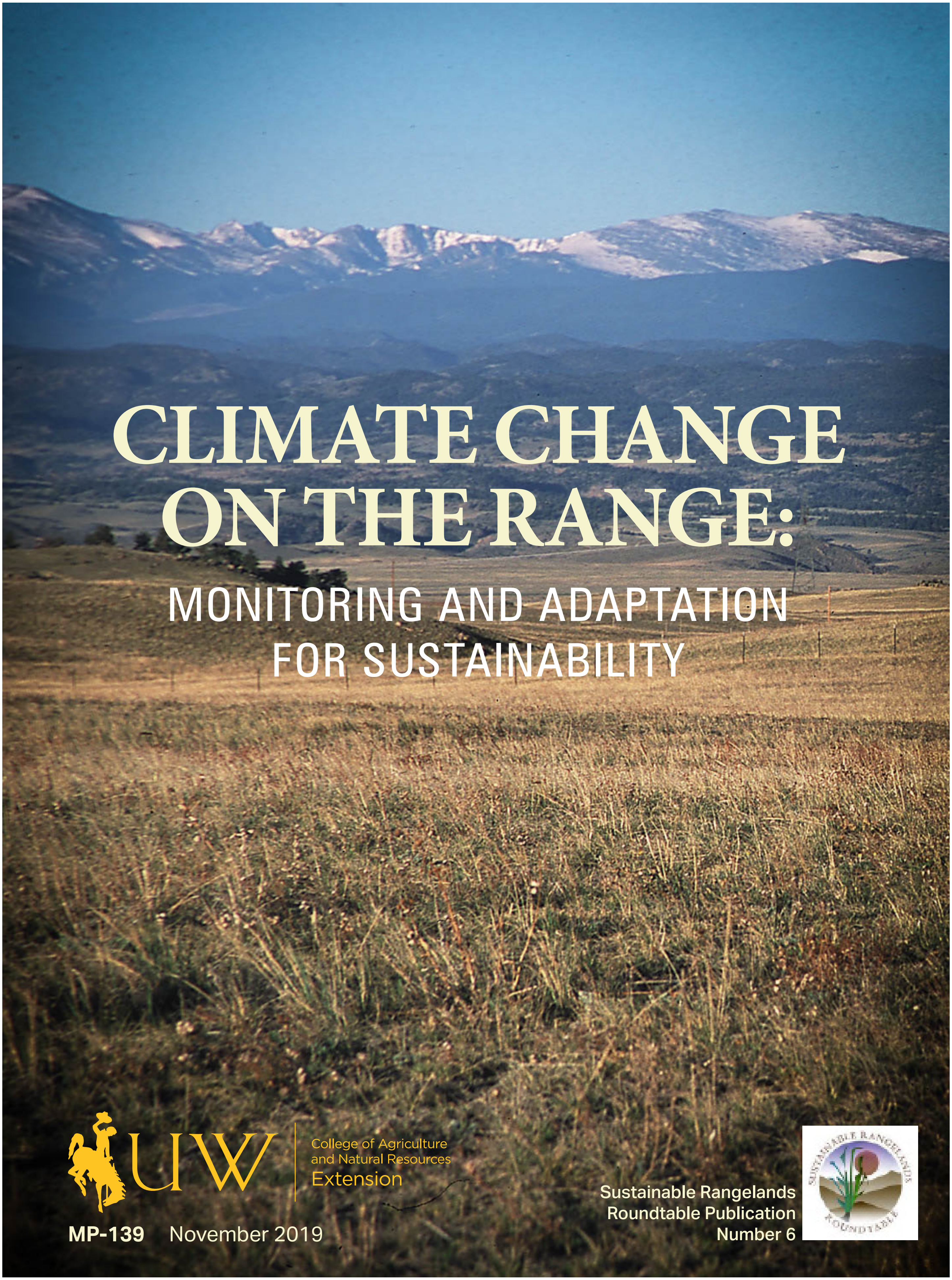

CLIMATE CHANGE ON THE RANGE:

MONITORING AND ADAPTATION FOR SUSTAINABILITY

UW College of Agriculture and Natural Resources Extension

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Sustainable Rangelands Roundtable Publication Number 6

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CLIMATE CHANGE ON THE RANGE:
MONITORING AND ADAPTATION FOR SUSTAINABILITY

CONTENTS

EXECUTIVE SUMMARY

Rangelands encompass over 770 million acres of land in the United States, and despite their classification into a single land “type”, these U.S. rangelands occur across a variety of ecosystems and have unique vulnerabilities and suggested management practices. There is consensus in the scientific community that rangelands are especially vulnerable to the effects of climate change, and that management will have to be adjusted in response to these changes. In this document, authors used the Intergovernmental Panel on Climate Change (IPCC) reports over the past decade, as well as studies from other experts in the field, to summarize projected changes to U.S. rangelands. Since U.S. rangelands are so diverse, authors divided the country into five eco-regions, organized into three separate sections: Southwest North America (including the desert Southwest and Great Basin); the Great Plains; and the Gulf Coast (including Florida coastal rangelands and the Texas coastal prairies).

Within each section, projected temperature and precipitation changes are reported, along with potential ecological responses to these changes. Authors then implemented the Integrated Social, Economic, and Ecological Conceptual (ISEEC) framework, developed by Fox et al. (2009), in the second half of the document to discuss how to identify and quantify changes to rangelands in the different eco-regions using a suite of indicators, and offer management alternatives to best adapt to these changes. Two case studies highlight challenges and achievements of land managers successfully adapting their rangeland management to mitigate climatic risk. The first case study features a 4th generation ranch operating on private rangeland in northern Texas, treating invasive species and using prescribed fire to manage vegetation. The second case study addresses public rangeland in northeast Colorado, with the added element of federal grazing regulations.

By learning as much as possible about how different ecosystems may respond to climate change, land managers can anticipate management adaptations necessary most likely to mitigate the most negative impacts of these changes. Consistently using a suite of indicators to assess the land and adapt management accordingly, will enhance land managers ability to sustain working rangelands for future generations.

Photo by Gary Kramer, USDA NRCS; Colorado

Introduction

There is widespread agreement climatic conditions are changing globally due to increasing concentrations of greenhouse gases in the Earth's atmosphere (IPCC 2013). Changes in climatic conditions are expected to continue and become more apparent in the coming decades. Climate change is projected to alter the global hydrologic cycle and affect surface and groundwater across the globe. There is still some uncertainty regarding rates of changes in temperature and considerable uncertainty about the direction of precipitation responses in many regions (IPCC 2014, USGCRP 2017). These climate change-related uncertainties complicate development of rangeland management practices to cope and adapt at regional and smaller spatial scales.

Recognizing that these changes can potentially have strong impacts on rangeland systems, the Sustainable Rangelands Roundtable (SRR) convened a working group to consider the sustainability of rangelands under changing climate conditions. While much work on climate change impacts has focused on measuring risk and reducing uncertainty, the SRR working group focused on adaptation to reduce vulnerability and enhance resilience.

Rangeland managers have always lived with climate variability. Rangelands in the semi-arid or arid western U.S. occur in ecosystems that experience occasional periods of drought of variable duration. As a result, precipitation tends to be the limiting factor affecting rangeland productivity; however, changes being observed now, and projected for future decades, in rangeland systems are new in that they are unidirectional (most regions will experience warming) and the rate of change is expected to accelerate (McCollum et al., 2017). The major effects of climate change on these ecosystems are experienced


Photo by Gary Kramer, USDA NRCS; Colorado

primarily through shifts in the relationships among water, soil, and plants (Campbell et al., 1997; Fay et al., 2008; Heisler-White et al., 2009; Morgan 2005). Climate change may also manifest itself in unique and unexpected ways at the local and regional scales (Williams and Jackson 2007) where most rangeland management decisions are made. The severity of changes that land managers will experience depends on the resilience of their rangeland systems. Resilience is the ability of systems (ecological or socio-cultural) to tolerate change without transitioning to a different type of system. Rangeland systems' resilience, in conjunction with innovative land management strategies, may temper the effect of climate change and the need for more drastic management actions (Holling 1973).

We lack precise understanding of how climate change will impact the management of ecological systems (Lawler et al., 2010); however, adaptive management can help us adjust to changing environmental conditions, reduce vulnerability to worst-case outcomes, and increase resilience to climate change. Scientists and natural resource managers having access to quality information is critical to efficiently develop adaptive management strategies. One key to the success of adaptive management is land assessment and monitoring information so managers can track systems' responses to climate change. Assessment and monitoring of the environment, ecosystems, socio-economic conditions, and human responses to climate change are vital to any successful adaptive management strategy. This knowledge can be used to optimize rangeland management for improved resilience, thereby benefiting social, ecological, and economic systems.

Criteria and indicators to monitor, assess, and manage rangelands were developed in response to a growing need among conservation and commodity organizations, government agencies, universities, and tribal governments to assess the rangeland sustainability (Maczko et al. 2004; Maczko and Hidinger 2008; McCollum et al. 2017). Fox et al. (2009) developed the Integrated Social, Economic, and Ecologic Conceptual (ISEEC) framework to provide a comprehensive assessment tool for understanding linkages and processes related to rangeland sustainability.

The following scenarios and examples show how the ISEEC framework may help land managers as they prepare for, and adapt to, climate change. We consider the SRR indicators as a way to evaluate resilience. We present examples from five regions organized into three sections: Southwest North America (including the desert Southwest and Great Basin); the Great Plains; and the Gulf Coast (including Florida coastal rangelands and the Texas coastal prairies).

Vulnerability and Resilience

Vulnerability is the sensitivity or susceptibility to harm and a lack of capacity to cope and adapt (Agard and Schipper 2014). Reducing vulnerability in a system can increase the resilience of that system in response to change. Managing for sustainability focuses on maintaining the functionality of a system in the face of change or maintaining the elements needed to restore the system when the change is large enough to affect the structure or function of the system. **Resilience** is the capacity of a system (ecological or socio-economic) to tolerate change while maintaining some level of functionality and provision of goods and services. The resilience of social systems is increased by our human capacity to anticipate and adapt to future changes. Linked social, ecological, and economic systems have the capacity to adapt to change, with managers playing an integral role in the system (Walker et al., 2002).

In technical terms, adaptation refers to actions taken to reduce the impacts of climate change, while mitigation refers to efforts to reduce the amount of climate change, for example by reducing carbon dioxide emissions or providing for carbon storage in soils and plants. Resilience and adaptive capacity have been used interchangeably, but Holling (1973) defines resilience as having three defining characteristics:

- the amount of change a system can tolerate (and the amount of stress it can sustain) while maintaining the same function and structure;
- the degree to which a system is capable of self-organization, requiring fewer feedbacks to be introduced by managers that can unintentionally result in the system deviating from the desired behavior; and
- the degree to which a combined social, ecological, and economic system can adapt and learn (Walker et al., 2002).

Projecting the particular outcomes of climate change at local and regional levels has proven difficult. Focusing on a suite of plausible futures (and the outcomes and vulnerabilities associated with each) and how different policy and management strategies may play out in each may be more useful (Lempert et al., 2004, Sarewitz et al., 2000). While decisions about how to adapt to climate change impacts may be sensitive to uncertainties, including multiple adaptation options can result in robust planning (Dessai and Hulme 2007).

Rangeland managers have a persistent need to consider how to adapt to the impacts of climate change on rangeland systems. Adaptation can encompass changes to processes, practices, and structures to moderate potential damages or take advantage of opportunities and adjustments to reduce vulnerability of communities, regions, or activities, such as livestock production (IPCC 2001). While climate change is global in scale, these adaptive strategies will need to be local or regional in nature and also must consider the social, ecological, and economic drivers and responses of rangeland change (Joyce and Marshall 2017).

Uncertainty in climate change projections presents challenges for rangeland managers to act, yet addressing climate change in management plans is necessary to protect natural resources. Addressing uncertainty around climate change impacts on rangelands will require flexible management strategies, regular monitoring, and practices/policies that allow managers to adapt as new knowledge is gained (Lawler et al., 2010). Managers must cope with uncertainty not only in the nature and level of projected climate change, but also in the responses of natural systems to change, along with those of the related economic and socio-political systems.

Photo by Gary Kramer, USDA NRCS; Montana

Projected Effects of Climate Change in U.S. Rangeland Regions

“Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen” (IPCC 2014). The rate at which warming is expected to continue varies depending on the greenhouse gas emissions scenarios (Figure 1). Increases in average surface temperatures range from upward of 5 °F in the lower emissions scenario to 10 °F in the higher emissions scenario by end of century (Figure 1). Warming is affected by proximity to oceans, with more severe warming projected for interior continental regions where most rangelands are located.

Temperature is a critical driver of atmospheric phenomena, so global changes in temperature are also altering precipitation patterns. In general, a warmer atmosphere tends to be more dynamic, with an increased frequency of severe storms and precipitation delivered in larger events (IPCC 2012). How these severe events will develop across the U.S. is likely to vary more than projections for warming. Overall, annual precipitation amounts are expected to increase at northern latitude and decrease in the south (Figure 2). The transition zone between areas of increased and decreased precipitation will move depending on the season. During winter, that zone stretches from approximately southern California to South Carolina, and in summer pushes north into Canada (Figure 2). The southern Great Plains and Pacific Northwest are projected to receive less precipitation, while winter and spring will be wetter or drier, depending on latitude. Despite uncertainty in the precipitation projections, the cross-hatching in Figure 2 indicates where the models are in agreement.

The implications of changing temperatures and precipitation will vary for different rangeland regions. For instance, continued warming is likely to have different implications for rangelands in the Northern Great Plains, where present-day cool temperatures can limit seasonal plant production, versus in south

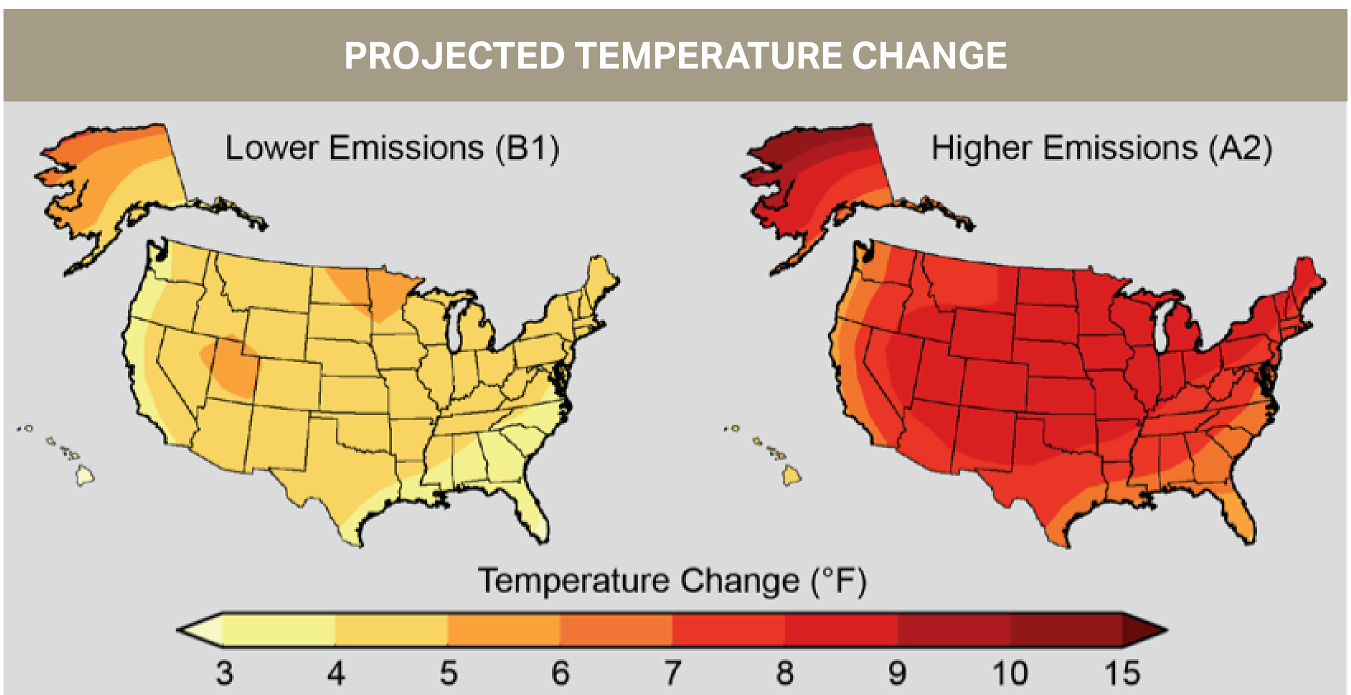


Figure 1. Maps show projected change in average surface air temperature in the later part of this century (2071-2099) relative to those observed in 1970-1999, under two scenarios: Scenario B1 assumes substantial reductions in heat trapping gases, and Scenario A2 assumes continued increases in global emissions (Melillo et al., 2014). (Figure source: NOAA NCDC / CICS-NC).

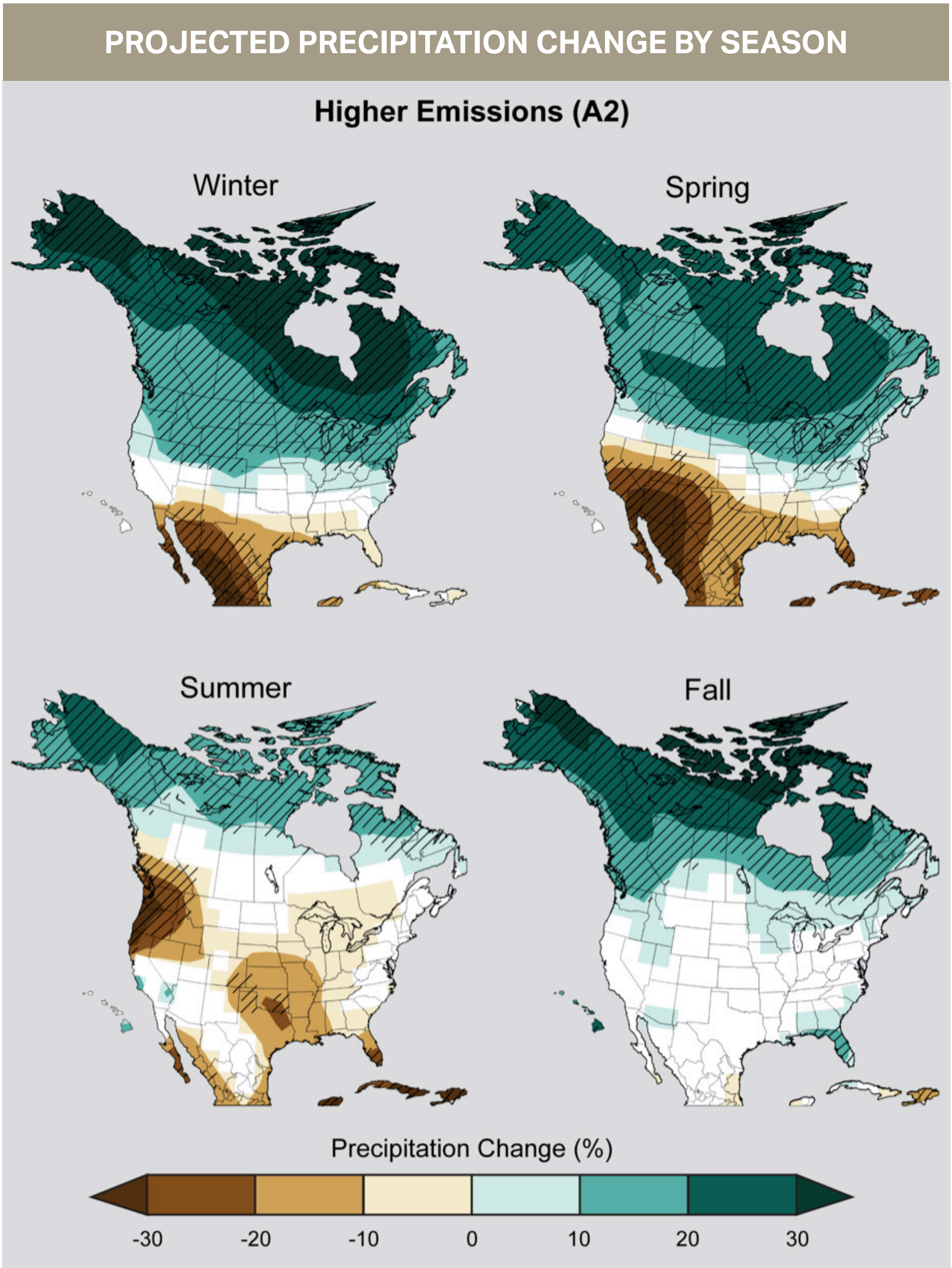


Figure 2. Projected change in seasonal precipitation for 2071- 2099 (compared to 1970-1999) under an emissions scenario that assumes continued increases in emissions (A2). Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the southwestern U.S. is projected to experience less precipitation in the spring. (Figure source: NOAA NCDC/ CICS-NC).

Florida, where the incidence of high temperature stress for livestock will increase in an already warm climate. To highlight some of these potential differences, we briefly review climate change scenarios and implications for three important United States' rangeland regions.

Southwest North America

The Southwestern quadrant of North America – a region from the High Plains to the Pacific Ocean, from northern California to southern Mexico – covers a major portion of the arid and semi-arid rangelands within the U.S. There is relatively high agreement among 24 climatic models of a drying trend in the years ahead (Seager and Vecchi, 2010).

In the U.S., the southern portion of this region includes the warm, scrub systems of the Chihuahuan Desert in southern New Mexico and the Sonoran and Mojave Deserts further west in Arizona, California, and southern Nevada (Figure 3). Shrubs and semi-shrubs dominate the relatively high altitude (4,000-6,000 feet) Chihuahuan Desert, while more diverse plant life occurs throughout the lower altitude Sonoran (1,000-3,000 feet) (Oosting 1956). Due to sometimes dramatic changes in elevation, vegetation within a bioclimatic zone can change abruptly within a short distance (Ryan et al., 2008), from creosote bush (*Larrea tridentata*) to cactus (*Cactaceae*)-dominated desert scrub to forested lands. Some of the most prolonged and serious U.S. droughts have occurred in this region. The Mojave Desert is the lowest elevation, hottest, and driest of the three southwestern deserts (Chihuahuan, Sonoran, and Mojave), with annual rainfall often less than 2 inches. It contains some of the same species as the other two warm deserts, plus the distinctive Joshua tree (*Yucca brevifolia*) at upper elevations in the north.

North of the Mojave, centered primarily in Nevada, is the Great Basin, which is a cold desert (4,000-8,000 feet). Sagebrush (*Artemisia spp.*) communities are dominant in the northern part of the Great Basin while evergreen shadscale saltbush (*Atriplex confertifolia*) and bud sage (*Picrothamnus desertorum*) are more important in the south (Oosting 1956). Much of this region has been invaded by cheatgrass (*Bromus*

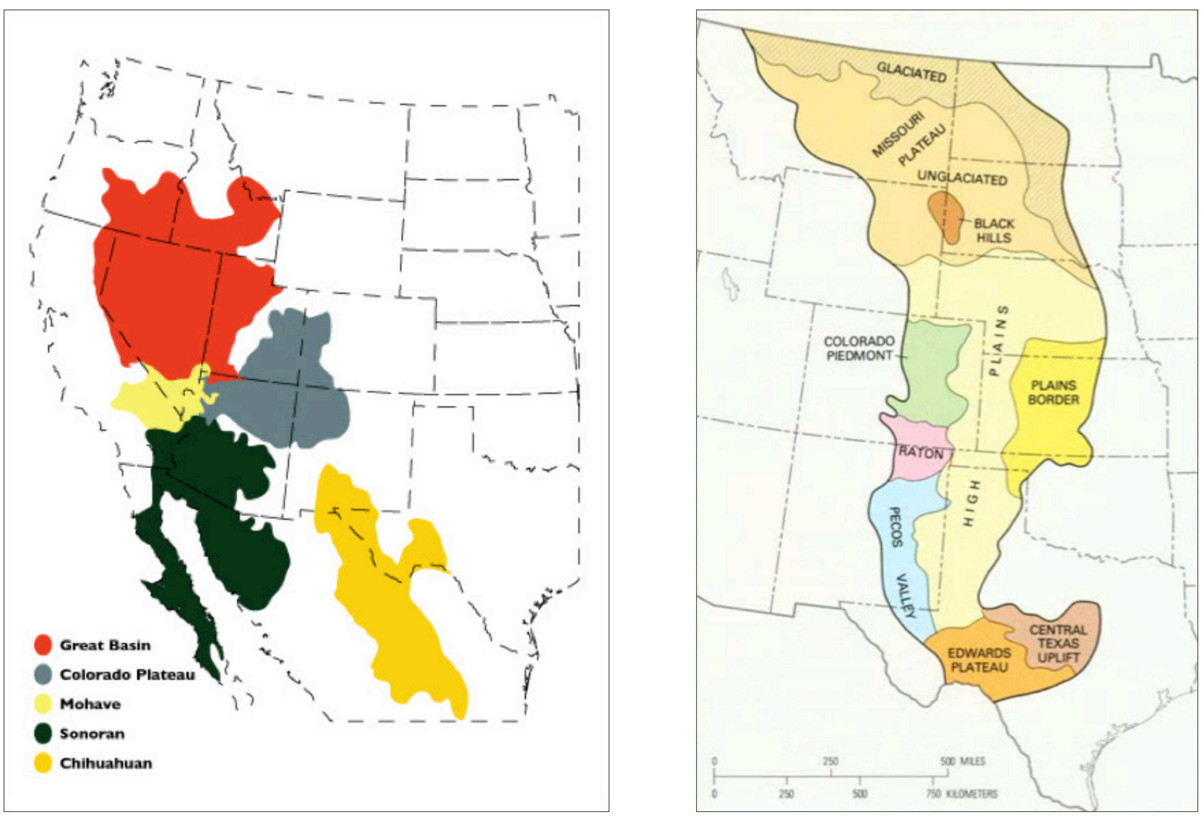


Figure 3. The Southwest (Tanaka et al., 2009) and Great Plains (Trimble 1980) regions.

tectorum) since the introduction of sheep and cattle into this region in the late 19th century by Europeans (Mack 1981). Because of the magnitude of this invasion and the effects to native ecosystems through associated changes in the fire cycle, this may be the most significant plant invasion of North America (Chambers et al., 2007).

The Colorado Plateau lies between the cold and warm desert regions in the Four Corners area (southeast Utah, southwest Colorado, northwest New Mexico, and northeast Arizona). Its vegetation is dominated by desert scrub, primarily low evergreen or winter-deciduous shrubs, plus perennial warm- and cool-season grasses. Important shrub species include blackbrush (*Coleogyne ramosissima*), Mormon tea (*Ephedra spp.*), saltbush (*Atriplex spp.*), and winterfat (*Krascheninnikovia lanata*) at the lowest elevations, replaced by sagebrush (*Artemisia spp.)* at higher elevations. Montane and sub-alpine trees dominate the tallest peaks, with pinyon-juniper (*Pinus edulis*, *Juniperus osteosperma*) woodlands being prominent on the southern edge of the plateau (Schwinning et al., 2008).

The grazing of livestock in the Southwest region over the past 200 years has had a significant impact on vegetation, causing major shifts in species abundance and considerable degradation (Guido 2009; Schwinning et al., 2008). Today, many land managers in the Southwest suggest rangeland degradation and experience with drought are two factors that have instilled in them a more conservative management strategy, aiming to enhance resource resilience rather than maximizing stocking rates or even perhaps profit.

Turning now to historical and future climatic conditions in the Southwest region, temperatures since 1950 have been hotter than any period in the last 600 years and are projected to increase 2.5°F to 5.5°F by 2041-2070, and 5.5°F to 9.5°F by 2070-2099 at the higher emissions scenario. The greatest increases in temperature are expected in the summer and fall (Garfin et al., 2014). Annual precipitation is projected to decline for almost all of the Southwest throughout the remainder of this century. With these declines in precipitation and increases in temperature, soil moisture stress is likely to be greater for most of this region (Figure 4).

Photo by Tim McCabe, USDA NRCS; Arizona

Within major river basins of the region, such as the Colorado River Basin, projections suggest more frequent, intense, and longer lasting drought than in the historical record (Garfin et al., 2014). Uncertainties regarding future responses of large monsoon storms (Seager and Vecchi 2010) complicate our ability to project how severe these hydrological droughts will be. Given the region's fragile ecology, combined with a likely drier, hotter future, the following concerns are raised:

- Water is expected to become increasingly scarce. Severe drought has occurred in the past and could be even more severe in the future.
- Increasing temperatures, drought, wildfires, and weed invasions will transform the landscape and render many rangelands less able to support current ecosystem goods and services (for example, livestock and wildlife).
- A warmer, drier environment will reduce the effectiveness of restoration measures, or their probability of success, on degraded lands.
- More intense precipitation events will accelerate erosion and flooding potentials, increase risks to people and animals, and decrease water use efficiency.
- More severe weather will decrease the region's attractiveness to tourism and recreation.

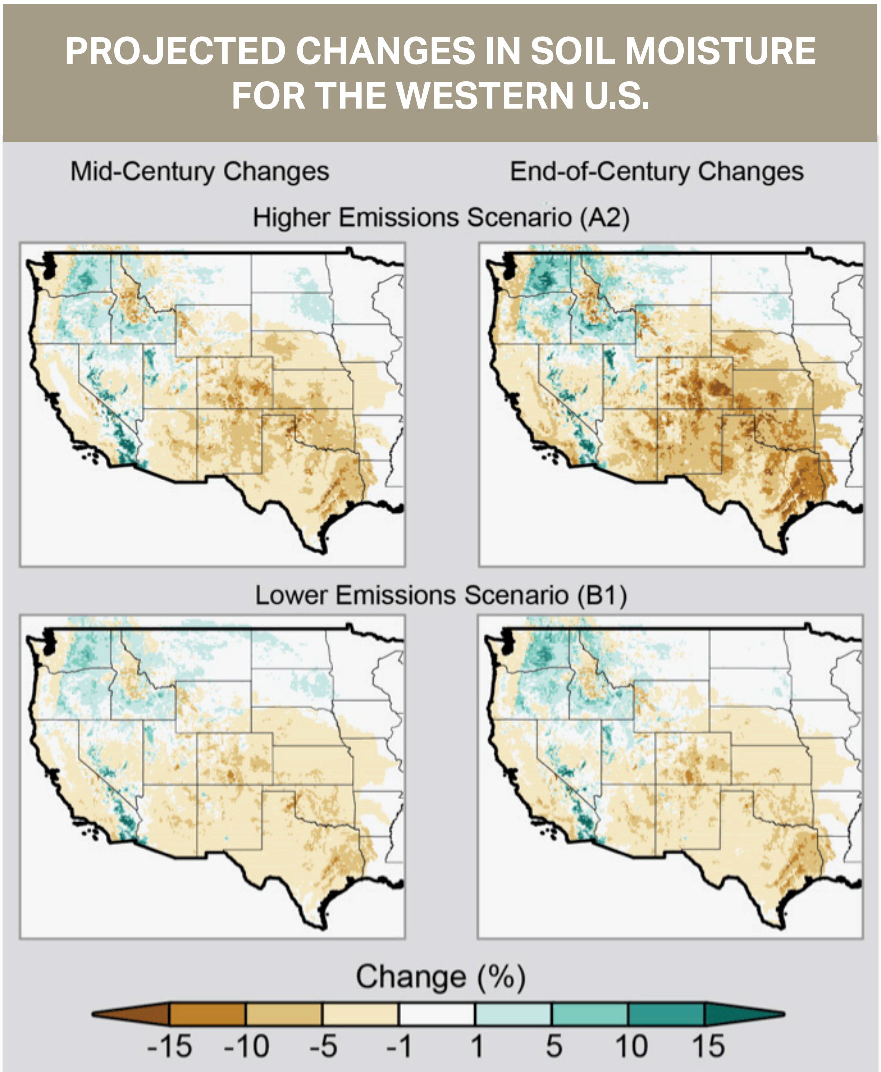


Figure 4. Average change in soil moisture compared to 1971-2000, as projected for the middle of this century (2041-2070) and late this century (2071-2100) under two emissions scenarios, a lower scenario (B1) and a higher scenario (A2) (Garfin et al., 2017). The future drying of soils in most areas, as simulated by the Variable Infiltration Capacity (VIC) model, is consistent with projections of future drought using the simpler Palmer Drought Severity Index (PDSI) metric (not shown). Only the western U.S. is displayed because model simulations were only run for this area. (Figure source: NOAA NCDC / CICS-NC).

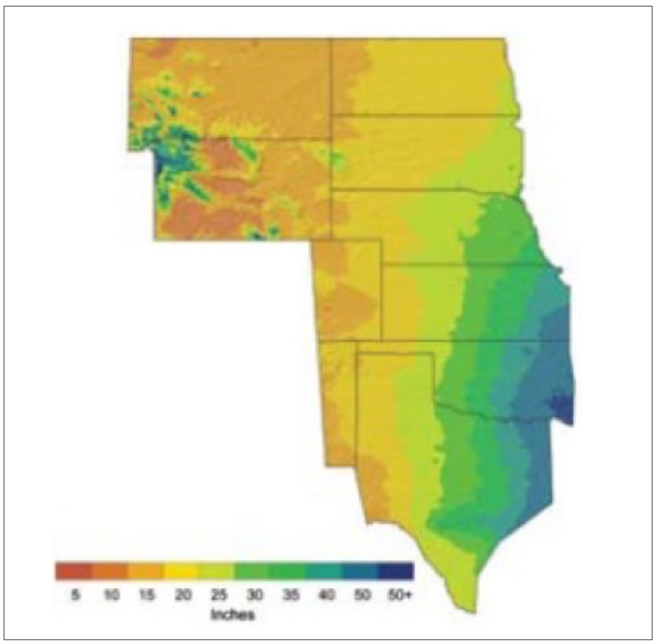
Great Plains

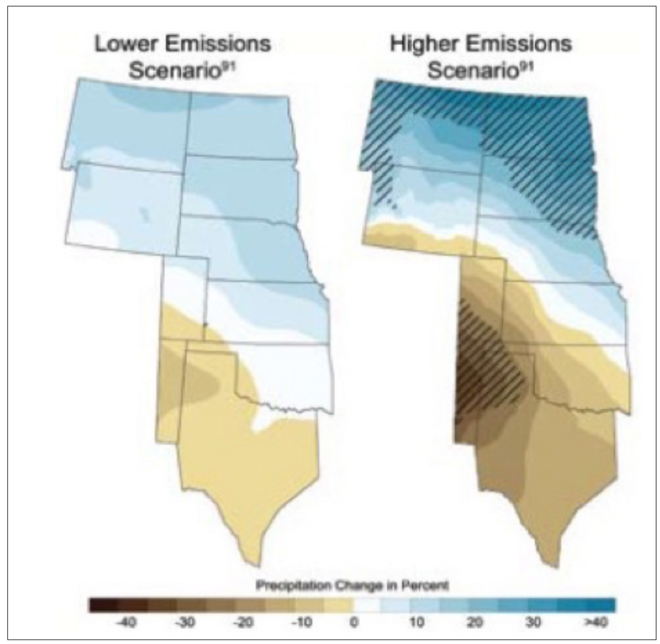
The Great Plains region comprises one of the largest native grasslands in the world. Although increasingly encroached upon by urbanization, 80 percent of the land area remains in agriculture, with over half of this area classified as rangelands and pasture (Ojima and Lackett 2002). However, agriculture's contribution to the economy has steadily declined through the 20th century, and is expected to continue (Freese et al., 2009). It is estimated that production agriculture recontributes directly only 4 percent of the economy in the northern Great Plains. Nevertheless, agriculture remains important for the region, particularly for rural communities when considering direct, indirect, and induced economic effects (Freese et al., 2009)

The Great Plains stretches eastward from the lee side of the Rocky Mountains (Figure 3) with a variable climate, transitioning from semi-arid in its western parts to a wetter, sub-humid climate as you move to its eastern edge, and from cooler temperatures in the north to warmer temperatures in the south (Figure 5a). Short-grasses dominate rangelands of the drier western Great Plains, especially in the southern half where warmer temperatures and a rain shadow created by the Rocky Mountains reduce water availability (Joyce et al. 2001; Launchbaugh et al., 1999). Cool-season grasses dominate northern latitudes, giving way to warm-season grasses at central to southern latitudes, and drought-resistant shrubs in portions of its southern reaches (Ehleringer et al., 1997; Epstein et al., 1997;

Joyce et al. ,2001; Terri and Stowe 1976). The growing season varies from 110 days in the northern Great Plains to 300 days in the southern Great Plains.

Over the past few decades, average temperatures have increased in this region, with fewer cold days, more hot days, and increased precipitation over most of the area (Karl et al., 2009[; Shafer et al., 2014]). Annual precipitation is expected to increase in the northern Great Plains and decrease in the southern Great Plains (Figures 5b & 6). Extreme events such as drought, heat waves, and intense precipitation events are predicted to become more common (Karl et al., 2009[, Shafer et al., 2014]). Temperature is projected to continue to rise, with larger increases in the northern reaches (Figure 5c); summer temperatures are expected to increase more than winter temperatures for the southern and central Great Plains (Karl et al., 2009[; Shafer et al. ,2014]). The desiccating effects of rising temperature may be partially offset by the beneficial effects of rising CO_2 on plant water use efficiency (Morgan et al., 2011), such that productivity, especially in the Central and Northern Great Plains, may remain somewhat stable until mid-century. Because of the differential responses of species and functional plant groups to CO_2 and warming (Polley et al., 2010; Morgan et al., 2011; Mueller et al., 2016), we cannot project with much certainty which species will respond more or less favorably to future conditions. Some of the more critical concerns for Great Plains rangelands include:





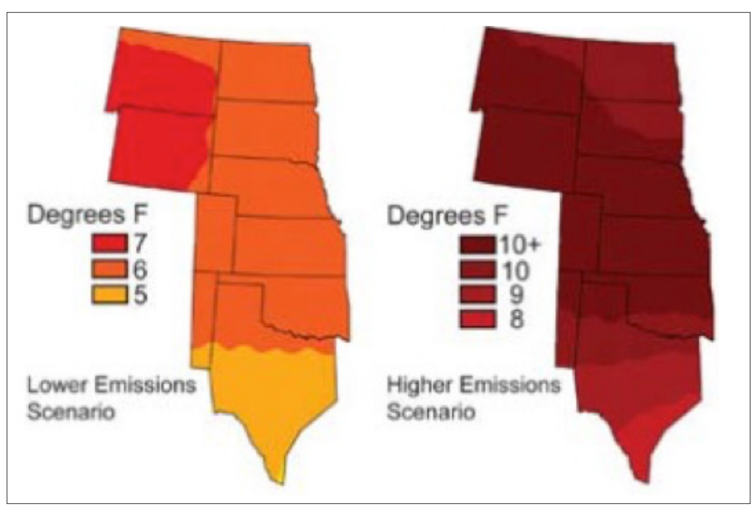


Figure 5. Past and future climates in the Great Plains. (a) Average annual observed precipitation (1971-2000) in Great Plains; (b) projected spring precipitation changes by 2080-2090s in the Great Plains for lower and higher emissions scenarios; and (c) summer temperature change in the Great Plains by 2080-2099 for lower and higher emissions scenarios (c). (Source: Karl et al., 2009).

PROJECTED CHANGE IN NUMBER OF CONSECUTIVE DRY DAYS

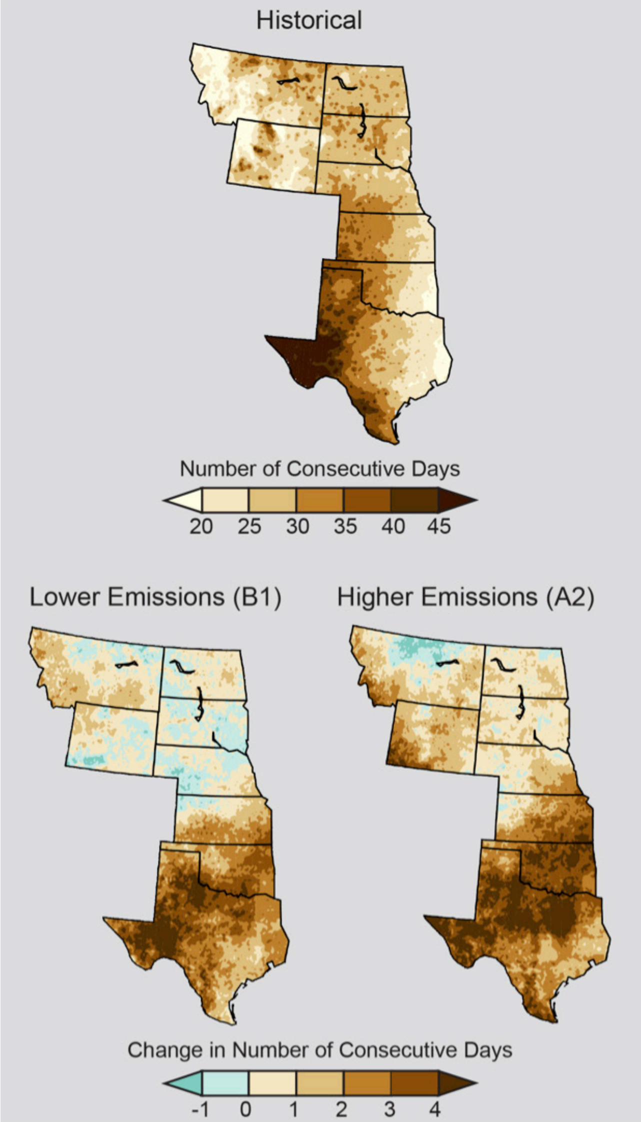


Figure 6. Current regional trends of a drier south and a wetter north are projected to become more pronounced by mid-century (2041-2070 as compared to 1971-2000 averages). Maps show the maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 (top), projected changes in the number of consecutive dry days assuming substantial reductions in emissions (B1), and projected changes if emissions continue to rise (A2). The southeastern Great Plains, which is historically the wettest portion of the region, is projected to experience large increases in the number of consecutive dry days. (Figure source: NOAA NCDC / CICS-NC).

- Increases in temperature, evaporation, and soil moisture deficits are expected in the region (USGCRP 2017).
- Warmer temperatures will enhance the northward spread of some plant and animal pests.
- Climate change is expected to alter the competitive balance among plant species, leading to species shifts, including increases in non-desirable plants (Morgan et al., 2007; Blumenthal et al., 2013, 2016).
- Climate change and associated change in plant species composition and quality are expected to alter critical habitat for wildlife, (for example, prairie potholes and playa lakes).
- Increases in temperature along with rising CO_2 may continue to enhance forage production in the northern Great Plains for at least the next few decades, but further south, warming-induced desiccation and lower precipitation may already be affecting net primary production.

Southeast

The humid, subtropical climate and abundant rainfall of rangelands in the southeastern United States distinguish them from the desert or semi-arid rangelands of the West. Two notable rangeland areas are the Texas Coastal Prairie (Gould, 1969) and the dry prairies and flatwoods of central and south Florida (Rauscher, 2008). These Florida rangelands have supported a large cattle industry since European settlement, given their 270-plus day growing season, abundant rainfall, and high productivity.

Prior to 1950, the dry prairies of Florida were mostly unfenced and dominated by native forage grasses like creeping bluestem (*Schizachyrium stoloniferum*), lopsided Indiangrass (*Sorghastrum secundum*), goobergrass (*Amphicarpum muhlenbergianum*), and little chalky bluestem (*Andropogon virginicus*). Since the 1950s, fenced pastures of bahia grass (*Paspalum notatum*) and Bermuda grass (*Cynodon dactylon*) have become more common. Rangeland vegetation in Florida is not particularly nutritious, so winter burning of native pastures has been a common practice to stimulate forage growth, nutrition, and palatability, and to improve wildlife habitat.

Similarly, the Texas coastal prairie has a growing season of more than 325 days and abundant annual precipitation (Scifres and Mutz 1975). Natural vegetation includes big bluestem (*Andropogon gerardi*), seacoast bluestem (*Schizachyrium scoparium*), and several *Panicum spp.* (Scifres and Mutz 1975). Introduced species like buffelgrass (*Cenchrus ciliaris*) have become more common in the mid-20th century. Woody plants are also common in the coastal prairie, including honey mesquite (*Prosopis glandulosa*), acacias (*Acacia spp.*), oaks (*Quercus spp.*), and pricklypears (*Opuntia spp.*). Much of this coastal prairie area has been drained and is now used primarily for row crops.

The climate of the Southeast has warmed slightly since 1970, rising an average 2°F, with the greatest increases occurring in the summer months (Carter et al., 2014). Regional precipitation has also increased in the northern and western parts of this region (Carter et al., 2014). Several areas have experienced an increase in heavy downpours, and extremely wet or extremely dry conditions have become the norm during summer.

Projections for the end of the 21st century suggest 4°F to 8°F of warming, with slightly larger increases for interior parts of the region. The number of days above 95 °F is projected to increase substantially (Figure 7); by the end of the century, north Florida is projected to

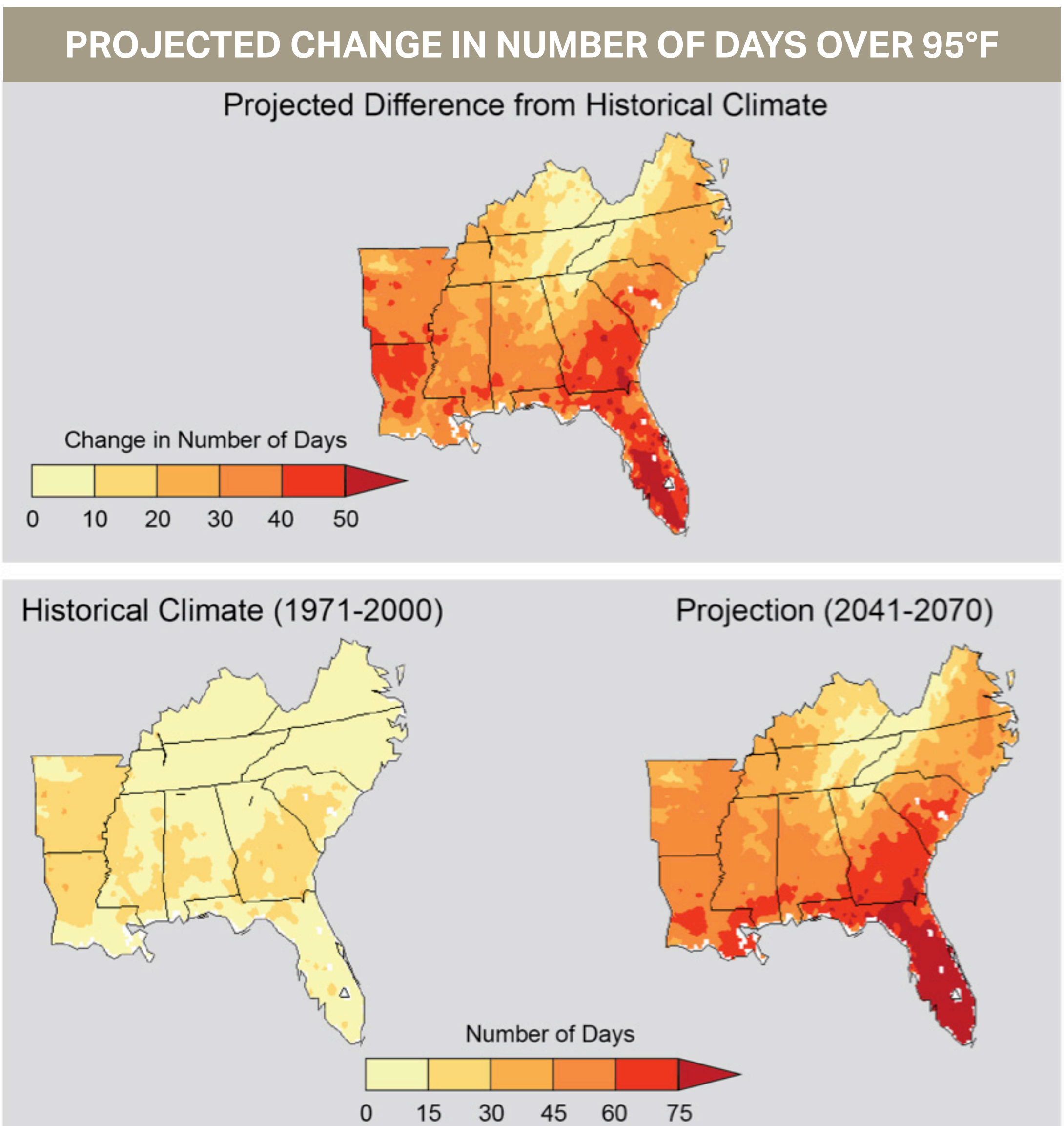


Figure 7. Projected average number of days per year with maximum temperatures above 95°F for 2041-2070 compared to 1971-2000, assuming emissions continue to grow (A2 scenario). Patterns are similar, but less pronounced, assuming a reduced emissions scenario (B1) (Carter et al., 2014). (Figure source: NOAA NCDC / CICS-NC).

Photo by USDA NRCS; New Mexico

have approximately 6 months of temperatures above 90 ° F compared to 2 such months in the 1960s and 1970s (Romm 2015). Future projections for precipitation for this region are more uncertain. The region sits between a drier region (southwest) and a wetter region (northeast), so model projections suggest a tendency towards less precipitation in the southwestern part of this region and wetter conditions to the northeast. Tropical storms are projected to be fewer in number globally but stronger in force, with more Category 4 and 5 storms (Carter et al., 2014). Some of the more important concerns about climate change and rangelands of the Southeast include:

- Decline in plant growth due to heat and drought stress.
- Decline in production of cattle and other rangeland livestock due to high temperature stress.
- Increased human illness and death related to greater summer heat stress.
- Warming, including warmer winters, plus increased incidence of heavy rainfall events. These effects may increase some disease and insect pests, while increases in drought may reduce some pathogens.
- Increased flooding of low-lying areas due to severe storms and sea-level rise, including storm-surge flooding of coastal areas.
- Saltwater incursion into freshwater aquifers is a related concern for irrigated agriculture and drinking water supplies for both livestock and humans.
- More frequent and intense wildfires.

Selecting Indicators to Assess Rangeland Sustainability under Climate and Environmental Change

Climate change will trigger broad environmental changes that strongly affect conditions and processes on rangelands. The resulting effects on ecosystem goods and services people use and value will stimulate responses in the way rangeland resources are managed and in policies implemented. Such responses will themselves have effects on rangeland conditions.

Indicators are one tool that can help make management responses to rangeland change more effective from the outset. Standardized resource monitoring provides consistent data that not only represents a point in time, but when collected repeatedly can be used to identify and evaluate trends in resource condition. This also makes it possible to improve the effectiveness of management responses over the coming decades as climate change continues and human responses become more consequential.

Indicators can be used to meet multiple needs. Rametsteiner et al. (2009) suggest that indicators provide more than an understanding of current conditions; they also establish a basis for understanding how humans and environmental systems operate and interact. Indicators have the potential to provide insight into ways that human and biophysical sub-systems influence each other and respond to disturbance and decisions; however, the identification, measurement and implementation of appropriate indicators continues to be a challenge facing decision-makers from local to global scales (McCool and Stankey 2004).

The use of sustainability indicators requires an integrated approach combining biophysical and socio-economic aspects and the relationships between them. The choice of indicators relies on framing the questions and selecting the appropriate suite of indicators at relevant scales. Many authors have expressed concerns and challenges facing the use of indicator approaches to assess sustainability (Cairns et al., 1993; Landres et al., 1988; Noss 1990; Noss and Cooperrider 1994; Simberloff 1997), such as:

- Monitoring programs often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of social, ecological, and economic systems;

- The choice of ecological indicators is often confounded in management programs that have vague long-term goals and objectives; and
- Management and monitoring programs often lack scientific rigor because of their failure to use a defined protocol for identifying indicators.

Perhaps the most challenging of these concerns is the third, often suggested as a reason indicators do not or cannot work consistently for assessing sustainability. This reinforces the need to use a systematic structural framework to help identify key interactions, stress points, and vulnerabilities. The SRR's ISEEC framework described in the next section is one such attempt. In the systematic process of analyzing the social, ecological, and economic context of rangeland systems, one can begin to identify linkages where effects of climate change might trigger responses.

While a conceptual framework to systematically guide one's thinking is essential to developing a system of indicators, identifying and developing indicators is science and art. One must consider the system, and interactions between components of the system, to identify points of stress and vulnerability. This will be illustrated in our discussion of regional management considerations.

What characteristics do indicators need to have to be useful conveyors of information? Dale and Beyeler (2001) summarized the structural criteria for ecological indicators as they must: (1) be easily measured; (2) be sensitive to stressors on ecosystems; (3) respond to stress in a predictable manner; (4) be anticipatory, signifying impending change in the ecosystem; (5) predict changes that can be mitigated by management; (6) be integrative across ecosystem processes (for example, soils, water, vegetation); (7) illustrate a known response to natural disturbances, anthropogenic stresses, and change over time; and (8) have low variability.

More broadly, the indicator selection characteristics agreed to by the SRR were the result of discussions on elements that would apply to social, ecological, and economic indicators. As evidenced by the 64 indicators originally identified by the SRR to assess social, ecological, and economic rangeland sustainability, there are a large number of potential indicators available to apply to resource questions;

Photo by Diane Shields, USDA NRCS; Idaho

however, one cannot practically monitor or measure them all. Decision makers and land managers need a method to choose the most important or applicable indicators for a given question; not all indicators must be monitored to address all issues. Rather, the full range of indicators offers a well-stocked toolbox from which appropriate indicators can be chosen.

The question then becomes how to select the most appropriate indicators for each question. SRR considered this question with regard to the full suite of SRR indicators. While several indicator selection frameworks have been identified for ecological indicators, comparable systems specifically for socio-economic elements were more difficult to find. Some criteria that apply to ecological indicators were also considered appropriate for socio-economic indicators; however this is not true of all selection criteria. SRR concluded ensuring inclusion of social, ecological, and economic indicators is important when evaluating sustainability. The full spectrum of indicators available to address rangeland issues should be evaluated for inclusion in research and assessment processes.

Indicator selection may vary depending on the question and issue. The selected measures should be kept as simple as possible while still providing necessary information for decision making. Primary characteristics for evaluating indicators include:

- **Importance/Informative**. The indicator needs to tell analysts something that they want to know.
  - Does the indicator provide information important for people to know?
  - Is it relevant to rangeland resources or conditions people value?

- **Relevance/Utility**. The indicator must help answer the question being asked, capture conditions and processes, and anticipate change.
    - Will the indicator provide early warnings of significant undesirable trends?
    - Does the indicator provide information about the consequences of rangeland management practices and uses?
- **Understandable/Clarity.** The indicator needs to communicate clearly to a broad audience.
    - Is the indicator easily understood by the people who intend to use it?
    - How likely is the indicator to become widely understood and accepted as a legitimate measure of an important rangeland condition or process?
- **Ability to Aggregate/Scale.** The indicator needs to be relevant at various scales and promote an integrated sense of sustainability.
    - Can measurements be made using consistent methods and protocols so data can be aggregated over an appropriate range of scales and times?
- **Data Availability and Integrity**. The indicator needs to be measurable and be measured in a standard, consistent, and appropriate way to generate high quality data.
    - Are there scientifically valid measurement and statistical methods for producing the indicator?
    - Are there scientifically valid bases for its interpretation and assessment?
    - Is it likely to improve scientific understanding of the behavior and causal relationships within and among the systems and subsystems involved?

Other considerations when evaluating which indicators to select include whether the indicators are affordable, provide added value, and are legally and scientifically defensible.

Using Indicators to Understand Implications of Climate Change and Socio-Ecological Interactions for Rangeland Resilience: A Gulf Coast Example

The Gulf Coastal Plain curves along the southern portion of the United States, stretching from the western half of Florida, through Alabama, Mississippi, Louisiana, and Texas to the border of Mexico in the south. The region is an extremely diverse landscape of terrestrial, freshwater, and coastal ecosystems varying amongst upland, alluvial, and shoreline landscapes (Ning et al., 2003). The Gulf Coast region maintains a unique climate compared to other regions along the same latitude. Due mainly to the influences of the Gulf of Mexico and the Atlantic Ocean, and to a lesser extent the El Niño/La Niña circulations in the Pacific, the region maintains typically mild winters with hot and dry summers (Twilley et al., 2001).

Future climate scenarios for the greater Gulf Coast region of the United States over the next century project that temperatures will rise, whereas precipitation projections remain uncertain (Carter et al., 2014). Understanding that some uncertainty exists, there have been some analyses of the potential impacts on major biophysical processes and their influence on socio-economic processes. To illustrate these potential interactions, we use the SRR's ISEEC framework (Figure 8). Through this framework, we can effectively visualize potential socio-economic and ecosystem impacts of climate change. The ecological subsystem of the framework recognizes biological interactions that drive ecosystem health and resilience while the socio-economic subsystem recognizes land management and resulting ecosystem health shifts (Fox et al., 2009).

At the top of Figure 8, the green boxes on the left represent the current state and condition of the biophysical (natural) ecosystem, while the blue boxes on the right represent the current state and condition of the socio-economic system and society. Ecological processes and socio-economic processes, represented by the boxes in the middle of the figure, act on the states and conditions in the current time period, resulting in new states and conditions in the future (bottom of figure). As Boyd (2010) notes, altered

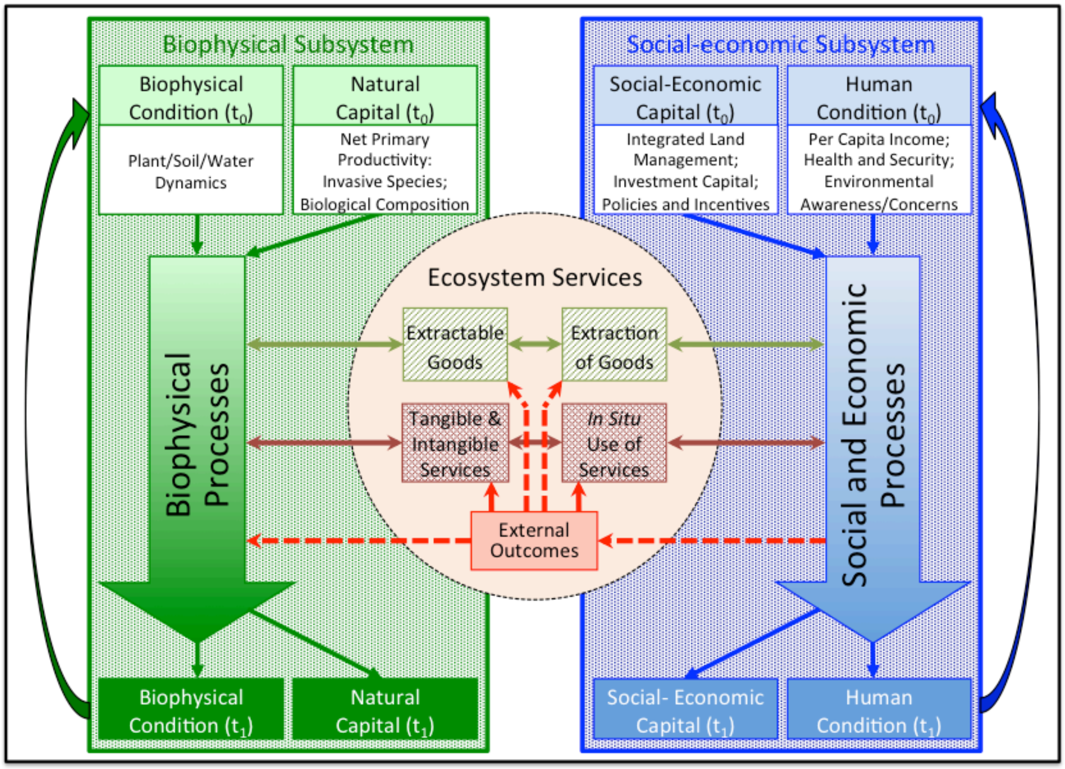


Figure 8. Integrated Social, Economic, and Ecologic Concept (ISEEC) for identifying links affecting delivery of ecosystem goods and services on rangelands (Source: Kreuter et al., 2012)

natural systems will in turn lead to social change, creating further feedbacks to the natural systems. We can assess vulnerabilities, resilience, and opportunities by examining how and why changes occur between time periods.

Interaction between the natural and the human realms occurs through ecosystem goods and services (EGS), i.e., the benefits that humans receive from natural systems. Rangeland EGS are discussed in detail in Maczko and Hidinger (2008). The EGS link natural and human systems and are the means through which socio-economic systems and processes affect and are affected by ecological systems and processes. Such interactions and effects occur through extraction of goods (for example, timber, forage, etc.) and their uses; tangible and intangible services (including processes that purify air and water, generate soils and renew their fertility, and detoxify and decompose wastes, among many others); pollution and other waste discharges (one means by which humans can have deleterious effects on EGS), and alteration of land forms and water flows (including such mechanisms as urbanization, landscape fragmentation, and degradation of wetlands, among others).

Many social and economic processes and actions can affect these EGS. Waste discharges occur as people burn fossil fuels, discard packaging from consumer products, and as other byproducts of economic production and social activity. Wastes released back into the ecosystem are acted upon by (or interrupt and otherwise alter) natural processes, and result in changes to natural system functions as reflected by EGS. Waste discharges, and EGS, can also be affected by recycling and efforts to conserve resources or shift away from behaviors that degrade the environment. Land is altered, habitats are fragmented, and composition of species change as land is subdivided and open space becomes residential development. Policy and regulatory actions, such as open space requirements or wildlife corridors, can mitigate alterations brought about by land use change.

Figure 8 illustrates specific examples of some natural and human processes and institutions that will play a role in the interactions and land management responses to climate change as they play out over time. The framework should be thought of as changes, perceptions of changes, and responses (with different responses occurring at different rates) occurring repeatedly over time. Effects and responses play out as natural conditions evolve and society responds to those changes. Land managers, policy makers, or society in general aim to either prevent negative changes in the first place (mitigation) or to change land uses and management practices in response to the changes (adaptation). For example, using wind rather than coal to generate electricity reduces carbon dioxide emissions and in turn mitigates the degree of climate change. Altering grazing practices or planting strategies to use less water is an adaptation to reduced precipitation, one of the potential consequences of climate change.

Potential Impacts of Projected Gulf Coast Climatic Conditions

Twilley et al., (2001) discussed the outcomes of two major climate change modeling efforts: Hadley Centre Model and Canadian Climate Centre Model. They illustrate five significant areas of climate change that could directly impact both biophysical and socio-economic processes in the greater Gulf Coast region: 1) temperature, 2) precipitation, 3) soil moisture, 4) runoff change, and 5) sea-level rise. Though these efforts do not agree across the board on impacts of climate change within the region, there are several areas where the models do agree that have the potential to dramatically affect ecosystem processes. First, the models project that there will be an increase in average temperature across the region in summer maximum, winter minimum, and July heat index. The range between these models for summer maximums is between 3-7 °F with winter increases between 3-5 °F. Both models project an increase in intensity of rainfall events with increased drought possibilities. There is some discrepancy between the models for soil moisture change, runoff change, and sea-level rise, but these are likely dependent upon temperature and precipitation patterns.

If these temperature and precipitation projections come to fruition, we can apply a more detailed Tier 2 version of the ISEEC framework to illustrate potential ecosystem process impacts (Figure 9).

Figure 9 illustrates a hypothetical Gulf Coast rangeland system including both biophysical and socio-economic processes. If projected climatic conditions do occur in the Gulf Coast region, impacts on current biophysical condition such as plant/soil/water dynamics will be highly influenced. Examples of possible impacts may include changes in hydrology, freshwater/saltwater

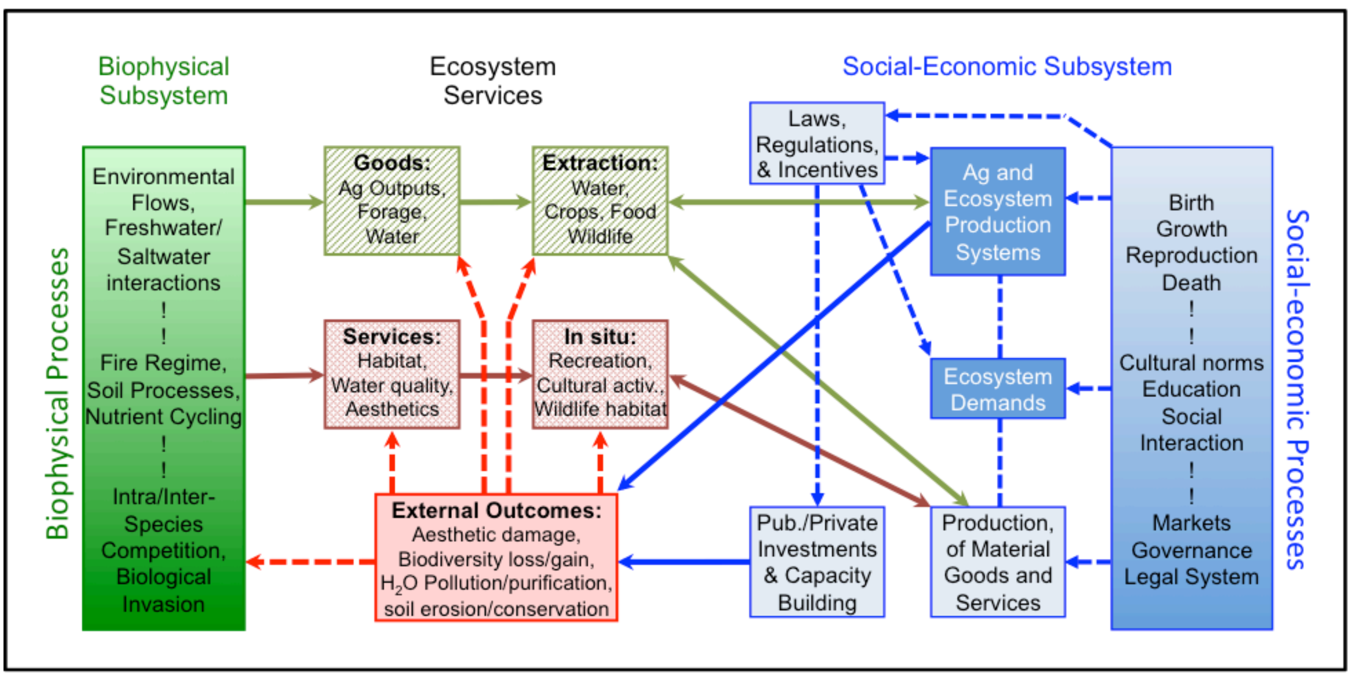


Figure 9. Application of the ISEEC framework to identify key biophysical-socioeconomic linkages that impact the delivery of ecosystem goods and services and that affect or are affected by potential climate change projections from rangeland ecosystems. (Source: Kreuter et al., 2012)

interactions, fire regime, soil physical/chemical/biological processes, nutrient cycling, inter- and intra-specific competition, and biological invasions. These basic processes would significantly impact current/future natural capital by changing net primary productivity and likely increase invasive species composition. These would, in turn, influence the overall biodiversity of both flora and fauna in the region.

As these basic biophysical processes adapt to new climatic conditions, the goods and services provided by the ecosystem will also change. In this hypothetical situation, goods such as agriculture outputs, forage, water, and their extraction are expected to change. Ecosystem services will be impacted, including shifts in habitats, water quality, and aesthetic value; along with *In situ* services such as recreation, cultural activities, and wildlife habitat. With the change in the ecosystem's ability to provide desired ecosystem goods and services, impacts will begin to be manifested in the socio-economic processes of the overall ecosystem.

Under changing climatic conditions, it is likely that new social and economic capital will be influenced. Laws, policies, regulations, and incentives will be implemented to adapt to the changing climate. These changes will require public and private investments and capacity building and affect agriculture and ecosystem production systems and production of material goods and services. All of these will influence the socio-economic demands placed upon the ecosystem. As social and economic capital changes, we would expect there to be a corresponding change associated with the human condition impacting population dynamics, cultural norms, education, social interactions, markets, governance, and legal systems. Ultimately, changes in the socio-economic subsystem, as influenced by biophysical processes and their response to climatic shifts, will feed back to the biophysical subsystem. We may expect, for example, aesthetic damage (loss in property value), biodiversity loss/gain, water pollution/purification, and changes in soil erosion/conservation.

Overall, projected climatic shifts will significantly impact the management of landscapes throughout the Gulf Coast region. Depending upon society's desired outputs, these climatic shifts can be either positive or negative. Through the use of the framework, land managers, agency personnel, and interested stakeholders can visualize the interactions of projected climatic changes and begin to address possible scenarios they may face and decisions on how to adapt or mitigate.

Adaptation and Mitigation

Rangeland managers need to consider how to adapt to shifting conditions caused by climate change, but also may benefit from activities that help mitigate climate change. Adaptation can encompass changes to processes, practices, and structures to moderate potential damages or take advantage of opportunities. Management can reduce vulnerability and increase resilience of communities, regions, or activities (IPCC 2001). While climate change is global in scale, adaptation and mitigation strategies can be local or regional in nature. To understand linkages between these strategies and rangeland management, it is important to consider the social, ecological, and economic drivers and responses of rangeland systems. These considerations lead to the practice of adaptive management or changing management decisions in response to new information. Adaptive management (Figure 10) involves assessment and identification of problem areas, followed by design and implementation of a potential solution/improvement, monitoring and

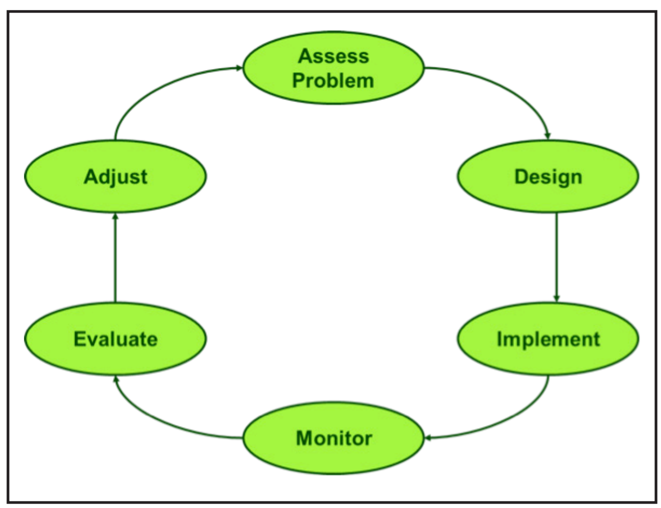


Figure 10. Adaptive Management Cycle. Adapted from Williams, B. K., R. C. Szaro and C. D. Shapiro. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C.

Photo by Tim McCabe, USDA NRCS; South Dakota

evaluation to track the efficacy of the changes, and additional data-driven shifts in management practices, if needed, as the adaptive management cycle repeats.

Monitoring of key variables allows one to focus on those areas of rangeland systems thought to be vulnerable to the impacts of climate change. The question becomes what to monitor. The ISEEC framework (Fox et al., 2009) provides a graphical means of deciding what parts of the system may be vulnerable and need monitoring. Similarly, the framework may be used to help identify opportunities for rangeland managers to participate in mitigation opportunities, for example storing carbon by planting trees or restoring grasslands.

Using the ISEEC framework (Figure 9) again for a simplified example, we can demonstrate adaptation in a ranching system. The natural system provides habitat, food, clean water, and air to support livestock. The beef that a ranch produces is used for human consumption. As more beef is produced through improved genetics, we would expect prices to decrease and consumption to increase. If monitoring were to show that overgrazing occurred due to this increase in production, there would likely be a negative feedback to the rangeland condition, resulting in lower long-term production with less beef produced. The cycle would continue and such monitoring could provide information on rangeland sustainability. Incorporating the simultaneous effects of climate change into this framework would add another level of complexity.

Changes in climatic conditions evoke responses in rangelands. These changes, in turn, lead to responses in social and economic systems. In areas where precipitation during critical months of the growing season is expected to decline, land managers might need to provide more forage or provide supplements to support their livestock. In this case, costs of production will increase if ranchers want to maintain their current level of production. If one response of land managers is to leave their livestock on the rangeland for longer periods of time to harvest the same quantity of forage, there will be increased stress on the land creating a risk of degradation, evoking further ecological response. In areas where increased forage production results from climate change (such as a result of more spring precipitation in northern rangelands), ranchers may choose to increase herd size to take advantage of that additional forage, resulting in additional economic activity.

Besides those direct costs or benefits to ranchers (described above) as climate change unfolds, there will also be effects on other ecosystem goods and services. Stocks of these ecosystem goods and services depend on how they are managed and are subject to various risks of loss. Decreasing resilience in a system increases the risk of such loss (Walker et al., 2002) and increased resilience enhances supplies of ecosystem goods and services (Carpenter et al., 2001).

Beyond the direct effects of climate change on those EGS, livestock management will affect the quality and quantity of EGS produced by the rangeland ecosystem. For example, if overgrazing were to occur in the desert Southwest due to climate change effects, we would expect changes in vegetation composition and increased erosion induced by climate change to be exacerbated by that overgrazing. Changes in vegetation composition will then affect wildlife habitat, aesthetics, and other values people place on rangelands. Erosion will have similar effects and can also affect air and water quality.

Management and social regulation could provide adaptation responses such as restoration of degraded rangelands, opening additional rangeland for grazing, or by restricting the length of time livestock can be in particular areas. Another series of social effects and responses could result from increased competition for water and energy resources between agricultural uses and human residential uses as conditions became warmer and drier. Residential and industrial demand for water will increase the pressure on agricultural irrigation uses for hay production, an important crop for livestock production. Monitoring of these response factors (indicators), such as hay supplies and prices, is an important component of adaptive management for rangeland sustainability.

Finally, rangeland managers may have opportunities to participate directly in climate change mitigation. Establishment of markets for carbon storage would allow managers to earn credits for undertaking or continuing management practices that sequester carbon in vegetation and soil organic matter. Measurement and certification methods would need to be developed to support the award of credits for specific management practices on specific sites (Maczko and Hidinger 2008). Range managers should consider a portfolio of strategies to both adapt to climate change and to participate in mitigation opportunities. This will allow them to hedge against potential future losses (Boyd 2010) and to respond to the inherent uncertainties discussed elsewhere in this paper.

Managing Ecosystem Goods and Services in Key Rangeland Regions

Climate change and disturbances influenced by climate change will affect the entire suite of ecosystem services that rangelands provide, including forage for wildlife and livestock production, fishing, hunting and other forms of recreation, clean water and air, and aesthetically-pleasing landscapes. They will do so by directly changing temperature and precipitation patterns and indirectly affecting disturbances such as fire, insects, invasive species, erosion, and drought. In addition, rising atmospheric CO_2 concentration has two important direct effects on plant physiology. Increased CO_2 tends to increase photosynthesis in many plant species and reduce transpirational water loss (Polley et al., 2010), often resulting in lowered evapotranspiration in grassland communities (Polley et al., 2008). These direct responses to CO_2 may actually enhance plant productivity and water use efficiency (Morgan et al., 2004, 2011; Polley et al., 2010). However, plant species differ in their sensitivity to CO_2 and some undesirable plants may be preferentially benefited (Morgan et al., 2007; Smith et al., 2000; Ziska et al., 2005). Implications of these direct CO_2 responses for regional hydrology and ecology and their interactions with climate change are still poorly understood. Core ecological processes also potentially affected include soil formation, energy flow, nutrient cycling, and biodiversity, which are collectively necessary for humans to exist (Havstad et al., 2007).

Rangeland managers depend upon multiple ecosystem services as sources of income and satisfaction that support their way of life. To maintain their current lifestyle, they must be prepared to adapt. Adaptation most often takes place reactively as rangeland ecosystems respond to environmental changes and land managers adjust their strategies to these responses. To be successful in a changing climate though, adaptation may have to occur before ecosystem processes reach critical thresholds. With a focus on vulnerable components of the rangeland ecosystem, monitoring must be conducted and resulting information shared in order for anticipatory/proactive adaptation to be possible.

Perhaps the greatest obstacle facing land managers is uncertainty about (1) the exact nature and magnitude

PRIVATE LANDS CASE STUDY:

The JA Ranch - Managing Through Uncertainty to Maximize Resource Resilience and Profits

The JA Ranch is owned and operated by James K. "Rooter" Brite, Jr., who was raised on the ranch that his grandfather, J.A. Brite, purchased in 1929 near Bowie, Texas. Rooter took over his father's cow herd in the mid-1960s and purchased the ranch in 1974, when he began full-time management of the ranch with his wife, Lynda, and, eventually his son, J.K.

The JA Ranch encompasses more than 3,200 acres and is a diversified operation with a 225-head Hereford cow/calf herd, 40 to 75 replacement heifers, and 400 to 500 stocker steers. The JA Ranch runs primarily on native tallgrass rangeland, at a stocking rate of approximately one animal unit per 10 acres. The ranch's best range sites produce upwards of 5,000 to 6,000 pounds of forage per acre during good years (Table 1).

Rooter contends that no ranch can survive without investing in soil, water, and rangeland conservation. The quality of the ranch's resources provides resilience to deal with environmental changes and management shifts. An active resource monitoring program informs many management decisions and is critical to successfully managing rangeland resources within a changing climate. Tracking resource data for plants, animals, soils, water, and productive capacity enhances the knowledge obtained from years of experience on the ranch to improve decision making.

The Brite family invests in conservation every year to improve the rangeland resource they manage. Grazing schedules are adjusted as needed to changing weather and climate conditions, available forage, market conditions, and other factors. Tradeoffs are made among the grazing pressure placed on the ranch's vegetation, the market prices of cattle and hay, and the costs of recovery, restoration, and re-stocking.

Photo courtesy J.K. "Rooter" Brite, Jr.

Mr. JA "Rooter" Brite, Jr. and wife Lynda Brite.

Maintaining the rangelands in the highest possible condition allows greater flexibility when environmental pressures increase from natural phenomena, such as drought in La Niña years like 2011.

By incorporating sound management techniques, such as weed control and prescribed fire, the resilience of native rangelands on the ranch is optimized. Weed control is used in pastures when needed to help increase grass growth at critical times. Prescribed fire is another tool used in years when there is adequate moisture and fine fuel loads. Rooter also follows a high-density, short-duration grazing rotation to allow his cattle to graze highly nutritious grass without damaging the rangelands.

The latitude to manage flexibly during periods of extreme weather is a significant benefit from engaging in resource conservation. Texas AgriLife Extension Service predicted that the drought, which began in September 2010, would have lasting effects on Texas agriculture. Texas weather officials said dryer-than-normal weather could last for a decade or more, and that it may take several years for overgrazed grasslands to recover and for ranchers to replenish their cattle herds. A lifetime of experience on the JA Ranch allowed Rooter to recognize worsening conditions early on. However, he was also aware that his ranch was in its best ever condition with substantial forage reserves. For Rooter, experience from managing the daily operations of his ranch over many years offers a better decision template than more formal information resources such as the U.S. Drought Monitor.

As the 2011 drought deepened, abundant forage production from the JA Ranch's tallgrass prairie allowed Rooter to bale and sell hay. With drought conditions becoming more extreme across the state, he was able to sell his hay for top dollar, eventually selling 500 tons of hay at prices that yielded profits ranging from $163 to $225 per acre. In contrast, had he grazed his own cattle on that forage, he would have seen a profit of approximately $15 per acre.

Tracking resource conditions and practicing sound management during better years allowed the JA Ranch to amass a tremendous forage reserve that not only supported their own cattle herd, but also allowed for significant sales of hay to ranchers with smaller forage supplies. At the same time, they chose to maintain the JA Ranch cattle herd which put pressure on the range

Photo courtesy J.K. "Rooter" Brite, Jr.

Mr. Brite says that no ranch can survive without investing in soil, water and range conservation; monitoring informs many management decisions.

resources. However, rangeland condition was so good that restoration costs would have been minimal relative to the high price of beef at the time, illustrating the value of adaptive management strategies and flexible management decisions.

The worst one-year drought in Texas history produced a statewide hay shortage, more than doubling the price, forcing many ranchers to sell or even abandon cattle and horses that they could not afford to feed. The previous record drought for one year came in 1956,

Transect – Ecological Site	Expected Ecological Site Production (lbs/acre)	2011 Production (lbs/acre)	2012 Production (lbs/acre)	2013 Production (lbs/acre)	2014 Production (lbs/acre)	2015 Production (lbs/acre)	2016 Production (lbs/acre)	2017 Production (lbs/acre)	2018 Production (lbs/acre)	2019 Production (lbs/acre)
Point 1 Loamy Prairie	4800	5943	1671	4580	4545	6493	5068	4956	3375	3704
Point 2 Tight Sandy Loam	3000	2808	1178	4148	6593	7955	2567	3974	3374	4366
Point 3 Sandy Loam	4400	4144	3000	3449	6209	5578	7068	5615	4975	5752
Yearly Averages (lbs/acre)	4,067	4,298	1,950	4,059	5782	6675	4901	4848	3908	4607

Table 1. Annual production in pounds per acre at three monitoring sites on the JA Ranch, 2011-2019. Data collected and analyzed by USDA Natural Resources Conservation Service, K. Derzapf and C. Stanley.

Photo courtesy J.K. "Rooter" Brite, Jr.

Monitoring site on the JA Ranch

with 70 percent of normal rainfall levels. However, 2011 shattered that 45-year old record with just 40 percent of normal rainfall. The drought not only reduced productivity of native rangelands and caused hay shortages, but also led to wildfires that incinerated millions of acres. Farmers and ranchers lost an estimated $5.2 billion, according to Texas AgriLife Extension Service economists, making it the state's costliest drought on record. Livestock losses are estimated at more than $2 billion; clearly creating challenging times for Texas ranchers and land managers.

Managing for resource resilience and then capitalizing on abundant forage through hay sales left the JA Ranch with fluid assets available for reinvestment and additional stocking when conditions improved. Coming through a long-term drought successfully requires resilient resources and skilled resource managers. The same resilience will serve ranchers well as they attempt to deal with other environmental phenomena attributable to climate change. Reducing vulnerability by balancing resource conditions, herd sizes, market prices, and resource restoration costs is a complicated endeavor but well worth the effort to ensure sustainability of a ranching operation.

Managing to maximize resource resilience protects the native range and the rancher's finances. While the JA Ranch emerged from the 2011 drought relatively unscathed, the next challenge facing ranchers who were forced to destock was restocking when the drought subsided. Unlike the 1950's drought, when ranchers received basement prices for their beef, the market forces in 2012 moved in a different way that few economists could have predicted. The nation's struggling economy somehow maintained demand for inexpensive protein like ground beef, allowing the market to absorb what would otherwise be an overabundance of breeding cows that do not yield high dollar cuts like rib-eye. The Dallas Observer cleverly noted that "these are Hamburger Helper times, and it just so happens that Texas has a surplus of hamburger cows" (Hargrove, 2011).

However, the end of a drought inevitably sees many ranches restocking at the same time, leading to high costs of replacement heifers. Imagine the cost savings for ranchers, like the Brites, whose operations were resilient enough to maintain a herd through the drought and avoid restocking costs while capitalizing on robust beef markets. In the long term, the JA Ranch provides evidence that conservation can pay for itself by improving resource resilience and providing a buffer to insulate the ranching operation, at least partially, from dramatic environmental and economic changes.

of climate change and (2) how ecosystems and society will respond to a changing climate. Adaptive management can be challenging, in practice, because measurable ecosystem responses to management changes often only occur within a reasonable time if the change in management is fairly extreme, a process that can involve substantial risk (Walters 1997). An alternative approach is to combine adaptive management with a process called evidence-based conservation (Sutherland 2006).

Evidence-based conservation is a course of action where conservation and management practices carried out by many practitioners are assembled and made available to all land managers (Sutherland et al., 2004). In essence, it is a community-based, collaborative form of adaptive management. The essential components of evidence-based conservation are (1) accumulating information pertaining to outcomes from management, (2) reviewing and summarizing the available information obtained, and (3) disseminating information to land managers. These components might need to be implemented by a broader group than land managers themselves, such as a management agency like the Bureau of Land Management (BLM), a technical assistance agency like the Natural Resources Conservation Service (NRCS), a non-government organization like the National Grazing Lands Coalition (NGLC), or a collaborator-driven group such as the Quivira Coalition or the Malpai Borderlands Group.

Regardless of how land managers devise mechanisms for adaptation to the changing climate, any individual or collective response must include monitoring to detect changes in rangeland resources brought about either by climate or management. Complementary to monitoring, ranchers and other land managers can also develop business plans and management strategies to enhance the ability of ecosystems and their own operations to adapt to climate change (Maczko et al., 2010; Maczko et al., 2012; Hamilton et al., 2011). One approach is to manage for biodiversity at the landscape level. Diverse landscapes tend to provide ecological redundancy which can provide resilience and adaptive capacity for ecological restoration or reorganization following a disturbance (Elmqvist et al., 2003). Perhaps the most effective way to maintain diversity is by maintaining the integrity of ecosystem function (Walker 1992). Livestock grazing, fire, and other management tools can be used to promote rangeland health and successional diversity of rangeland landscapes (Curtin et al., 2002). Ritten et al., (2010) found it optimal for producers with long time horizons to incur lower returns initially to improve rangeland health. Their results indicate that a producer must be aware of current rangeland conditions to make optimal decisions, thus underscoring the importance of monitoring. Grassroots coalitions of land managers have the ability to keep rangelands healthy and diverse across more extensive areas than individual operations, while enhancing management flexibility at the same time (Yaffee 1996).

In the following sections, we examine how SRR indicators can help ranchers and other rangeland managers identify issues of management concern in adapting to climate change. Regional examples from the Southwest, the Great Basin, the northern Great Plains, the southern Great Plains, Florida, and the Gulf Coast are presented.

Management Considerations and Potential Indicators in the Southwest

Southwestern rangelands are generally limited by precipitation. Annual precipitation is bimodal, characterized by a highly variable winter and early spring period, followed by monsoonal rains in July and August (Swetnam and Betancourt 1998). The winter precipitation is important for recharging soil moisture; however, it is the summer rainfall that primarily controls rangeland productive capacity for grazing animals (Paulsen and Ares 1961). Managers can anticipate relatively wet or dry winters on the basis of predicted El Niño or La Niña events, respectively (Sheppard et al., 2002), but the summer monsoon is less predictable.

Livestock adjustments remain the primary rangeland management tool in the Southwest (Torell et al., 2010). Stocking rates depend on both present productivity and residual biomass remaining from the previous year's utilization (Paulsen and Ares 1961). During extreme droughts it may become necessary to remove nearly all livestock. Because of the importance of seasonal precipitation, it should be monitored at key points in the growing season.

Photo by Gary Kramer, USDA NRCS; New Mexico

Shrubs can dramatically reduce forage production and cause accelerated erosion. Shrub encroachment into desert grasslands is driven, in part, by precipitation (Swetnam and Betancourt 1998) and in some locations may be promoted over the long-term by rising CO_2 (Morgan et al., 2007; Polley 1997) and temperature (Shaw et al., 2000). Southwestern rangeland managers should attempt to control shrubs at an early stage of invasion into their rangelands. Generally, land managers should learn about different state and transition models that apply to their local ecological sites. These models can improve understanding of how their landscapes might respond to climate change and inform them of options for responding to this change (Bestelmeyer et al., 2004).

Forage quality also affects rangeland management in the Southwest, where forage quality is correlated with precipitation (Cable and Shumway 1966). One way land managers can better take advantage of forage quality, particularly during the critical periods of calving and prior to weaning, is by adjusting the timing of calving (Vavra and Raleigh 1976). Winter calving, at the time of winter forage growth, is possible in the Southwest because of the mild weather typically present at that time. As temperatures increase over time and growing seasons lengthen this might become even more feasible.

Given the projections that the Southwest will become increasingly arid during this century (Seager and Vecchi 2010), land managers must plan on droughts becoming more intense, if not more frequent. Management that improves resilience or reduces vulnerability, or both ecological and financial risk, will be key for adapting. Although little research to date has focused on the synthesis of ecological and economic sustainability of grazing management under a varying climate (Torell et al., 2010; Ritten et al., 2010; Craine et al., 2010 are some early entries), research has shown that a profit maximizing stocking rate may be lower than a stocking rate that maximizes livestock production (Workman 1986). This implies using a subset of indicators related to economics and perhaps social interactions as well. Livestock prices, livestock product demand, cost of alternative feedstock and supplements, local labor market conditions such as unemployment and wage rates, and local community and economic stability could be considered for indicators.

Management Considerations and Potential Indicators in the Great Basin

The Great Basin/sagebrush steppe region comprises the largest semi-desert rangeland ecosystem in North America (Miller et al., 1994). Although a large portion of the region is publicly owned, numerous private ranches rely on these lands for livestock forage. Privately-owned rangelands tend to be situated near permanent water sources and are used for hay production, winter grazing, calving, and lambing.

Great Basin and sagebrush steppe rangelands have been substantially impacted by disturbances over the last 150 years, much of it caused by human activity (Miller et al., 1994). Invasions by non-native species, altered fire regimes, livestock grazing, mechanical plant control, and climate change have cumulatively altered the vegetation and underlying ecosystem processes in

Photo by Ron Nichols, USDA NRCS; Utah

the Great Basin to a greater extent than in any other biome.

Cheatgrass (*Bromus tectorum)* is a major factor limiting rangeland management in the Great Basin/sagebrush steppe. It occupies about 5 million acres in the Great Basin (Bradley and Mustard 2005). Pinyon-juniper woodlands have also been filling areas within their historical range, while also expanding into adjacent sagebrush communities. The implication is that many of these rangelands will lose forage resources as their canopies become more closed (Miller et al., 2008). Although some vegetation changes are dramatic and easy to detect without quantitative monitoring (Sharp et al., 1990), using "key species/life form cover and abundance change" as an indicator may be more useful for subtle transitions. Such indicators would enable ranchers to make earlier management decisions. This indicator could also incorporate the extent of invasive plants.

Maintaining biodiversity can help promote higher vegetation cover, which, in turn, makes sagebrush ecosystems more resilient and resistant to plant invasions (Anderson and Inouye 2001). Because of the nature of ecological disturbances and the manner in which sagebrush and pinyon-juniper ecosystems respond to them, management to minimize loss of desired native plant communities will be most beneficial when carried out at the landscape level. One approach for promoting diverse, native ecosystems is to use a "triage" system for management, whereby restoration and management resources are applied to larger blocks of land where they have the best chance of maintaining desired conditions (Wisdom and Chambers 2009). The aforementioned indicator for cover/abundance of key species could be valuable in helping decide where and how to employ restoration management. Socio-economic indicators that consider cost-benefit tradeoffs, such as cost of livestock production could also help.

Habitats already dominated by cheatgrass, or totally occupied by pinyon-juniper with little or no understory, require restoration investments that exceed the financial resources available to most ranchers. Habitats that have not yet been taken over by cheatgrass can possibly be maintained by adjusting stocking rates and grazing systems in a way that encourages native perennials. When restoration treatments are needed though, landowners may qualify for financial and technical assistance from the USDA NRCS's Environmental Quality Incentives Program (EQIP). EQIP helps plan and implement various conservation practices that can improve rangeland health on areas taken over by cheatgrass or pinyon-juniper.

Although not a direct form of management, ranchers in the Great Basin can also help mitigate the impacts of future disturbances, including climate change, by partnering with the BLM and other public agencies to restore federal rangelands. The involvement of local communities in federal lands restoration is a key component in the "Great Basin Restoration Initiative," which strives to help balance the social, ecological, and economic factors facing those who use, live on, and appreciate the land (Pellant et al., 2004).

Management Considerations and Potential Indicators in the Northern Great Plains

Land managers in the Northern Great Plains region may have more time and opportunity to manage proactively to mitigate the effects of climate change because of the nature of the systems they manage. Research has demonstrated the productive capacity of the Great Plains grasslands can be reliably predicted on the basis of precipitation just prior to or early in the growing season. By adjusting stocking rates in a planned manner, before forage utilization becomes too high, land managers can minimize long-term declines in productive capacity caused by grazing-induced changes in species composition (Derner and Hart 2007). Moreover, adjusting stocking rates downward when less forage is expected can help maintain grazing animal performance and maximize profit (Torell et al., 1991). Some of the important indicators to consider for this region are discussed below.

With the expected increase in precipitation and longer growing season in the north, along with continued increases in atmospheric CO_2, we expect an increase in forage production. Forage quantity and quality can either be monitored directly, by measuring them incrementally or at peak standing crop, or indirectly, by estimating forage utilization and resulting animal weight gain (for quality).

In the Northern Great Plains, ranchers are not the only users of public rangelands; recreation is another important use. We expect that recreation will increase over time and the total value of recreation will increase. Monitoring visitor use information (such as number of visitors, fees received), ideally by enterprise (like hiking, hunting, skiing), could assist managers in making decisions about recreation ventures. These decisions will, of course, generate impacts, both positive and negative, on the environment. Density of roads and human structures, for example, are expected to increase while the extent of bare ground (erosion potential) is expected to decrease.

Photo by Gary Kramer, USDA NRCS; Colorado

As these ecological and economic changes are occurring, we expect that the investment in rangeland improvement practices will either remain static or actually decrease if the increased precipitation negates the need for more costly interventions. As demand for recreation opportunities increases we expect more investment in recreational facilities.

Lastly, if all of the above hold true, there may be little incentive to change economic policies to assist the ranching sector. Census Bureau human population projections for the Northern Plains show less growth than for other parts of the United States. So social and environmental pressures on land owners may be more moderate than in other regions, but so too may be financial resources, such as state income taxes.

If the indicators mentioned above are monitored over time, we expect that decision-makers will have information that can be used in the adaptation process. Making the information readily available to the community at large, with appropriate interpretation, may lead to more informed decisions and social acceptance of those decisions.

Management Considerations and Potential Indicators in the Southern Great Plains

Recalling the dust bowl of the 1930's, with its effects on erosion, productivity, and livelihoods in the Southern Great Plains (Schubert et al., 2004), observers can reasonably imagine the potential impacts of climate change in the region (Hansen and Libecap 2004). Climate projections show increases in summer temperature, evaporation, and drought frequency, coupled with more frequent extreme events. These effects spell out a future in which adaptive management will be crucial if land managers are to succeed. The principal threats to rangeland management under a changing climate in the Southern Plains include increases in undesirable and invasive plants, loss of forage production, decreased water availability, and heat stress in livestock.

Photo by Lynn Betts, USDA NRCS; Iowa

A key to minimizing impacts from invasive species is to maintain rangeland health. In a climate of recurring droughts, livestock can both promote and hinder the three primary attributes of rangeland health - soil stability, hydrologic function, and biotic integrity (Pyke et al., 2002). Grazing systems that allow animals to target invasive species and are flexible enough to not degrade the vegetation and soils during droughts will be an important management consideration. Two approaches to keep from overgrazing during dry years are to maintain a reserve of forage via conservative stocking and to employ a flexible stocking system, using yearlings, that allows ranchers to quickly reduce herd size (Campbell et al., 2006).

In much of the Southern Great Plains, summer temperatures are expected to increase by as much as **13 °F by 2080 to 2099 (**Shafer et al., 2014). Resulting increases in evapotranspiration are expected to significantly impede the recharge of the Ogallala Aquifer, creating even more pressure on water resources for agriculture, livestock grazing, and human use (Rosenberg et al., 1999). Grazing systems and livestock breeds that can do relatively well on rangelands where water becomes less available will be more successful.

Ranchers in the Southern Plains might consider shifting from British breeds of cattle (*Bos taurus*) to Brahman style breeds (*Bos indicus*) to increase water use efficiency, increase the ability to tolerate higher temperatures, and to help better endure increased pressure from horn flies, grubs, and other ectoparasites (Byford et al., 1992). Recent genetic improvements in meat quality traits of tropical cattle breeds may help overcome the primary drawback of Brahman style breeds – reduced meat tenderness and taste (Johnston et al., 2003).

Some indicators that might be suitable for monitoring in the Southern Great Plains include infestation by invasive species, changes in ground water systems, and rate of return on range livestock enterprises. Furthermore, if demand for decreasing water supplies results in changes in the extent and distribution of row-crop agriculture and rangelands, the extent of land area in rangeland may be a useful indicator to inform policy.

Management Considerations and Potential Indicators in Florida Rangelands

Livestock have grazed in central and southern Florida for nearly 400 years, since the time of early Spanish settlers. Central Florida, in particular, was mostly unpopulated and its open savannas were well suited for rangeland management (Yarlett 1985). In subsequent years, the natural fire return interval of 4-7 years was shortened to 1-3 years. This use of fire, along with the lumber and the turpentine industries, opened up millions of acres of pine flatwoods to agricultural use, including livestock grazing. Today, approximately 4 million acres of flatwoods and associated grazing lands can be classified as rangeland (Reeves and Mitchell 2012).

Pine flatwoods are Florida's most extensive ecosystem type, covering about one half of the state. They are characterized by low, flat, poorly-drained lands with an open overstory of pines and frequent fires. The primary forage grasses include bluestems (*Andropogon spp.* and *Schizachyrium spp*), lop-sided Indiangrass (*Sorghastrum secundum*), and wiregrass (*Aristida spp.*). Saw palmetto (*Serenoa repens*) is a common shrub. Because of their flat nature, minor differences in elevation, soils, and water table can result in major changes in ecosystem structure and function.

Flatwood sites are dominated by undesirable plant species that increase with improper grazing. Poor grazing management can reduce stocking rates by 75 percent or more (WFREC 2011). Little grazing systems

PUBLIC LANDS CASE STUDY:

Using Adapative Management to Reduce Environmental and Economic Risks on the Pawnee National Grassland

There is much talk today about preparing for climate change effects using risk management. But how do we do this given the uncertainty in projections for future climate conditions? One way is to start exploring our current risks from weather and climate and how effectively we address those risks. We might then ask the question—are we adapted to the current climate? What are the current risks with respect to environmental damage or economic loss? How is the current climate a factor in those risks?

East of the Front Range of Colorado, the Pawnee National Grassland (PNG; Figure 11), managed by the USDA-Forest Service (FS), sits within a mosaic of private land, State of Colorado land, and the USDA Central Plains Experimental Range. Drought, extremely warm temperatures, high winds, and blizzards are all events that affect these multiple land owners and human-ecological communities settled within the landscape. The Pawnee National Grassland is managed for multiple ecosystem goods and services – domestic livestock grazing, biodiversity, threatened and endangered plants and animals, recreational opportunities, and oil and gas development. These multiple goods and services interconnect the interests of public land managers with private land ranchers. Nearly all of the PNG is managed for livestock grazing.

Vegetation on the PNG is as the name implies – grassland – in particular short-grass steppe (Lauenroth and Burke 2008). The desired outcome of rangeland resources on the PNG is to provide available forage for both wildlife and domestic livestock produced in a manner consistent with other resource objectives as well as the Forest Plan. The semi-arid climate results in a mean annual temperature of 46.7 °F and mean annual precipitation of 13.4 inches (Pielke and Doesken, 2008; Evans et al., 2011). Precipitation occurs primarily at

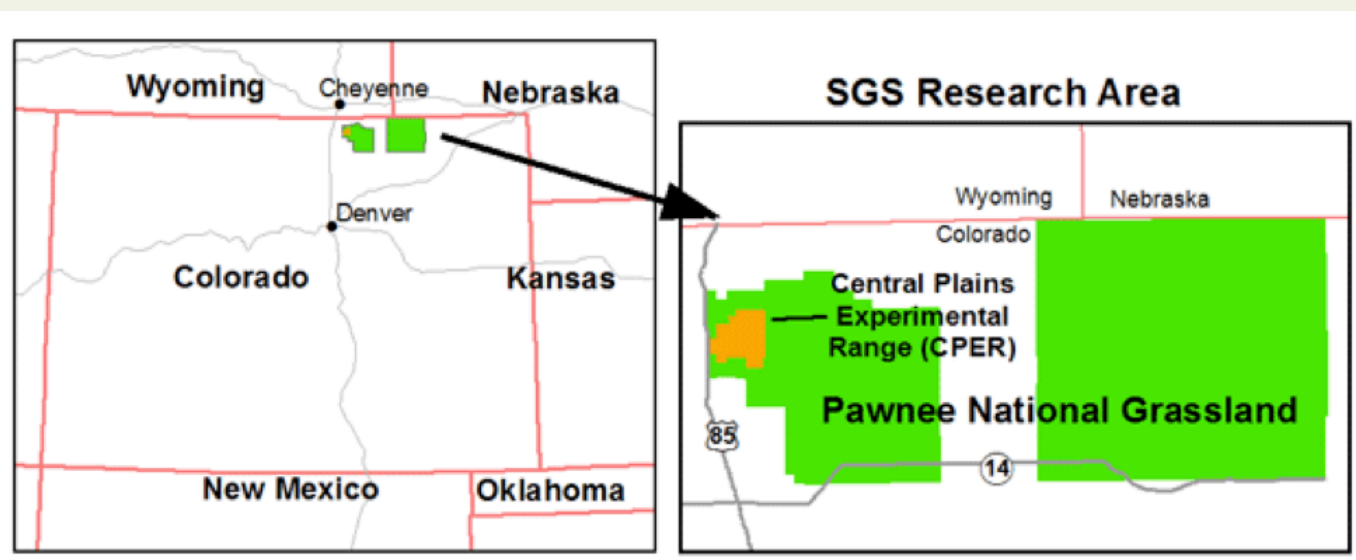


Figure 11. Pawnee National Grassland and Central Plains Experimental Range in Northeastern Colorado (Source: Colorado State University)

the start of the growing season (March through July) with the potential for drought to occur at any time. In the short term, seasonal thunderstorm patterns may fluctuate, creating localized drought or dry conditions annually. Multi-year droughts of 8 to 14 years were seen in the 1930s and the early 1950s (Evans et al., 2011). The 2002 drought severely impacted many economic sectors in Colorado (Pielke et al., 2005). Climate change brings the potential for future long-term sustained droughts. Maximizing the resilience of the system and reducing risk of resource impairment is important, as is reducing the risk of economic hardship in situations where the environmental and socioeconomic systems are tightly bound. Weather, and the longer-term climate, affects human communities as it affects the environment. How can resource management proactively and collaboratively address risks to the environment and to the family-run operations dependent upon the goods and services from the PNG?

Adaptive grazing management is used on the PNG to create and maintain diverse structure to include a mix of short and mid-tall structure vegetation, riparian and chalk bluff areas. Plant communities with these different structural components are required to meet habitat needs for a variety of wildlife, particularly Management Indicator Species (MIS) and threatened and endangered species (TES) habitat.

For the purpose of grazing permit administration, the PNG is divided into two units: the Crow Valley Unit on the west side, which contains approximately 98,000 federal acres, and the Pawnee Unit on the east side, which contains approximately 92,000 federal acres. Grazing management is accomplished through a total of 162 active allotments in partnership with two grazing associations (Crow Valley Livestock Cooperative and the Pawnee Cooperative Grazing Association), along with issuance of twelve direct on-off term permits.

Annual allocations are cooperatively determined at spring meetings with the FS Range Staff and Grazing Association Boards. The majority of grazing on the PNG occurs during the summer/fall season between the months of May through October. Most allotments are continuously grazed for this period. Range condition on the PNG is generally considered as ‘good’ to ‘fair’ using historical classification terms. In the years preceding 2009, very dry conditions forced allotments to be vacated earlier than initially planned. The FS and Grazing Associations felt a need to create a predictive method to arrive at mid-season grazing decisions. In response to this request, the PNG developed an annual stocking strategy that employs the past year’s conditions and stocking, historic conditions, and desired conditions for each allotment. Specifically, data in three key elements are assembled:

(1) Precipitation

- 15-year average annual precipitation
- 15-year growing season average precipitation
- Previous-year precipitation
- Previous-year growing season precipitation

(2) Stocking

- Stocking rates for the past 15 years
- The previous year’s stocking levels

(3) Management and Resources

- Current allotment management
- Desired condition and current trend
- Priority resources

Using these elements, individual allotment conditions are now rated as poor, moderate, or good and then stocking recommendations for each allotment are developed (Figure 12). Allotment grazing strategies are further broken down by initial turnout stocking and mid-season adjustments, based on moisture and allotment conditions. This strategy is designed to be adaptive, laying out possible scenarios so that the permittees can better anticipate grazing conditions on federal lands and make appropriate adjustments in their operations. Intensive short- and long-term monitoring programs have been implemented to support grazing strategies and predict trends – towards or away from desired conditions.

The recommended allotment strategy recognizes the risks for both the federal managers and private land owners/permittees. Federal land managers must manage the impact of weather on the availability and use of ecosystem services from the PNG. Individual ranchers must manage the economic risk arising from environmental conditions that affect the quantity and quality of forage from both federal and private land. And when a drought is widespread, forage supply may be insufficient to meet increased demand. The recommended allotment strategy uses historic, present, and desired information on environmental conditions as well as past and current stocking levels to develop an adaptive approach to annual grazing allotment management.

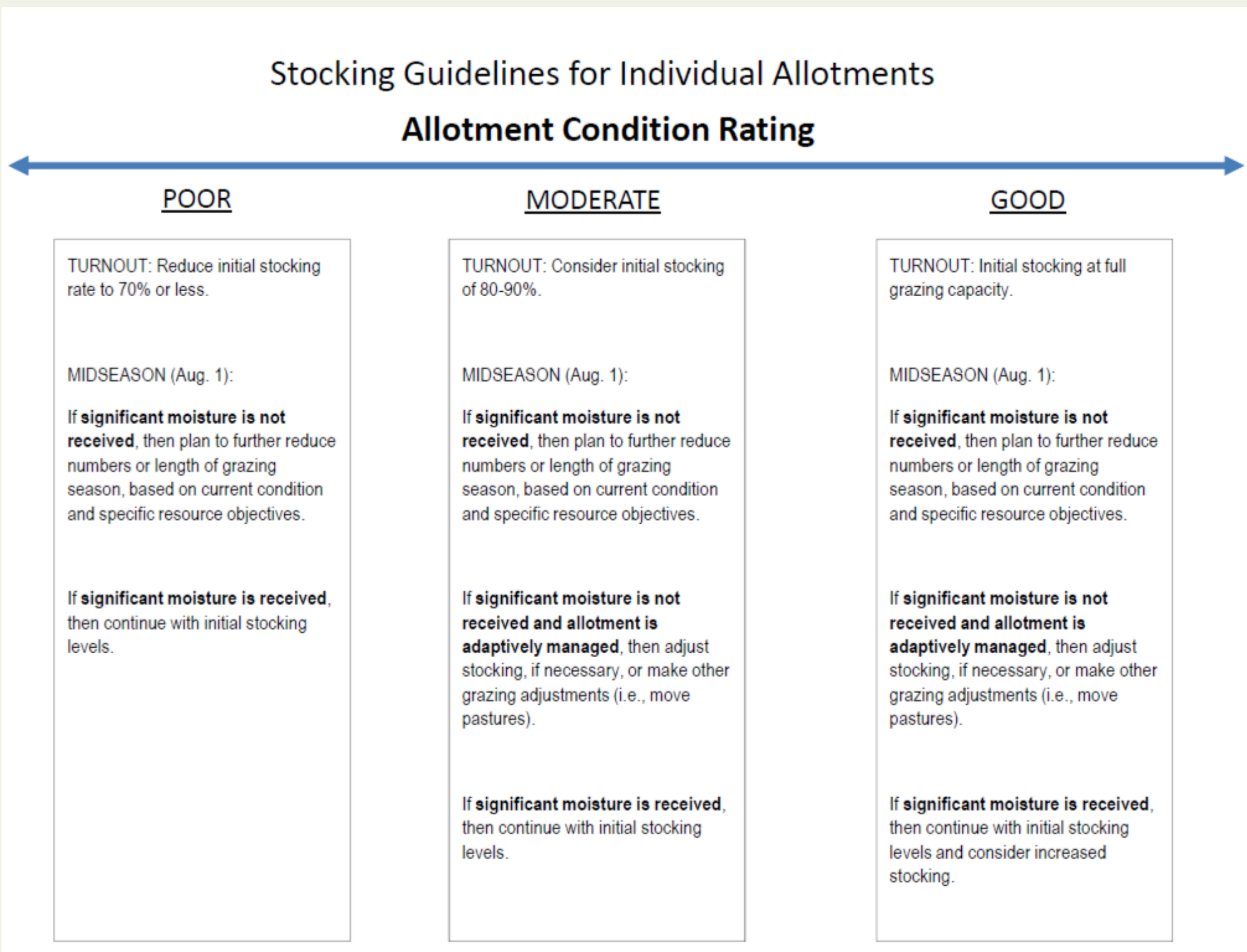


Figure 12. Recommended allotment stocking strategy. Pawnee National Grasslands, Colorado.

research has been reported for the Florida flatwoods and associated marshes. However, an informative discussion of grazing system trials at the Avon Park Air Force Range was reported by Penfield (1985).

Rangelands in Florida are in reasonably good health, when judged against the function of core ecological and natural resource processes – soil stability, hydrologic function, and biotic integrity (Figure 8). However, earlier reports rated much of Florida's rangeland condition, judged only under the guidelines of vegetation structure, to be poor to fair. These divergent assessments might identify an important management goal of maintaining an adequate understory of palatable forage species, in addition to functional ecological processes.

Regional climate projections for Florida and the Southeast suggest an increase in annual air temperature during the 21st Century of 2 °C to 3 °C, consistent with ocean warming. Precipitation is expected to show modest changes. Perhaps the major effect of climate change on land management will be the acceleration of temperature and precipitation extremes; such as, hot and cold spells, dry periods, and storms causing torrential rainfall events (Melillo et al., 2014; IPCC 2012).

Water tables in Florida are expected to be greatly affected during dry periods associated with future climates (Lu et al., 2009). They will also be impacted by human activity indirectly tied to climate change. As sea level rises (Titus and Narayanan 1996), shallow aquifers near the coastline, where most people live, have already become too salty for domestic use, forcing municipal water managers to move wells further inland, where flatwood rangelands are found. Moving inland, where sea level rises are less of a concern, the degree to which water tables might be lowered by climate change (like drought) and the associated impacts on vegetation remain largely unknown. However, upland sandhill ecological sites tend to produce less forage than flatwoods (WFREC 2011), suggesting that falling water tables could reduce productivity for grazing.

Photo by Scott Bauer, USDA NRCS; Florida

Like other regions of the United States, climate change is expected to exacerbate the spread of invasive species in Florida (Dukes and Mooney 1999). Florida and Hawaii are currently the two states most influenced by invasions of tropical and subtropical species because of their mild climates and islands (and peninsula) are generally more susceptible to invasions (Vitousek et al., 1987). Tropical soda apple, a thorny, tall herb, native to Argentina has increased from a single collection in 1988 to nearly 1 million acres at the present time, costing ranchers millions of dollars to control (Duncan et al., 2004). This invasive species outcompetes native forage species and is a major problem throughout Florida.

Three plant/animal indicators along with one soil/water indicator – rangeland area by plant community, extent of wetlands, area of infestation of invasive plant species, and changes in groundwater systems – will be useful to track biophysical trends of Florida rangelands.

Livestock diseases and parasites are expected to become more problematic in Florida with a changing climate, particularly in response to extreme weather events for which livestock cannot achieve prior conditioning (Hahn and Mader 1997). A changing environment will likely mediate host-parasite interactions, just as climate changes will affect the parasites directly (Sutherst 2001). Among the negative effects that increasing temperatures and extreme weather events can cause are increased pests and diseases, as well as increased thermal heat loads, and reduced conception rates and weaning weights (Hatfield 2008).

Major management considerations for Florida ranchers will continue to focus on maintaining rangeland health and productivity and controlling animal parasites. Rangeland health and productivity can be addressed by using weed and brush control, prescribed fire, planting improved forage varieties (when applicable), and different grazing systems. One useful indicator that integrates several factors affecting rangeland health is the number of domestic livestock in an area. The rate of return on investments for range livestock enterprises, as a socio-economic indicator, might also be sensitive to rangeland health and restoration.

Management Considerations and Possible Indicators in Gulf Coastal Rangelands

The Gulf Coastal Plain curves along the southern portion of the United States, stretching from the western half of Florida, through Alabama, Mississippi, Louisiana, and Texas to its border with Mexico. The region is an extremely diverse landscape of terrestrial, freshwater, and coastal ecosystems encompassing upland, alluvial, and shoreline physical landscapes (Twilley et al., 2001). Uplands are dominated by temperate hardwood forests, pine barrens, scrub forests, and coastal prairies. These systems are inextricably linked by the flow of water from the uplands to the coastal regions.

Coastal regions are especially sensitive to the interactions between uplands and coastal estuaries and bays. Changing intensity of precipitation events coupled with increases in temperature will likely result in long-term changes in the hydrological cycle. In addition, the likelihood of more extensive droughts across the region will increase the strain on management strategies by reducing water availability to plants and animals.

Coastal regions are also sensitive to biological invasions. Current issues surrounding the expansion of Chinese tallow (*Triadica sebifera*) and other highly invasive species are the subject of great concern within the region. Changes in temperatures may enable the migration of some sub-tropical species into the region, thus extending the challenges of management. Changing species composition and production may also be influenced by the longevity and intensity of drought. Increased potential for catastrophic wildfires associated with drought (Van Speybroeck et al., 2007) increases the opportunity for fire-tolerant, less desirable species to infiltrate the region. This downward spiral can produce situations where

Photo by Beverly Mosely, USDA NRCS; Texas

management alone will not be sufficient to maintain desired ecosystem goods and services.

Several management alternatives exist for dealing with these climatic stressors, including conservative stocking rates, flexible grazing strategies (combining cow-calf and yearling enterprises), and shifting to breeds that are more heat and drought tolerant. Other management actions that may be necessary include developing additional water or expanding its distribution, employing insecticides to reduce expected increases in ticks and other ectoparasites, and developing shade to mitigate heat stress. Heat has been shown to increase respiration, decrease feed and water intake, make immune systems vulnerable, and degrade fertility in ruminants (Bernabucci et al., 2010).

Research by Torell et al., (2010) concluded that changing from a cow-calf to a mix of cow-calf and yearlings provides a higher net return on investment than a conservative grazing strategy. Their work assumes that any drought management actions take place before a drought occurs. Obviously, if a rangeland is fully stocked when a drought happens, destocking will be necessary to maintain the plant and soil resources.

Animal and rangeland scientists are studying tradeoffs involved in changing from English cattle breeds to more heat-adapted breeds, such as Brahmans (Luna-Nevarez et al., 2010). Humped cattle have as little as one-half the water turnover rate as English breeds, meaning they can return to water sources less frequently, and thus range farther from water while grazing (Kay 1997). They also have other adaptions to repel and release heat through lighter skin color, higher skin area to weight ratio, and elevated sweating rates (Bailey 2012).

Increasing temperature can cause changes in production, not only through its effect on forage production, but also on how it influences forage quality. Cattle decrease their forage intake and digestibility when crude protein falls below a threshold (Rittenhouse et al., 1970). Dietary crude protein and digestible organic matter are known to decline with rising temperatures (Craine et al., 2010), which could cause managers to use supplements for longer periods of time when plant protein falls below threshold levels.

Indicators that may be sensitive to climate change in the Coastal Plains should focus upon how high temperatures and less dependable water might affect land management. Examples include annual forage production, extent of infestations by invasive species, changes in groundwater systems, changes in frequency and duration of surface no-flow periods, and rate of return on investment for range livestock enterprises.

Conclusions about Rangeland Management, Monitoring and Assessment for Adaptation to Climate Change

Rangeland ecosystems are more susceptible to droughts, invasive species outbreaks, wildfire, and other episodic events when they lack diversity and resilience. Ranchers and other private and public land managers should therefore consider making the maintenance of rangeland health, soil health, and productive capacity business and/or management goals. Identifying and monitoring vulnerabilities and focusing adaptive management to improve resilience is one way for managers to respond to changing conditions.

Regardless of the region in which they live, private land managers should consider the benefits of diversifying their business plan to generate multiple sources of income, so as to decrease their vulnerability to climate change and increase their flexibility to changing conditions. There are a number of resources to help ranch operators with planning, including state Extension Service educators, NRCS conservationists, private consultants, local bankers, nonprofit organizations, and state organizations. The Sustainable Ranch Management Assessment Guidebook http://www.sustainablerangelands.org/ranchassessment/pdf/ranch_guidebook_B1216.pdf, developed by the Sustainable Rangelands Roundtable, also offers guidance on optimizing resource capabilities and ranch productivity in the context of a business plan.

By learning as much as possible about how their ecosystems might respond to climate change, land managers can better anticipate necessary responses to change and incorporate that knowledge into their management planning and monitoring. Questions that will help land managers identify climate change impacts and determine appropriate strategies include, but are not limited to, the following:

- Is precipitation expected to increase or decrease in their area?
- Will their key plant species, whether warm-season or cool-season, be expected to benefit or suffer from climate change?
- Are grasslands expected to give way to woody plant communities, and where is that most likely to happen?
- Is there increasing vulnerability to invasive species, insects, disease, or fire?

Managing to improve resilience and provide for ecosystem services requires landowners and managers to incorporate all of the above information into a plan. This plan should identify and establish a system of indicators for monitoring the ecosystem conditions and processes, goods and services produced by the land, as well as weather and major risk factors associated with climate change. Ultimately, a system of indicators used in a consistent monitoring program should enable managers to follow trends, anticipate, and proactively adapt to changing conditions. As shown by five regional examples, ecosystem responses to climate change are expected to differ in magnitude or direction, resulting in different responses of the social and economic systems. These differences must be planned for if rangeland ecosystems and communities that depend upon them are to be managed sustainably for future generations.

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