time during the normal grazing period. The producer is eligible to receive assistance in an amount equal to four monthly payments.
- D4 (exceptional drought) in a county for 4 weeks (not necessarily 4 consecutive weeks) during the normal grazing period. The producer is eligible to receive assistance in an amount equal to five monthly payments.

For a map of counties eligible for LFP payments, see https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/livestock-forage/index.



Drought conditions (percent area)

	None	D0–D4	D1–D4	D2–D4	D3–D4	D4
Current	67.31	32.69	10.98	5.18	2.62	0.76
Last week 7/18/2017	70.67	29.33	10.58	4.77	2.31	0.22
3 months ago 4/25/2017	78.33	21.67	6.11	1.07	0.03	0.00
Start of calendar year 1/3/2017	53.89	46.11	22.53	8.63	3.15	0.96
Start of water year 9/27/2016	53.60	46.40	18.96	8.10	3.20	1.16
1 year ago 7/26/2016	49.07	50.93	20.75	7.13	2.92	1.11

July 25, 2017
(Released Thursday, Jul. 27, 2017)
Valid 8 a.m. EDT

Intensity
- D0 Abnormally dry
- D1 Moderate drought
- D2 Severe drought
- D3 Extreme drought
- D4 Exceptional drought

(Richard Heim, NCEI/NOAA)

when air temperatures and soil water are both favorable). Production and retention of photosynthetically active foliage are critical to restore belowground growth, which is reduced by drought stress and grazing stress.

- Expect a flush of broadleaf plants after drought breaks. Many forbs and native plants are highly nutritious and palatable at early growth stages. When these plants are grazed, pressure on desirable forage species recovering from drought is reduced.

The most popular drought management options focus on reserving forage supply, reducing herd size, and buying feed (Coppock 2011, Kachergis et al. 2014). The fact that many ranchers use similar drought management practices, potentially triggering major price fluctuations, highlights the market risks associated with drought. This reinforces the importance of flexibility in drought management strategies for drought adaptation because using diverse practices may help a producer reduce market risks (Kachergis et al. 2014).

Flexibility can be improved through the following actions:

- Vary stocking rate with forage supply (e.g., incorporate yearling livestock).
- Wean early to extend the forage base.
- Practice early and heavy culling of less productive cows, such as late-calving cows and older cattle.
- Remove yearlings from summer pastures early.
- Consider curtailing the production of replacement heifers for one year.
- Supplement bulls earlier than other classes of livestock if necessary, so they are in acceptable condition when the breeding season begins.
- Maintain a percentage of the livestock, such as yearlings or stockers, as a readily marketable class of stock.
- Consult with agency managers early to discuss which options are allowable under their permit (e.g., switching from cow-calf to yearling operation).

FEDERAL AGENCY GUIDELINES FOR DROUGHT MANAGEMENT

All USFS range managers and line officers are required to adhere to national and regional agency policies, and to follow their national forest/grassland plans and allotment management plans (AMP). These policies and plans match the number of livestock and/or season of use with forage produced and forage available for use, while considering rangeland conditions and long-term ecosystem health. Handbook directives are critical because they indicate the need for managers to build trusting relationships with stakeholders, especially permittees who are authorized to graze on USFS lands. It is good practice to proactively prepare for drought by having open discussions with permittees and to prepare solutions before the next drought begins, thus maintaining long-term productivity of rangelands and economic viability of livestock producers and communities.

Range managers in the USFS aim to not only protect landscapes but also aid local economies and social structures in dealing with drought. During drought, agencies can reduce the use of certain landscapes as well as assist local livestock producers. In an emergency, the USFS may withhold validation of a permit or require that livestock be removed from the range without advance notice to the permittee. However, permittees are rarely instructed to remove cattle without advance notice, even though plans are subject to change based on events such as fire and drought. Agencies can also authorize the use of available forage. During regional-scale droughts, temporary grazing permits may be issued to allow grazing use of USFS lands where such use will not result in resource damage.

Permittees, range extension specialists, and industry leaders have expressed the importance of helping permittees maintain a reduced core-allotment livestock herd. The core herd represents well-adapted, high-quality breeding stock. Livestock operators who are best positioned to maintain their core herds built over generations have some component of yearlings in their operation every year. Replacing a core herd is a long, expensive process.

Permittees have different abilities and desires to move livestock within an allotment or pasture (which is a subdivision of an allotment), and have different resources and conditions available to them outside of USFS lands. Moisture patterns can be significantly different from one allotment and even one pasture to the next. Allotments and pastures have different vegetation, topography, elevations, soils, rangeland health, forage production, and residual vegetation. It follows that rangeland management strategies are different for each allotment (e.g., fences, water, graze periods, pasture size, day herding, etc.). As a result, Federal managers are encouraged to develop strategies for each grazing allotment by involving permittees, most of whom follow weather, current range conditions, and projected forage growth conditions on their allotment.

Policy for drought management in the BLM exists at the Instruction Memorandum level and is not currently addressed in Handbooks. Instruction Memoranda with general policy are periodically issued from National Headquarters, as each drought becomes significant enough to be addressed, typically with a duration of 2–3 years. The principal guidance is the same as in the USFS: (1) work with affected permittees to adjust grazing use (timing of use, duration of use, livestock numbers) to maintain health of vegetation and soil resources, (2) allow temporary water hauling if appropriate, and (3) help find alternative forage in rested pastures or areas with non-use where appropriate for maintaining wildlife use. BLM regulations provide local officers with the authority to issue decisions to close allotments or portions of allotments, or to modify grazing when immediate protection of resources is needed because of drought, fire, flood, insect outbreaks, or potentially damaging effects of continued grazing.

The authorized officer consults with affected permit holders, interested parties, and appropriate State agencies before issuing the decision, which is effective immediately. This requires careful collaboration with stakeholders, especially permittees. Changes in grazing management or adjustments in season and number of livestock are either agreed upon by the permittee and BLM prior to making the adjustment, or implemented by BLM decision. Permittees may unilaterally decide to remove livestock from an allotment as a result of drought or other disturbance, then notify BLM of the removal. Ability to make adjustments on public land is often limited by availability of open water and its effect on distribution of grazing use.

PLANNING AND COLLABORATION

Proactive planning and collaboration can facilitate responsive management decisions during drought. Planning for the next drought must occur in advance because management options decline as drought intensifies. A drought preparation plan is strategic when it focuses on preparing an operation for drought in the long run (5–10 years) by identifying practices that can be implemented proactively to increase options for responding to drought (Hawkes et al. 2018). The rapid onset of droughts (i.e., flash droughts; see chapter 1) across the Great Plains suggests a need to incorporate these features in drought plans.

The primary goal in every drought management plan should be to maximize the number of potential management options in order to protect the resource before and during drought conditions, thus facilitating fast recovery in wetter years (Howery 2016). A drought plan should minimize financial hardships and hasten vegetation recovery following drought, identifying action to be taken at the first sign of drought as well as later. Plans for stocking rate adjustments need to be specific in terms of method and date, with timing of actions based on seasonal checkpoints associated with vegetation response. High plant vigor and good range condition are critical for rapid recovery from drought. There are no tools that can compensate for overgrazing, and timing and intensity of grazing are important factors in allowing pastures to recover from stress.

In some cases, an inventory of drought preparedness may be recommended to determine if it is feasible to implement the full range or a subset of responses. A drought preparedness inventory is a proactive practice that improves flexibility and demonstrates if a particular operation and location are indeed prepared for drought. A variety of management options should be considered to realize the full capacity of flexibility and where it may need improvement. Contingency options are limited if reliable infrastructure and resources are unavailable. Infrastructure (e.g., cross-fencing, water development, etc.) may need to be improved, repaired, or developed in order to implement a drought plan.

Working with all stakeholders to co-produce a strategic drought preparation plan helps build a shared vision, understanding, and realistic expectations and timelines. However, agencies and producers have different priorities, funding issues, and workloads that need to be understood and reconciled by collaborators. Each Western State has a drought management plan, and local and Tribal governments may also have plans. Being aware of the drought management plans developed by governmental entities that exist within each jurisdictional area helps ensure that local drought management efforts are compatible. Different agencies may participate in local drought management planning to coordinate information about needs and available resources. Building a collaborative vision and understanding is likely to result in a productive plan with feasible contingency options when critical responsive actions need to be implemented in a timely manner. The collaborative process also builds working relationships that improve trust, efficiency, and communication.

For managers of Federal lands, preparing contingency plans and identifying infrastructure needs begin with the National Environmental Policy Act (NEPA) process, AMPs, and annual operating instructions. These require time and make planning for drought in advance even more critical. By starting the planning during the NEPA or AMP process, proactive practices are implemented before responsive decisions are needed. In preparation for drought management decisions, having buy-in on the plan from all parties will trigger timely responses that protect resources. Managers may consider development of triggers that invoke automatic changes in management to reduce potential surprises. Such triggers are already being developed in the Southwestern Region, where the Standardized Precipitation Index (SPI) is being used to adjust management according to unfolding conditions. These triggers and linkages with SPI can be found in the Regional Supplement to the Grazing Permit Administration Handbook (Forest Service Handbook [FSH] 2209.13).

ROLE OF PUBLIC LAND MANAGERS IN PROMOTING RESILIENCE

Public land managers who work with private producers are uniquely positioned to promote resilience to drought in both the social and ecological dimensions of natural resource systems. Few people know the land base and what may work the best on a particular operation better than a private-sector ranch manager. Therefore, private landowners are increasingly recognized as key partners in the sustainability of multiple ecosystem services (Brunson and Huntsinger 2008, Charnley et al. 2014). Public land managers can act as knowledge brokers at the public-private lands interface to facilitate management for multiple uses and under extreme or variable weather conditions. Managers can serve as technical advisors to assist in drought planning and communicate about conditions on rangelands, promoting adaptive strategies that help limit the financial and ecological impacts of drought.

No allotment or operation exists in isolation from broader networks of social and ecological systems. At the allotment or ranch scale, adaptation can be influenced by belief in the ability to act (self-efficacy) (Marshall 2010). Managers who are well-informed about climate and weather can anticipate drought by developing drought management plans preemptively, employing conservative stocking rates and incorporating climate-adaptive breeds and genetic lines in livestock herds (Anderson et al. 2015, Derner and Augustine 2016). On a shorter time scale, they can anticipate variability using local knowledge and a growing number of weather-related decision-support tools and forecasts available (Reeves et al. 2015), although these may have limited adoption due to a lack of trust and skill (Marshall et al. 2011). Once drought occurs, managers can track variability through flexible stocking of diverse animal classes (e.g., with yearling or stocker animals) (Ritten et al. 2010, Torell et al. 2010). Use of spatial variability in the landscape and grass banking of stored forage are other tools to offset the effects of drought on forage supply (Derner and Augustine 2016, Gripne 2005).

At the community and regional scales, managers can promote flexibility by moving risk across space (movement of livestock to other areas) (Huntsinger et al. 2010), across time (storage of forage, water, or other resources), or across households (pooling labor, equipment, and information) (Fernández-Giménez et al. 2015, Mearns and Norton 2009). These risk-movement strategies can pair well with diversified agriculture and other market-based adaptation approaches on private lands to further enhance resilience to weather variability across landscapes (Sayre et al. 2012). Again, the adoption rate and success of adaptation strategies and tools, and the effectiveness of public agency involvement therein, depend on the structure and extent of social relationships across space and time (Fernández-Giménez et al. 2005, Marshall et al. 2011).

Natural resource social science offers insights for public land managers seeking to promote understanding and use of drought adaptation strategies. This research indicates that many producers have years or generations of experience with drought (Coppock 2011, Marshall 2010). Traditional grazing management practices, many of which maximize livestock and vegetation production in the short term, are imbedded in production cultures and have been co-produced over decades by researchers, public managers, and ranchers (Bement 1969, Sayre 2017). Needs-based communication efforts designed to promote a two-way exchange of ideas and listening build on existing manager knowledge (Pannell and Vanclay 2011). Effective communication can create opportunities to explore new strategies that will address more uncertain or variable climate/weather scenarios in the future.

Decision making on ranches is context specific (Roche et al. 2015), and ranching operations and operators are diverse. Operators have varying levels of willingness and ability to act for drought adaptation and may have limited proactive strategies in place to cope with reduced water and forage supply and market shifts (Darnhofer et al. 2016, Kachergis et al. 2014, Wilmer and Fernández-Giménez 2016). Permittees make decisions within place-based economic, ecological, and cultural contexts and serve in different decision-making roles throughout their tenure on family operations. This means that one best practice is unlikely to fit all operations over time, even within a small geographic area. Considerable value exists in diverse decision-making approaches that foster ecological variability and build capacity to manage for the effects of drought and other objectives (Wilmer et al. 2017). Risk management models, decision maps, peer-to-peer learning, and scenario planning activities can be used to communicate data and adaptive strategies (Dunningham et al. 2015).

Collaborative adaptive management (CAM) allows resource managers to develop a community of practice that is informed about variable weather and complex ecosystems (Armitage et al. 2009, Filipe et al. 2017, Lawson et al. 2017, Susskind et al. 2012). Collaborative adaptive management incorporates some elements of experimental design with facilitated outcome evaluation and decision making by a diverse group of stakeholders (Beratan 2014), allowing managers to test hypotheses and reduce uncertainty about ecosystem processes and drought response, rather than focusing solely on prescriptive management (Holling and Meffe 1996). Collaborative adaptive management also has the potential to empower managers to operationalize scientific and weather information for specific decisions (Dunningham et al. 2015). Effective CAM requires long-term commitment from participants and hosting organizations, attention to local political contexts, and explicit efforts to incorporate multiple types of knowledge in decision making (Filipe et al. 2017, Harrison et al. 1998, Hopkinson et al. 2017).

CONCLUSIONS

As the climate continues to warm in the future, weather in the Great Plains is expected to become increasingly variable and drought is expected to be more frequent. Monitoring tools and good communication can help range managers anticipate, detect, prepare for, and respond to drought. Sustainable management of native grasslands may be the best drought protection plan of all. Rangeland management differs based on local conditions, but core principles remain, primarily restoration or maintenance of diverse native species that nurture belowground ecosystem health and facilitate a range of species tolerances to meet changing conditions, including drought. Similarly, protection of the soil resource will maintain water-holding capacity and support vegetation cover, attenuating drought effects. Fire and variable-intensity grazing are primary disturbances in rangelands and provide mechanisms to increase vegetation heterogeneity. Where plant communities exhibit serious dysfunction in any of the three widely recognized attributes of rangeland health (soil stability, hydrological function, biotic integrity; National Research Council 1994), restoration of native species can be prioritized to promote competition with invasive annual grasses.

Numerous strategies are available for livestock producers to prepare for drought and buffer economic volatility, ranging from conservative stocking to economic diversification. Herd liquidation to prevent degradation of rangelands is a shared strategy during drought, which causes economic loss due to selling at the same time and buying simultaneously after recovery. Although economic downturns provide disincentives to reducing stocking rates, delayed response to drought may degrade rangelands if high stocking levels are decoupled from forage production, resulting in long-term productivity declines, which makes retention of a core herd more challenging. Information about drought scale, severity, and forecasts improves decisions on how to balance short-term gains and losses against risk of damage to future productivity.

Communication among livestock owners, grazing association boards, governmental agencies, and other stakeholders will help achieve favorable outcomes during drought years, facilitating a return to profitability and sustainability. Preparation of scientifically informed plans for addressing drought begins before drought conditions appear. Proactive practices increase management options and flexibility, and collaboration and positive relationships are crucial for the planning process before, during, and after drought. Successful practices can inform the next cycle of preparation for drought, a process that needs to become embedded in management of rangelands.

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