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Climate Change Effects on Rangelands: Affirming the Need for Monitoring

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Abstract There is widespread agreement that climatic conditions are changing and that such changes will likely continue, becoming more apparent in coming decades. There is also agreement that changes will occur differentially across regions and landscapes. Yet, there remains uncertainty regarding the extent and magnitude of various changes and, in some cases, even the direction of likely change. Uncertainty poses a problem for land and resource managers as they seek to adapt to changes and mitigate adverse effects of climate change. We argue, first, that a focus on vulnerability to climate change (and change in general) and its effects is more useful for managers than a focus on the probability and consequences of particular changes. Second, we argue that monitoring, based on systematically considered and selected indicators, provides managers information they need to adaptively manage for sustainability. These arguments are illustrated by looking at current and likely future conditions on rangelands in two regions: the Great Plains and the desert Southwest of the USA.

Keywords: Monitoring, Rangelands, Vulnerability, Indicators, Land Management

1 Introduction

There is widespread agreement that climatic conditions are changing, regardless of the cause, and that such changes will likely continue; becoming more apparent in coming decades (Christensen et al. 2007). Significant global warming is predicted to occur more rapidly than has occurred in the past 100 years. Climate change is altering the global hydrologic cycle and is expected to have substantial and diverse effects on precipitation patterns in different regions. Predictions include increased intensity of precipitation events worldwide, increased wet days at high latitudes, and increased drought across many mid-latitude continental interiors. However, there is still considerable uncertainty regarding rates of changes in temperature and the direction of precipitation responses in many regions (Christensen et al. 2007). This uncertainty greatly complicates our ability to develop specific management practices to cope and adapt.

In addition to climate change, rising atmospheric CO_2 concentration, which has been steadily occurring since industrialization, has two important direct effects on plant physiology. Increased CO_2 tends to increase photosynthesis in many plant species. It can also reduce transpirational water loss. These direct responses to CO_2 may actually enhance plant productivity and water use efficiency, although 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.

Rangeland managers have always lived with climate variability. However, the changes being observed now and predicted over future decades present a new challenge in that they are unidirectional (most regions will experience warming) and the rate of change is expected to accelerate beyond what modern humans have experienced. Thus, climate change may manifest itself in unique ways at local and regional levels (Williams and Jackson 2007).

Lawler et al. (2010) discussed the difficulty in dealing with a problem like climate change that most agree will have important impacts on management of ecological systems but about which adequate knowledge is lacking. They proposed management schemes that will employ adaptive management, leaving the potential to adjust to changing environmental conditions. Key to the success of this approach is monitoring so the manager can track system response to change. We argue that monitoring the environment, ecosystem, socio-economic, and human system responses to climate change is necessary and that such knowledge can be used to optimize natural resource management for the benefit of social, economic, and ecological systems.

Rangelands in the mostly arid or semi-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 ecology and productivity. It is not surprising that the major effects of climate change on such ecosystems are experienced primarily through changes in soil-plant-water dynamics (Campbell et al. 1997; Fay et al. 2008; Heisler-White et al. 2009; Morgan

2005). However, the degree to which climate change will impact rangelands and society is likely to differ considerably by region according to present vegetation and condition, and each region's economic and social structures and conditions.

In response to a growing need among conservation and commodity organizations, local, state and federal agencies, universities, and tribal governments to assess the sustainability of rangelands, the Sustainable Rangelands Roundtable (SRR) developed a set of criteria and indicators to monitor, assess, and manage rangelands (Mitchell 2011). As a mechanism for showing the importance of standardized indicators and promoting their use, the SRR devised an integrated social, economic, and ecological conceptual (ISEEC) framework to guide a comprehensive assessment of rangeland sustainability (Fox et al. 2009). In this paper we explore the utility of the ISEEC framework for evaluating the responses of diverse rangelands to climate change. We selected the Great Plains and desert Southwest regions of the U.S. (Figure 1) for this purpose because of their large extent and differences in their expected responses to climate change.

2 The Great Plains

The Great Plains (Fig. 1a) has a variable climate. It is semi-arid in the western region transitioning to a wetter, sub-humid climate in the east, and from cooler temperatures in the north to hotter temperatures in the south (Fig. 2a). 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 further reduce water availability (Joyce et al. 2001; Launchbaugh et al. 1999). Cool-season C_3 grasses dominate northern latitudes, giving way to warm-season C_4 grasses at central to southern latitudes,[1] and drought-resistant shrubs in portions of the southern reaches (Epstein et al. 1997; Joyce et al. 2001; Terri and Stowe 1976; Ehleringer et al. 1997). The growing season varies from 110 days in the northern Great Plains to 300 days in the southern Great Plains.

Approximately 80% of the land area in the Great Plains is used for agriculture and dry land farming, with over half the agriculture contributed by rangelands and pasture, and 25% by dry land cropping (Ojima et al. 2002). The rural plains lost about a third of their population in the 20th century and that trend is expected to continue (Freese et al. 2009). However, due to population growth and migration to urban areas, the region is expected to continue growing overall. Ojima and Lackett (2002) suggested it may increase from 9 million in population in the late 1990s to approximately 14 million by 2050. Agriculture's contribution to the economy is expected to continue to decline, as it has for a long time. About 4% of the economy in the present-day northern Great Plains is contributed directly by production agriculture.

[1] Most grasses fall into one of two physiological groups, with C_3 and C_4 referring to the photosynthetic pathway for carbon fixation. The C_4 grasses have a photosynthetic pathway that adapts them to hot climates and low water availability.

Nevertheless, agriculture remains important for the region, particularly for rural communities when considering direct, indirect, and induced economic effects (Freese et al. 2009).

Over the past few decades, average temperatures have increased in this region, with fewer cold days, more hot days, and increased precipitation over much of the area (Karl et al. 2009). Annual precipitation is expected to increase in the northern Great Plains and decrease in the south (Fig. 2b). Extreme events such as drought, heat waves and intense precipitation events are predicted to become more common (Karl et al. 2009). Temperature is predicted to continue to rise, with increases being greater in the northern reaches (Fig. 2c), and summer temperatures expected to increase more than winter temperatures for the southern and central Great Plains (Christensen et al. 2007; Karl et al. 2009). Some of the more critical concerns set to impact Great Plains rangelands include:

- Climate change and rising atmospheric CO_2 are expected to alter the competitive balance among plant species, leading to species shifts, including increases in invasive plants. For instance, although rising CO_2 often favors C_3 plant species (but see Owensby et al. (1993) for a contrary result), increases in temperature ought to favor C_4 plants. The net effect of those changes is unknown.
- Climate change and an altered balance of plant species is expected to alter critical habitat for wildlife, e.g., 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.
- Increases in temperature, evaporation, and drought frequency are expected.
- Warmer temperatures will enhance the spread of some plant and animal pests northward.

All of the above are likely to influence land-use change, as cities and rural agriculture continue to compete for limited water resources, and changes in climate influence optimal zones for ecological systems that are integral to rangeland uses.

3 The Desert Southwest

The Southwest landscape features primarily deserts including the Chihuahuan in southern New Mexico and Arizona transitioning to the Sonoran and southern sections of the Mojave Desert further west into California and southern Nevada. It also includes higher altitude regions of the Colorado Plateau; and montane areas occur in northern sections of New Mexico and Arizona (Fig. 1b). Desert vegetation predominates in the south, with woody and forested vegetation being more common in the north. 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.

Population growth in the region has been rapid since the 1940s. Much of this population growth has occurred in Arizona, where population increased 40% from 1990-2000 (Carter 2003). This growth has resulted in significant rangeland conversion and competition for limited natural resources.

Raising stock animals began in Arizona in the late 18th century, and grew in the 19th century, first as a result of the mining boom and Jesuit missions, and later with the migration of mostly Texas ranchers after the Civil War that ultimately resulted in over-stocking and widespread rangeland degradation (Guido 2009). Land managers today point to that rangeland degradation and experience with drought as two factors that have instilled a more conservative management posture. However, it remains uncertain how droughts of the past few centuries (since livestock introduction) will compare to future scenarios. Warming in the past few decades has been higher in the southwest than other regions of the United States, and is expected to continue (Karl et al. 2009). Annual precipitation is predicted to decline for almost all this region for the remainder of this century (Fig. 3). Uncertainty remains regarding the effect of climate change on the region's summer monsoonal precipitation pattern that delivers most of the region's precipitation. Given the region's fragile ecology in addition to an uncertain, but likely drier and hotter, future the following concerns are raised.

- Water is expected to become increasingly scarce, although there is uncertainty regarding monsoonal responses. Severe drought has occurred in the past and could be exacerbated.
- Increasing drought, temperature, wildfire, and weed invasions will transform the landscape and render many rangelands less able to support livestock and wildlife.
- A warmer, drier environment will reduce the effectiveness of restoration measures, and/or their probability of success, to restore degraded lands.
- More intense precipitation events will decrease water use efficiency, increase erosion and flooding potentials, and increase risks to people and animals.
- More severe weather will decrease the region's attractiveness to tourism and recreation.

The responses of arid lands to climate change involve an interaction of factors that tend to reinforce, accentuate, or counteract climatic effects. While the particular outcomes of climate change for rangeland ecosystems are difficult to predict, the novel environments that climate change will bring suggest substantive potential changes in plant communities and wildlife habitat.

4 Summary of Regional Concerns

Although climate change concerns and its impacts on rangelands are similar for the Great Plains and Southwest, the issue of precipitation change and its implications for society are likely more

critical and uncertain for the Southwest. In the Southwest, water is already a scarce resource, and even slight changes in factors that affect the water balance (temperature, CO_2, precipitation dynamics) can have huge impacts on its ecology. While there is a strong consensus that this region is headed towards a drier future, uncertainty regarding the effects of climate change on the monsoonal dynamics complicates such future predictions. A variety of entities – cities, rural economies (from intensively irrigated agriculture to rangeland), land management agencies, and Native American tribes – are all keenly interested in water. There is already conflict over this and other natural resource issues. In contrast, precipitation may not be the most limiting factor for rangeland productivity in the northern Great Plains; instead it may be temperature. Though precipitation may not be the binding constraint, rising temperatures may affect the timing of water availability as more precipitation falls as rain, resulting in rapid runoff, as opposed to snow where runoff is more gradual. And, even where the primary precipitation is snowfall, rising temperatures imply an earlier melting and runoff. For the foreseeable future, combined warming and rising CO_2 may benefit productivity on those rangelands. In regions further south, combined effects of rising CO_2, warmer temperatures, and altered precipitation patterns may have little net effect on plant productivity in the short term, although more variable weather may lead to corresponding variability in rangeland productivity.

Management is still considered one of the main factors influencing the condition of rangeland ecosystems everywhere and should not be neglected in discussions of climate change. Climate change needs to be understood in the context of management. We will examine these relationships using livestock ranching as the example across the regions. Ranching is one of the most widespread economic uses of rangelands and livestock management affects most other rangeland ecosystem goods and services.

5 Climate Change and its Effects are Confounded by Uncertainty

Uncertainty as to how climate change will develop and its impacts on agro-ecosystems complicates our endeavors to adapt management and develop appropriate mitigation strategies. There is no consensus on how to characterize this uncertainty, or whether the answer is more scientific research or immediate policy action (Congressional Budget Office 2005). Standard logic suggests that potential consequences of irreversible decisions made under uncertainty, when there is the prospect of obtaining better information in the future, should temper any irreversible commitments in order to better utilize information that may become available (Ingham et al. 2007). There are tradeoffs, however, between waiting for better information that may never come and taking action that has some probability of mitigating adverse effects.

To help address this complex issue, numerous benefit-cost analyses have been conducted to assess the effectiveness of greenhouse gas abatement strategies (Hof et al. 2008). Such analyses typically consider a range of discount rates, include assumptions about values and time horizons, and incorporate scientific uncertainties regarding damages, baselines, climate

sensitivity, and abatement costs. Results of these analyses have been mixed. Some conclude that the benefits of stringent climate change policy outweigh the costs (Stern 2006), while others posit that tradeoffs among uncertain future climate impacts and concrete present costs for controlling greenhouse emissions can only justify low levels of abatement (Keller et al. 2004; Manne and Richels 2004; Nordhaus 2007; Pearce 2003). Hof et al. (2008) concluded that both stringent and moderate climate policy can be justified depending on the parameters and assumptions used in the cost-benefit analysis. Uncertainty regarding the incidence and magnitude of changes in climate and the effectiveness of mitigation strategies leads to ambiguity in assessing or even estimating the outcomes of management. The question of how much certainty is necessary in climate change projections to justify investment in adaptation efforts and whether such certainty might be forthcoming in the near future is central to societal action on the matter (Dessai and Hulme 2007). The Intergovernmental Panel on Climate Change (IPCC) assessment reports have attempted to incorporate current tenets of risk communication to carry a consistent message despite uncertainty. The IPCC deals with uncertainty by presenting various levels of likelihood of particular changes and the scientific confidence in those likelihoods (IPCC 2007); in effect trying to communicate the uncertainty of the uncertainty. In contrast, Patt and Dessai (2005) deduced, using survey results from climate change experts and university students, that this IPCC approach does not preclude the possibility of biased and inconsistent responses and reactions to climate change information; thereby exacerbating the problem of dealing with the uncertainty.

In the case of climate change where both probability of occurrence and consequences of changes are highly uncertain, it may be useful to reframe the discussion in terms of vulnerability of rangeland systems to climate change. Vulnerability describes characteristics inherent in a system that create a potential for harm to occur, but are not dependent on the risk of a particular event (Sarewitz et al. 2003). As such, these vulnerabilities to effects of climate change may be more readily observed and acted upon by managers. A framework of risk focuses on accruing increasingly more accurate predictions about the nature, level, and impacts of an event or series of events. Such a focus can be problematic in cases such as climate change where there is little to no experience with the phenomena we are trying to predict. Understanding the uncertainties and incorporating them into management may become impossible (Sarewitz et al. 2003). However, understanding and reducing vulnerabilities relies less on prediction of unfamiliar phenomena by focusing more on what is reasonable and what is not; informed by history, general scientific insight, personal experience, and personal priorities (Sarewitz et al. 2003). A focus on vulnerability management rather than risk management acknowledges the limits of quantitative prediction and presents a decision process that is flexible and reflexive to adapt to uncertainty and experience.

6 Interactions between Biophysical and Socioeconomic Systems and Management

Rangeland managers need to consider how to adapt to the changed conditions on rangeland systems. Adaptation can encompass changes to processes, practices, and structures to mitigate potential damages, or take advantage of opportunities. Management can reduce vulnerability of communities, regions, or activities (IPCC 2001). While climate change is global in scale, these adaptive strategies are local or regional in nature and must consider the ecological, social, and economic drivers and responses of rangeland systems.

More and better information contributing to better informed decisions is critical for adaptive management. Monitoring allows one to focus on those areas of the system known or thought to be vulnerable. The question becomes what to monitor. The Integrated Social, Economic, and Ecologic Conceptual (ISEEC) framework (Fox et al. 2009), by pointing out and clarifying linkages between system components and social, economic, and ecological states and processes is complementary to a focus on vulnerabilities. Indeed, thinking within such a framework can steer managers toward identifying and monitoring vulnerabilities.

Figure 4 presents the ISEEC framework. More detailed explanation can be found in Fox et al. (2009) but some basic explanations are presented here. At the top of Figure 4, the green boxes on the left represent the current state and condition of the biophysical ecosystem, while the blue boxes on the right represent the current state and condition of the socioeconomic system and society. Ecological processes and social and 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). Assessment of sustainability occurs through an interpretation of how and why changes occur between time periods.

Ecosystem goods and services (EGS) and changes in EGS form a primary bridge between the biophysical and socioeconomic realms and are the means through which social and economic systems and processes affect and are affected by ecological systems and processes. Such interactions and effects occur in forms such as extractions of ecosystem goods (timber, forage, etc.) and their uses; tangible and intangible ecosystem services (including core ecosystem processes that purify air and water, generate soils and renew their fertility, 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, habitat fragmentation, 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 ecosystem function 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 changes brought about by land use change.

Figure 4 illustrates some specific examples, within the ISEEC framework, of some ecological and socioeconomic processes and institutions that will play a role in the interactions of changes and land management responses to climate change as they play out over time. The arrows show a detailed interface between the biophysical and human realms. The production and uses of EGS, and feedbacks between ecological and socioeconomic processes and institutions are illustrated. The framework should be thought of as changes, perceptions of changes, and responses (with different responses occurring at different rates) occurring iteratively over time. Iterations capture the effect and response pattern that is played out as ecological conditions change and society responds to those changes. Land managers, policy makers, or society in general will strive to mitigate deleterious effects and try to shift or adapt human behavior in an attempt to "fix" the changed ecosystem. Those social and economic responses result in further changes in the functioning of EGS that feed back on core ecological processes resulting in changes in the state and condition of the ecosystem.

In this simplified example using ranching, the ecosystem 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, we would expect prices to decrease and consumption to increase. As quantity demanded increases we expect prices to increase, signaling ranchers to produce more beef. If monitoring were to show overgrazing occurring 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 adds a level of complexity.

Changes in climatic conditions evoke biophysical responses in rangeland ecosystems as previously discussed. These biophysical changes, in turn, lead to responses in social and economic systems. In areas of lower precipitation, land managers might need to provide more forage or provide supplements to support their livestock. Costs of production will increase if ranchers want to maintain their level of production. If one response of land managers is to leave their livestock on the rangeland for longer periods of time to provide additional 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, 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 effects unfold, there will be effects on other ecosystem goods and services. Livestock management will affect the quality and quantity of EGS produced by the rangeland ecosystem beyond the direct

effects of climate change on those EGS. As an 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, but can also affect air and water quality.

Management and social regulation could provide mitigation 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/livestock 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. Changing conditions and reactions cause feedback responses that become an iterative cycle over time. Monitoring of these response factors (indicators) is an important component of adaptive management for rangeland sustainability.

7 How Does One Choose Among Potential Indicators?

Indicators can be utilized to meet multiple needs. Rametsteiner et al. (2009) suggested that indicators provide more than an understanding of current conditions; instead, they establish a basis for understanding how humans and/or 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 decisions and disturbances initiated from both sides of the framework. However, the identification, measurement and implementation of appropriate indicators continues to be a challenge facing policy- and decision-makers from local to global scales (McCool and Stankey 2004).

The use of sustainability indicators requires an integrated approach combining biophysical and socioeconomic aspects. The choice of indicators relies on framing the questions and selecting the appropriate suite of indicators to assess the pertinent questions at appropriate scales. Many authors have expressed concerns and noted challenges facing the use of indicator approaches to assess sustainability (including Cairns et al. 1993; Landres et al. 1988; Noss 1990; Noss and Cooperrider 1994; Simberloff 1997; among others):

- Monitoring programs often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of the social, economic, and ecological 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 that 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 ISEEC framework described above is one such attempt. In the systematic process of analyzing rangeland ecosystems, considering the social and economic context of rangeland ecosystems in addition to the ecological components, one can begin to identify linkages where effects of changes can trigger responses. Such linkages are places to consider indicators that can focus attention on stress and vulnerabilities.

While a conceptual framework to systematically guide one's thinking is essential to developing a system of indicators, identifying and developing indicators is both science and art. One must consider the system and interactions between components of the system to identify points of stress and vulnerability.

What criteria do indicators need to meet in order 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 stresses 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 (e.g. soils, water, vegetation, etc.); (7) illustrate a known response to natural disturbances, anthropogenic stresses, and change over time; and (8) have low variability. The same set of criteria can be extended to social and economic indicators.

8 Managing Rangeland Ecosystem Goods and Services with an Uncertain Future

Climate change and rangeland 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 varying temperature and precipitation patterns and indirectly affecting disturbances such as fire, insects, invasive species, erosion, and drought. Also affected are core ecological processes of soil formation, energy flow, nutrient cycling, and biodiversity that maintain properly functioning ecosystems, and which are collectively necessary for humans to exist (Havstad et al. 2007).

Perhaps the greatest obstacle facing land managers is uncertainty over (1) the exact nature and magnitude of climate change and (2) how ecosystems and society will respond to a changing climate. Adaptive management can be of limited effectiveness because measurable ecosystem responses to management changes often occur within a reasonable time only 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 whereby 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. Those components might need to be accomplished by a broader group than land managers themselves such as a management agency like the Bureau of Land Management (BLM) or the Natural Resource Conservation Service (NRCS), or a non-government organization like the Grazing Lands Conservation Initiative (GLCI), 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 uncertain future of changing climate, any individual or collective response must include monitoring indicators that will provide the best chance of detecting changes in rangeland resources brought about by either climate or management.

9 Management Considerations in the Northern Great Plains

The ultimate question is how to manage for ecosystem goods and services under the uncertain future of climate change. Land managers on the Northern Great Plains may have more time and opportunity to manage proactively to mitigate effects of climate change just because of the nature of the systems they manage.

One management tool that all land managers should consider is the setting and adjustment of stocking rates. Research has demonstrated that the productive capacity of some 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 are shown in Table 1. These are adapted from the SRR national indicators (listed in Mitchell (2011)). Table 1 also indicates the direction of change expected in each indicator as a result of climate change and identifies the linkage (numbered arrows) in the ISEEC model (Figure 4). With the expected increase in precipitation and longer growing season in the north, along with continued rising of atmospheric CO_2, we expect an increase in forage production (indicated by the + sign on Table 1, associated with Arrow 1). While ranchers may increase the number of livestock on rangelands to take advantage of this, we expect that the land available for

grazing will not change (Arrow 4). Because of the increase in productivity, the rate of return on investment in the ranch and the proportion of total income from ranching would be expected to increase (Arrow 4). Since forage will be more abundant, its value should decrease (Arrow 5) while the value of other products is indeterminate. We expect that recreation will increase over time and the value produced by recreation will increase (Arrow 7).

At the same time, there will be impacts, both positive and negative, on the environment. As indicated in Table 1, density of roads and human structures are expected to increase while the extent of bare ground (erosion potential) is expected to decrease (Arrow 6). Other effects on the ecosystem are expected to be negligible.

As these changes are occurring, we expect investment in rangeland improvement practices to remain static or increase slightly due to higher returns on investment (Arrow 8). Investments to restore rangelands may stay static or decrease as the increased precipitation may negate the need for more costly interventions. As demand for recreation opportunities increases, we can expect more investment in recreational facilities (Arrow 9).

Finally, if all of the above hold true, there may be little incentive to change economic policies to assist the ranching sector. We expect, however, that as the population increases in this region, more of the public will become involved in land management decisions. In order for ranchers and the public to adapt to the effects of climate change, education and technical assistance will grow in importance (Arrow 10).

If the indicators described above are monitored over time, we expect that decision-makers will have a set of data that can be used in the adaptation process. Making the information readily available to the community at large, with appropriate education on data interpretation, will lead to more informed decisions and social acceptability of those decisions. As noted, this region of the country may have more time to adapt to changes brought on by climate change than some other regions.

10 Management Considerations in the Southwest

Southwestern rangelands are generally limited by precipitation. Annual precipitation is bimodal, characterized by a highly variable winter and early spring period and 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 (Tab. 1, Arrow 1) and provides forage (Tab. 1, Arrow 4) for grazing animals (Paulsen and Ares 1961). Managers can anticipate relatively wet or dry winters on the basis of predicted El Niño and La Niña events, respectively (Sheppard et al. 2002), but the summer monsoon remains less predictable.

Livestock adjustments (Tab. 1, Arrow 4) remain the primary rangeland management tool in the Southwest (Torell et al. 2010). Stocking rates depend on both present productivity and residual biomass (Tab. 1, Arrow 5) remaining from the previous year's utilization (Paulsen and Ares 1961). During extreme droughts (Tab. 1, Arrow 1), 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.

Shrub encroachment into desert grasslands (Tab. 1, Arrow 6) 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). Because shrubs can dramatically reduce forage production and cause accelerated erosion (Tab. 1, Arrows 1, 3, 6), Southwestern rangeland managers should attempt to control shrubs at an early stage of invasion into their rangelands. Land managers should learn about different states-and-transitions that apply to their local ecological sites. These models can serve as tools to better understand how their landscapes might respond to climate change and organize options for responding to it (Bestelmeyer et al. 2004).

Forage quality constitutes a factor affecting rangeland management in all regions. In the Southwest, forage quality (Tab. 1, Arrow 5) is correlated with precipitation (Cable and Shumway 1966). One way land managers can better take advantage of forage quality 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 generally present at that time. As temperatures increase over time and growing seasons lengthen this might become even more feasible (Tab. 1, Arrow 4).

Given the predictions of climate models that the Southwest will become increasingly arid during this century (Seager et al. 2007), land managers must plan on droughts becoming more intense, if not more frequent. Management that reduces vulnerability, and thereby both ecological and financial risk, will be key to any planning framework (Tab. 1, Arrows 4, 5, 7, 8, and 9). Although little research to date has focused on the synthesis of ecological and economic sustainability under a varying climate (Torell et al. 2010; Ritten et al. 2010; Craine et al. 2010 are some early entries), research has shown that an optimal (profit maximizing) stocking rate for economic returns may be lower than a stocking rate that maximizes livestock production (Workman 1986). This implies a subset of indicators related to economic and social interactions. Livestock prices, livestock product demand, cost of alternative feedstock and supplements, local labor market conditions such as unemployment and wage rates, local community and economic stability could be considered for indicators (Tab. 1, Arrows 5, 6, 7, 8, 9, and 10).

11 General Comments on Rangeland Management

Regardless of the region in which they live, land managers should consider diversifying their business plan to provide for multiple sources of income so as to decrease their vulnerability to

climate change and increase their flexibility to adapt to changes and cycles in 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.

Ranchers and other private and public land managers should make the maintenance of rangeland health and productive capacity a business goal (as reinforced by findings alluded to above in Ritten et al. 2010), particularly at the landscape level. Ecosystems are more susceptible to droughts, invasive species outbreaks, wildfire, and other episodic events when they lack diversity and resilience. Identifying and monitoring such vulnerabilities and focusing adaptive management on those vulnerabilities is one way for managers to respond to changing conditions in spite of uncertainty.

Land managers should learn as much as possible about how their ecosystems may respond to climate change. Answers to some basic questions will allow them to anticipate responses to change and incorporate that knowledge into their management planning. Questions related to determining indicators to monitor include but are not limited to the following. Is precipitation expected to increase or decrease in their area? Will their key species, whether they are warm-season or cool-season plants, 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 and disease, and fire?

Management for ecosystem services requires landowners and managers to incorporate all the above information into a plan based on a systematic framework to identify and establish a system of indicators for monitoring the ecosystem processes, goods and services produced by the land, 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 changes, and proactively adapt to changing conditions. As shown by our examples of the northern Great Basin and desert Southwest, ecosystem responses to climate change are expected to differ in magnitude and/or direction with resulting differences in 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 for sustainability.

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(a) (b)

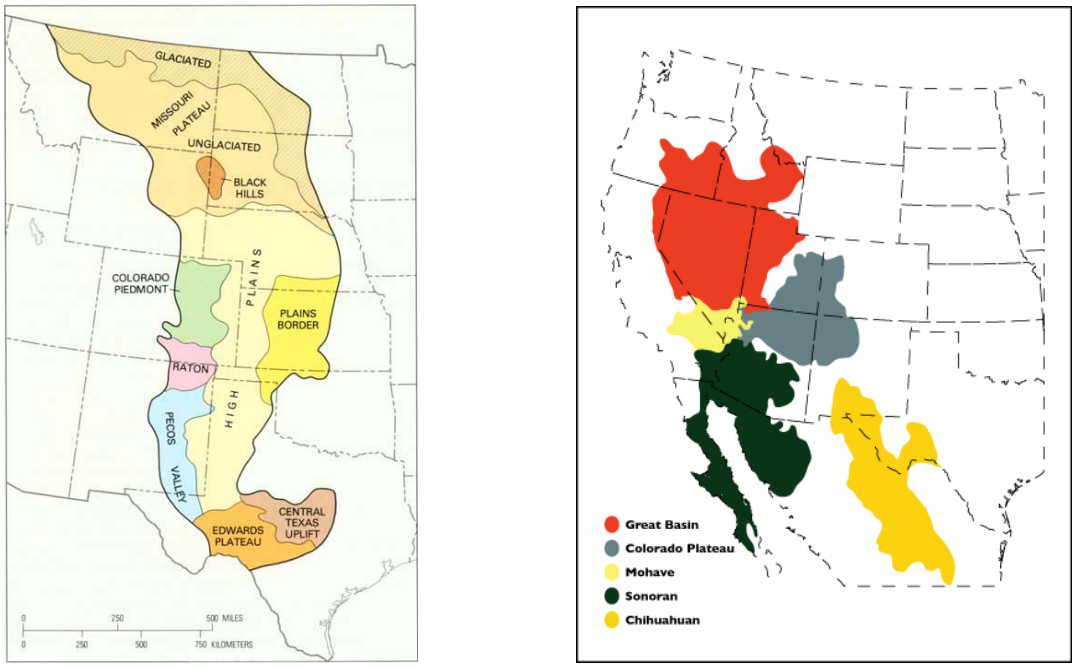


Figure 1. The Great Plains (a) (Trimble 1980) and desert Southwest (b) (Tanaka et al. 2009) regions.

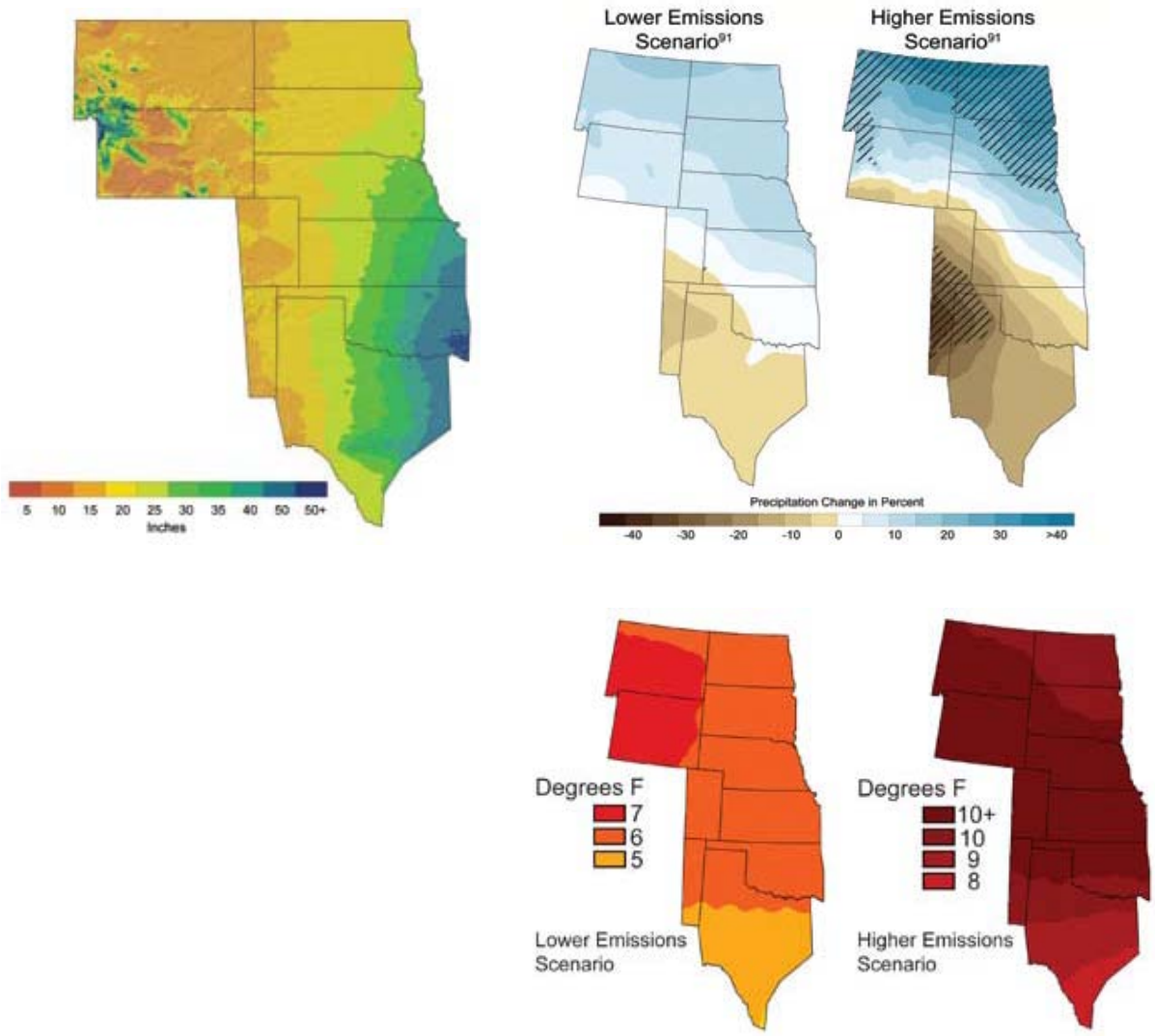
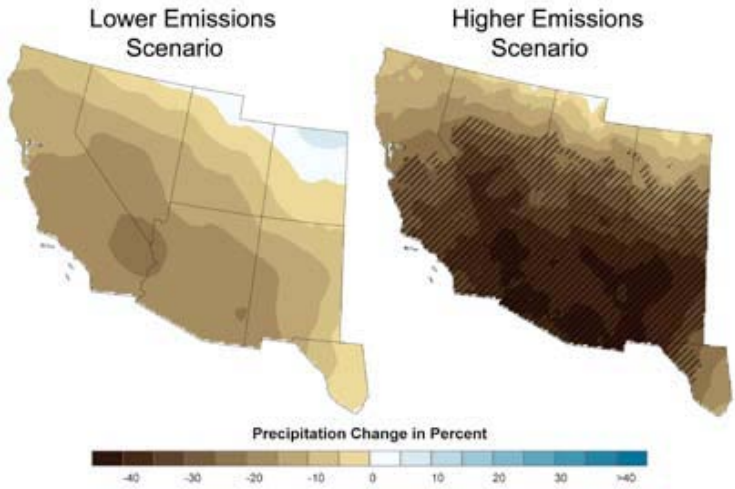


Figure 2. Past and future climates in the Great Plains. Average annual observed precipitation (1971-2000) in Great Plains (a); projected spring precipitation changes by 2080-2090s in the Great Plains for lower and higher emissions scenarios (b); and summer temperature change in the Great Plains by 2080-2099 for lower and higher emissions scenarios (c). (Source: Karl et al. 2009; Image credit: U.S. Global Change Research Program; www.globalchange.gov).

Figure 3. Percentage change in March-April-May precipitation in Southwestern U.S. for 2080-2099 compared to 1961-1979 for lower and higher emissions scenarios (Karl et al. 2009; Image credit: U.S. Global Change Research Program; www.globalchange.gov).



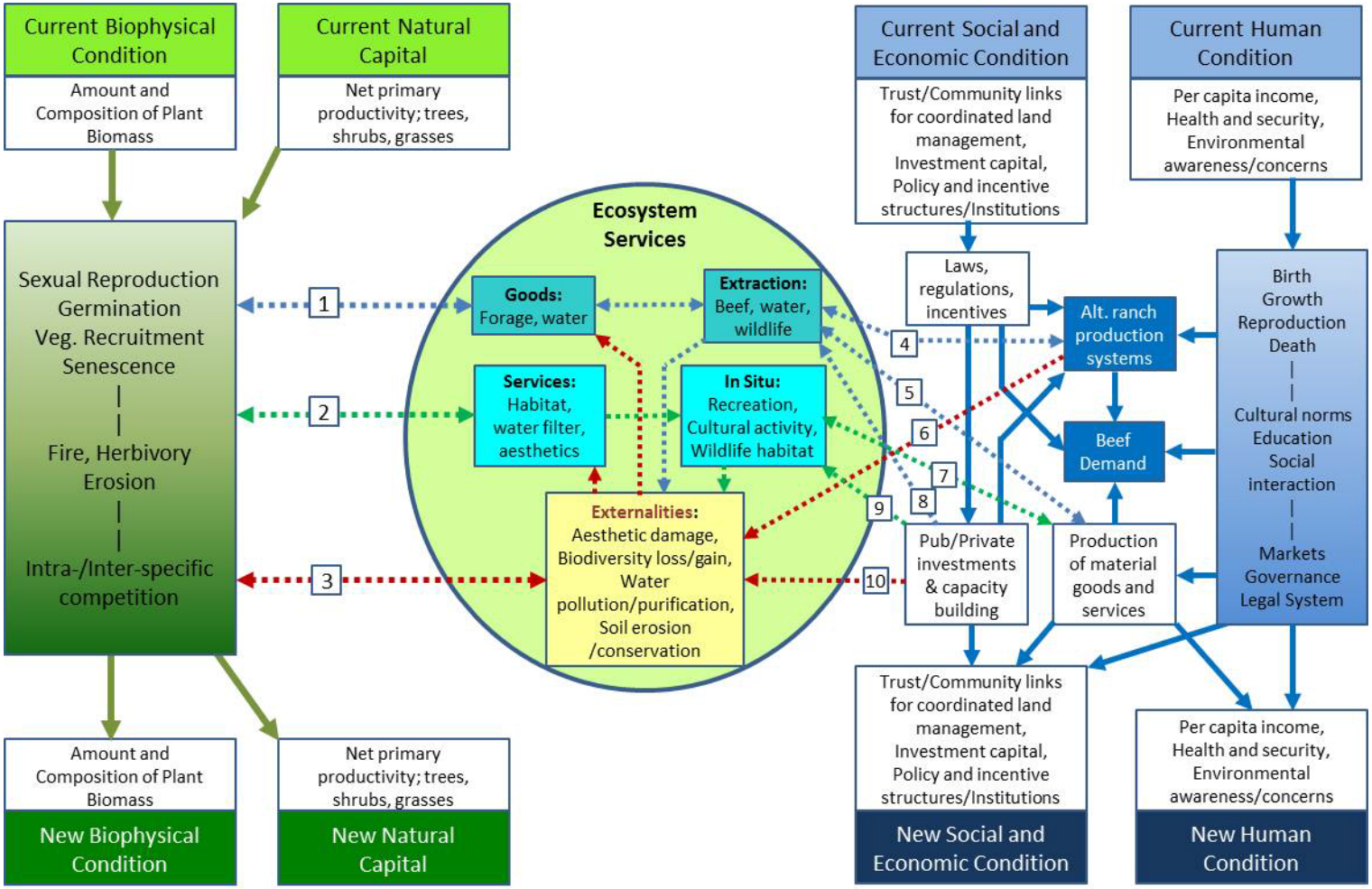


Figure 4. Integrated Social, Economic, and Ecologic Conceptual (ISEEC) framework for climate change effects on ranching on rangelands. Based on Fox et al. (2009).

Table 1. Indicators to detect expected effects on rangelands from climate change. "+" indicates a positive change, "-" a negative change, "0" no change, and strength by the number of symbols. Arrow numbers refer to the linkages (arrows) in the ISEEC model (Figure 4).

		Expected Climate Change Effects	
Arrow	Indicator(s)	Northern Great Plains	Southwest
1	Precipitation	+	-
	Rangeland annual productivity	+	-
2	Increase in the frequency and duration of surface no-flow periods in rangeland streams	+	+++
	Extent and condition of riparian systems	0	--
3	Area and percent of rangeland with a significant change in extent of bare ground	0	+++
	Integrity of natural fire regimes on rangeland	0	--
4	Rate of return on investment for range livestock enterprises	+	-
	Level of dependence on livestock production for household income	+	-
	Percent of available rangeland grazed by livestock	0	-
	Number of domestic livestock on rangeland	+	--
5	Value of forage harvested from rangeland by livestock	-	+
	Value of production of non-livestock products produced from rangeland	+/-	+
6	Change in area and percent of rangeland with a significant change in extent of bare ground	-	++
	Area of infestation and presence/absence of invasive and non-native plant species of concern	0	+
	Area and percent of rangeland with accelerated soil erosion by water and wind	0	++
	Fragmentation of rangeland and rangeland vegetation communities	0	+
	Density of roads and human structures	+	+
	Presence and density of wildlife functional groups on rangeland	0	--
7	Number of visitor days by activity and recreational land class	+	++
	Value produced by recreation industry as percent of total	+	-
8	Value of investments in rangeland, rangeland improvements infrastructure	0/+	---
	Expenditures (monetary and in-kind) to restoration activities	0	+
9	Value of investments in recreation/tourism infrastructure	+	++
10	Economic policies and practices	0	+
	Public information and public participation	+	++
	Professional education and technical assistance	+	++