

Chapter 15

Managing Climate Change Risks in Rangeland Systems

Linda A. Joyce and Nadine A. Marshall

Abstract The management of rangelands has long involved adapting to climate variability to ensure that economic enterprises remain viable and ecosystems sustainable; climate change brings the potential for change that surpasses the experience of humans within rangeland systems. Adaptation will require an intentionality to address the effects of climate change. Knowledge of vulnerability in these systems provides the foundation upon which to base adaptation strategies; however, few vulnerability assessments have examined and integrated the climate vulnerability of the ecological, economic, and social components of rangeland systems. The capacity of ecosystems, humans, and institutions to adjust to potential damage and to take advantage of opportunities is termed adaptive capacity. Given past attempts to cope with drought, current adaptive capacity is not sufficient to sustain rangeland enterprises under increasing climatic variability. Just as ecosystem development is affected by past events, historical studies suggest that past events in human communities influence future choices in response to day-to-day as well as abrupt events. All adaptation is local and no single adaptation approach works in all settings. A risk framework for adaptation could integrate key vulnerabilities, risk, and hazards, and facilitate development of adaptation actions that address the entire socio-ecological system. Adaptation plans will need to be developed and implemented with recognition of future uncertainty that necessitates an iterative implementation process as new experience and information accumulate. Developing the skills to manage with uncertainty may be a singularly important strategy that landowners, managers, and scientists require to develop adaptive capacity.

Keywords Adaptive capacity • Socio-ecological systems • Risk • Vulnerability • Adaptation planning

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15.1 Introduction

The management of rangelands has long involved adapting to climate variability in order that economic enterprises remain viable and ecosystems sustainable (Marshall and Stokes 2014). Rangeland management has never been just about the land; “managers have sought to maintain a relationship between rangelands and the people who hoped to benefit from the land, and to do it in such a way that those benefits were realized while the land retained its capacity to provide what society valued” (Brunson 2012). This relationship and the corresponding benefits will be challenged under climate change (IPCC 2014a; Crimp et al. 2010; Chap. 7, this volume).

Climate change brings to this relationship the potential for large-scale modifications, including those that surpass the experience of humans currently living on rangelands. Since the early 1990s, the global scientific community has been studying and reporting on the nature of these global changes in climate, the human and natural activities contributing to these global changes, and the associated impacts to land and water (IPCC 2014a). Warming temperatures are projected as well as changes in seasonal precipitation patterns, total annual precipitation, and the potential for increased drought (Chap. 7, this volume). While rangeland managers and enterprise owners have incorporated strategies to address variability in climate, these future changes may be beyond the variability they have experienced in their lifetime. The enterprise owner and their family, the manager, and employees are embedded within social and economic networks and institutions that are interdependent with the ecological system which includes soil, plants, animals, and ecosystem processes. This interdependent system is formally called a socio-ecological system (Berkes and Folke 1998; Brunson 2012). We view the socio-ecological rangeland system as a collective of economic enterprises (livestock and other market outputs) and the ecological system (Fig. 15.1) (Chap. 8, this volume). We use this framework to explore adaptation to climate change.

The global conversation about adaptation has expanded from an initial focus on ecological and economic impacts and adaptation strategies to a broader vision of ecological, economic, and social impacts and adaptation strategies. Adaptive capacity is the ability of plants, animals, and humans, as well as the systems and institutions to adjust to potential damage or to take advantage of opportunities under climate change (Table 15.1). Social values of the enterprise owner influence management goals while at the same time community values, local and regional economics, and government policy are influencing the owner’s values and decisions. Thus understanding the interdependent nature of the socio-ecological rangeland system is key to understanding and facilitating adaptation in rangeland systems (Fig. 15.1).

This chapter explores adaptation to climate change in the context of socio-ecological systems. We review the evolving concept of adaptation and the development of strategies for adaptation to current and future climate change. We explore what we might learn about past attempts to cope with climatic events and how a historical perspective could frame future adaptation strategies on rangelands. Four case studies from around the world are summarized to describe

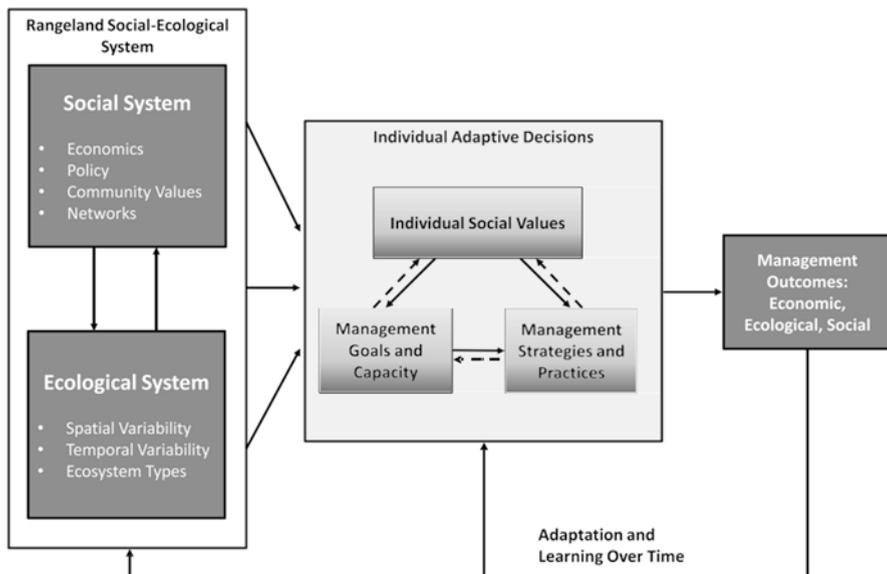


Fig. 15.1 This adaptive decision-making framework emphasizes how the sustainability of individual ranching operations depends on their capacity to adapt to the changing parameters of the social-ecological systems in which their enterprises are embedded (Lubell et al. 2013)

past and future adaptation strategies. We examine what adaptation management on rangelands might look like in the future. The biophysical consequences of climate change on rangelands are described in Chap. 7 of this volume.

15.2 Evolution of Climate Change Adaptation

Our understanding of what adaptation means in response to a changing climate has evolved through the last 25 years and likely will continue to evolve. This evolution is most visible in the five assessment reports of the Intergovernmental Panel on Climate Change (IPCC) where each report (1992, 1995, 2001, 2007, 2014) synthesized the most current published scientific literature on climate change. Two threads in these reports that highlight an evolution in our scientific understanding are of specific interest. First, the definition of adaptation as applied to climate change and related topics such as adaptive capacity has evolved. Second, the discussion of rangelands has shifted from an emphasis on the mismanagement of rangelands to an exploration of the effects of climate change and potential adaptation responses.

Increasingly, the assessment of climate change impacts, vulnerability, and adaptation in the IPCC reports has come to include the economic and social impacts of climate change, and the role of humans in managing natural systems. In the first three IPCC reports, chapters related to rangelands or ecosystems focused on ecological

Table 15.1 Definitions of terms used in this chapter

Term	Definition
Adaptation	Process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects
	<i>Incremental adaptation</i> —adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale
	<i>Transformational adaptation</i> —adaptation that changes the fundamental attributes of a system in response to climate and its effects
Adaptation options	Array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social
Adaptive capacity	Ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases
Resilience	Capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation
Risk	Potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs
Vulnerability	Propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt

All definitions from Agard et al. (2014) unless otherwise noted

effects of climate change with very brief discussions of adaptation options (IPCC 1990; Allen-Diaz et al. 1996; Gitay et al. 2001). In the first IPCC report, rangeland adaptation responses were broadly identified as developing emergency and disaster preparedness policies, improving the efficiency of natural resource use and needed research on control measures for desertification, and enhancing adaptability of crops to saline conditions (IPCC 1990). In the Third Assessment Report, the overuse of rangeland resources and the associated rangeland degradation were seen as more impactful than the future effects of climate change (Gitay et al. 2001). Consequently, adaptation options such as selection of plants (legume-based systems) and improved livestock management were identified as a means to address current rangeland degradation as well as the potential effects of climate change.

As the focus expanded to include societal impacts and responses, the structure of the IPCC assessment reports included a more in-depth discussion of adaptation limits and transformation in social and natural systems. The Third Assessment pro-

vided a definition of adaptation that specifically included humans: “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2001). In this report, adapting to climate change was seen not only as reducing vulnerability to climate change but also as promoting sustainable development, development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Adaptation was characterized in terms of purposefulness (autonomous versus planned), timing (anticipatory, proactive, reactive), temporal scope (short versus long term), spatial scope, form (e.g., structural, legal, institutional), and criteria to evaluate its performance. Although the Third Assessment report did not discuss adaptive capacity with respect to rangelands, adaptive capacity was defined and that definition has been retained by subsequent reports (Table 15.1). In the Fourth Assessment report, adaptive capacity was recognized as being influenced by social variables, in addition to biophysical and economic resources (Adger et al. 2007).

By the Fourth Assessment Report, the scientific and management communities had contributed an extensive literature that could be reviewed in chapters focused on the assessment of adaptation practices, options, constraints and capacity, and interrelationships between adaptation and mitigation. Adaptation rarely was implemented in response to climate change alone and high adaptive capacity did not, in general, lead to actions to reduce vulnerability to climate change. The report identified significant barriers to implementing adaptation that spanned the inability of natural systems to adapt to the rate and magnitude of climate change, but also constraints in technology, financing, cognitive and behavioral components, and social and cultural settings. With respect to ecosystems, adaptation options focused only on altering the context in which ecosystems developed and little attention was given to the human systems component. It was acknowledged that identifying adaptation responses and options for ecosystems was a rapidly developing field (Fischlin et al. 2007). However, it would take a reframing of adaptation in the context of risk to bring the ecological, economic, and social components into a more integrated framework.

In the Fifth Assessment, the definition of adaptation became “the process of adjustment to actual or expected climate and its effects.” The definition expands on the human role. “In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects” (Table 15.1). Though subtle, this definition is different from previous IPCC definitions in that there is *intentionality* to the adaptation action. It is not just the restoration of a rangeland ecosystem; the adaptation action includes specific consideration of climate change objectives in management. The definition of adaptation was further nuanced. Moving beyond adaptation categories of anticipatory and reactive, private and public, and autonomous and planned, only two types of adaptation were defined in the Fifth Assessment: incremental and transformational (Table 15.1). The report notes that adaptation options to date have been mainly incremental and stresses that adaptation may require transformational changes,

in which potentially impacted systems move to fundamentally new patterns, dynamics, and/or locations.

The concept of risk is used in this most recent IPCC Assessment to frame decision making in a changing world, with continuing uncertainty about the severity and timing of climate change impacts and with limits to the effectiveness of adaptation (IPCC 2014b). Risk is defined as “the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values” (Table 15.1). This introduction of risk allows the discussion of adaptation to integrate the risk of climate-related impacts, climate-related hazards, and vulnerability and exposure of human and natural systems as these risks, hazards, and vulnerabilities interact and are impacted by socioeconomic and climate drivers (Fig. 15.2). When climate change factors from more than one economic sector or geographic region are included in a risk assessment, risks that were not previously assessed or recognized emerge. An example of such interaction is the policy to encourage the use of bioenergy to mitigate climate change by reducing fossil fuel emissions, but which has led to shifting cropland acreage from food production to bioenergy crop production and consequently raising prices for food crops, resulting in a reduction in food security and increasing human vulnerability to climate change

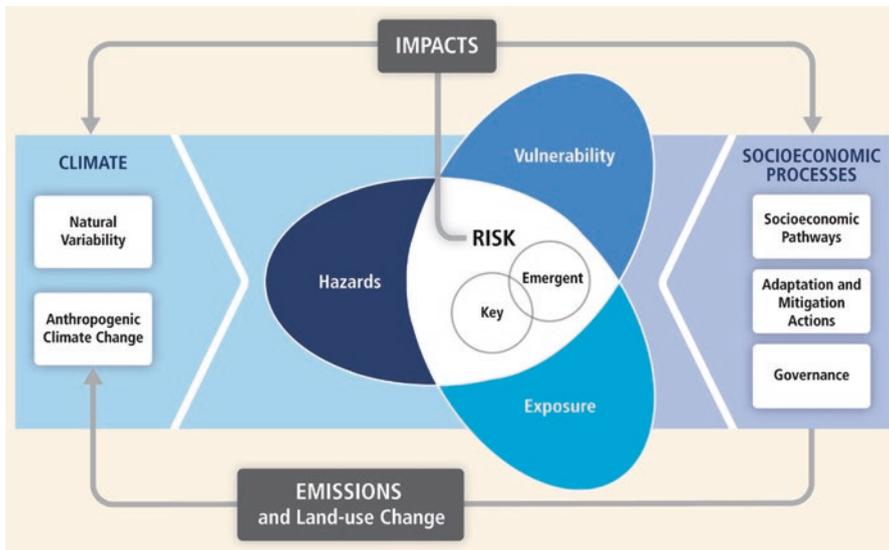


Fig. 15.2 Schematic of the interaction among the physical climate system, exposure, and vulnerability to produce risk. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Vulnerability and exposure are largely the result of socioeconomic pathways and societal conditions (although changing hazard patterns also play a role). Changes in both the climate system (*left side*) and socioeconomic processes (*right side*) are central drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (Oppenheimer et al. 2014; Fig. 19.1)

(Oppenheimer et al. 2014). This Fifth Assessment report summarizes the key risks globally (Oppenheimer et al. 2014); we will explore the key risks identified for rangelands later in this chapter.

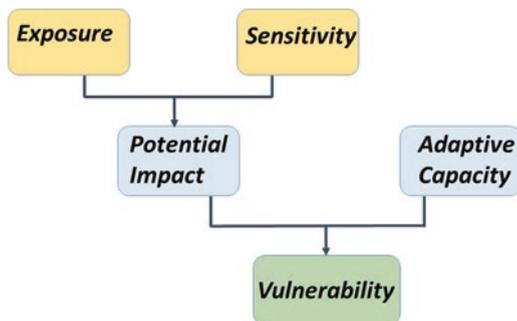
15.3 Assessing Vulnerabilities to Implement Adaptation Actions

Knowledge of vulnerability provides the foundation upon which to develop and select specific adaptations and strategies. However, assessing vulnerability has been challenging as the definition of vulnerability has varied across the ecological-socio-economic spectrum and there has been no standard methodology to assess vulnerability of climate change (Fussel and Klein 2006; Glick et al. 2011; USGCRP 2011). Social characteristics of individuals and communities have been incorporated into vulnerability assessments with respect to disasters; however, most existing climate vulnerability assessments of plants, animals, or ecosystems have limited information on the related social and economic effects of climate (USGCRP 2011). Further, most approaches to assessing vulnerability in natural resource settings have not directly addressed risk.

Within ecological systems, the commonly used framework has focused on quantifying exposure, sensitivity and adaptive capacity of individual plant or animal species, or the ecosystem (Fig. 15.3) (Glick et al. 2011; Furniss et al. 2013). In some cases, the sensitivity of plants, animals, and ecosystems to changes in climate has been documented in the scientific literature or observed in long-term resource inventories (Peterson et al. 2011); additional sources of information include traditional knowledge (Laidler et al. 2009) and expert knowledge (Alessa et al. 2008; McDaniel et al. 2010; Moyle et al. 2013). Tools have also been developed to quantify ecological responses to future climate scenarios (Joyce and Millar 2014), although natural resource vulnerability assessments have been qualitative as well as quantitative.

Vulnerability of economic enterprises on rangelands has not been widely addressed. Few studies have explored the intersection of environmental variability and risk with economic variability and risk in livestock operations (see Torell et al. 2010). Few adaptation strategies identified in ecological or economic vulnerability assessments address social vulnerabilities. However, often the need for understanding the social

Fig. 15.3 Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity for ecological systems (modified from Glick et al. 2011)



component is identified: for example recognizing that rangeland manager perceptions about climate change inhibit their receptivity to adaptation options (Briske et al. 2015). Vulnerability of the agricultural economic sector has been quantified using market models to identify likely shifts in livestock and crop management strategies based on economic return (Heyhoe et al. 2007; McCarl 2011; Mu et al. 2013).

**Box 15.1: Adaptively Managing Environmental and Economic Risks:
Pawnee National Grassland, Colorado, USA**

East of the Rocky Mountain Front Range, the Pawnee National Grassland, managed by the USDA—Forest Service, sits within a mosaic of private and State of Colorado land, and the USDA Central Plains Experimental Range. The Pawnee National Grassland is managed for multiple ecosystem goods and services—domestic livestock grazing, wildlife, 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 (Fig. 15.6). Drought can occur at any time in the region and multiyear droughts of 8–14 years occurred in the 1930s and the early 1950s (Lauenroth and Burke 2008; Evans et al. 2011). Facilitating ecosystem resilience and reducing risk of resource degradation are important to these grassland managers. Reducing economic risks when drought reduces forage availability from public and private land is important to the private land livestock owners. Drought often brings conflict between environmental and economic interests because it directly involves environmental and socioeconomic systems.



Domestic livestock grazing on Pawnee National Grasslands (photo courtesy of David Augustine)

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Adaptive grazing management has been used to create and maintain diverse vegetation structure—a combination of short and mid-tall vegetation patches—that is needed to meet habitat needs for wildlife. The desired objective of rangeland management is to provide available forage for both wildlife and domestic livestock in a manner that is consistent with other resource objectives. Grazing management is accomplished on a total of 162 active allotments in partnership with two grazing associations. The majority of livestock grazing occurs May through October and most allotments are continuously grazed for this period. Annual grazing allocations are cooperatively determined at spring meetings with the FS Range Staff and Grazing Association Boards.

The 2002 drought and high temperatures severely impacted many economic sectors in Colorado (Pielke et al. 2005). In the years preceding 2009, very dry conditions forced grazing allotments on Pawnee to be vacated earlier than initially planned. Grazing association boards and permittees desired more notice about stocking adjustments in order to make more informed decisions about their overall operation. To address these concerns, an annual stocking strategy was developed that employs resource and management information to allocate livestock at the start of the season with a mid-season reevaluation of stocking levels. Resource and management information includes (1) precipitation over the previous year and the last 15 years both annually and for the growing season; (2) stocking rates for the previous year and the last 15 years; and (3) management and objectives including the current management, desired condition of the rangeland, current trends, and priority natural resources to be managed. Using this information, initial stocking recommendations for each allotment reflect condition assessments (poor, moderate, good). Midseason grazing adjustments are based on soil water availability and midseason allotment condition. This strategy is designed to be adaptive, as well as lay out possible scenarios so that the permittees are able to better anticipate their grazing on federal lands and make appropriate adjustments in their overall operations.

Allotment strategy development recognizes the risks of the federal managers and the risks of the private landowners and permittees. USFS personnel have the responsibility to manage the environmental risk as weather and other environmental stressors affect ecosystem services produced from the Pawnee National Grassland. The individual livestock owner has the responsibility to manage the economic risk as influenced by the supply and quality of forage from both federal and private land and livestock market fluctuations. When a drought is widespread, increased demand and high cost of forage may be coincident with volatile and declining cattle prices. The adaptive process gives the federal grassland managers and the permittees information and a timeline in which to make decisions relative to the risks they manage.

Vulnerability has been characterized as a function of both people's sensitivity to a change event and their capacity to adapt to it (Marshall et al. 2013). Consequently, people can be vulnerable because they are highly sensitive to change, or have insufficient adaptive capacity to accommodate change, or both. Importantly, people that are highly sensitive to change are not necessarily vulnerable if they have correspondingly high levels of adaptive capacity. According to this characterization, it is possible to identify who is more vulnerable than whom, and why. Climate sensitivity within the social subsystem is typically measured as a function of resource dependency (Marshall 2011). That is, the more dependent landowners are on the current rangeland enterprise, the more sensitive they are likely to be to climate change. Dependency can be described in economic terms, such as the goods and services produced, income sources, and alternative employment opportunities, and in social terms, including occupational identity, place attachment, employability, networks, environmental knowledge, and awareness (Marshall 2011).

Few assessments have contributed directly to implementation of adaptation actions on the ground (Noble et al. 2014). This lack of action can be ascribed to several factors (Yuen et al. 2013; Joyce and Millar 2014). The assessment could lack clear definitions of vulnerability and adaptive capacity, or have too narrow of a focus, such as natural resources that cannot be managed or changed. Weak quantitative components could include incomplete data, or inadequate descriptions of the interactions between climate change and other environmental stressors. The assessment may have no connection to management decisions such as insufficient information or a method to successfully prioritize among sensitive resources or to evaluate adaptation management. Lastly, the assessment may have failed to engage decision makers and/or the public. Further, few adaptation actions incorporate incentives to encourage human behavior toward management to sustain resilient ecosystems (for example, sustained drought management, Marshall 2010; Marshall and Smajgl 2013). Vulnerability assessments may often fail to implement adaptation because opportunities for collective learning by managers, the public, and decision makers are minimized or overlooked (Yuen et al. 2013). Collective learning arises when various goals, values, knowledge, and points of view are made explicit and questioned to accommodate conflict and reach common agreement. Collective learning represents the basis for identifying the collective action to tackle a shared problem (Yuen et al. 2013) and may be particularly important in a vulnerability assessment of a socio-ecological system.

Codependency between ecological and socioeconomic subsystems suggests that vulnerabilities are intrinsically linked. Further these systems operate in larger societal institutional systems. Using the vulnerability components of exposure, sensitivity, and adaptive capacity, linkages between the ecological and the social subsystems can be conceptualized (Marshall et al. 2014). In this portrayal of a linked socio-ecological system, ecological vulnerability to climate change can be seen as the exposure to climate change in the social subsystem (Fig. 15.4). Vulnerability in the socioeconomic subsystem is a function of the sensitivity of the social subsystem (dependency on natural resources), the adaptive capacity of the socioeconomic subsystem, and the vulnerability of the ecological subsystem (Marshall et al. 2014). There is feedback

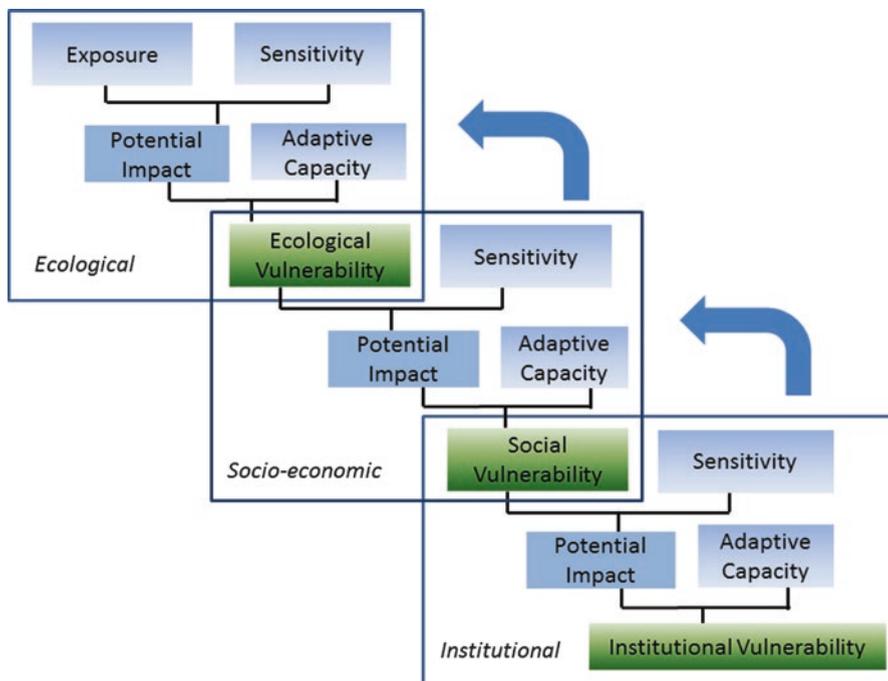


Fig. 15.4 A framework for conceptualizing vulnerability across ecological, socioeconomic, and institutional domains (modified from Marshall et al. 2014). Social vulnerability consists of sensitivity to change, the degree of resource dependency (ecological vulnerability), and adaptive capacity. Similarly, institutional vulnerability consists of institutional sensitivity to change, exposure (social vulnerability), and institutional adaptive capacity

from the socioeconomic system to the ecological system—this feedback may positively or negatively affect ecological vulnerability. We have added an institutional component to the model where the exposure term for the institutional subsystem is the vulnerability of the social subsystem. Vulnerability of the institutional subsystem feeds back to the socioeconomic and the ecological subsystems. Institutional components can be market structures, as when collapse of livestock enterprises led to restructuring of the regional livestock market in the 2012 drought in the USA. Institutional components involve government intervention as in the case with drought relief programs in the USA or national relief following dzud (severe winter weather disaster) in Mongolia. These interventions often do not reflect collective learning or desired collection action across the social and the institutional subsystems and thus may not facilitate resilient decision making at the enterprise or individual level (Thurow and Taylor 1999; Fernández-Giménez et al. 2012). As new markets, new government regulations, and climate change introduce new learning opportunities, vulnerabilities can arise at the household unit or livestock enterprise.

Box 15.2: Collaborative Management as a Means to Minimize Climate Risk: Mongolian Plateau, China

Inner Mongolian rangelands can be environmentally challenging for people and the primary industry of raising livestock. The climate of Inner Mongolia is cold; average annual temperatures vary between 1 and 2.5 °C. Precipitation is low and erratic with the majority occurring during three summer months. Winter storms can be harsh and frequent drought is associated with wind erosion. The culture had adapted to this harsh climate using strategies based on three core components: mobility, cooperation, and reciprocity (Dalintai et al. 2012). These strategies helped to sustain the resilience of this tightly connected socio-ecological system. For drought, these strategies included *otor* and *surug*. In *otor*, herds, through kinship relations, were moved to better grasslands in response to drought conditions; *surug* was a system in which herder leased a core number of their young female animals to herders in areas not as affected by drought. When the conditions in the original herders' area improved, they took back their livestock—this short-term leasing provided a way to maintain the core of their herd by matching forage production with animal demand.

The social setting in this area of China has seen a continual change since the 1950s with collectivization between 1950s and mid-1980s and then market reforms in the early 1980s. These changes affected many of the tight connections in the socio-ecological system. Collectivization strengthened production but weakened the mobility component by encouraging seminomadism. Market-oriented reforms emphasized rights of ownership by individual households, attempting to incentivize herders to use their grasslands rationally and sustainably. However, these changes eroded the strategies to adapt to the harsh climate. Mobility of herders was limited; consequently grasslands were overgrazed. Further, government structures assumed the role of providing services, weakening the kinship-based social structure of cooperation and exchange. At the start of the twenty-first century, a top-down effort by the government was initiated to address the degradation of grasslands. Grazing management strategies included restrictions on where and when grazing could occur, thus making it difficult for herders to migrate herds. Grass planting occurred and the government instituted a supplemental feed program. Herders were also moved away from the grasslands. These changes exacerbated the herders' poverty. However, degradation continued; Dalintai et al. (2012) suggest that the policy aimed at protecting the grasslands and improving herder's living standards proved ineffective because these most recent changes were implemented in a top-down manner. Essentially, over all of these social and economic changes, the vulnerability of the socio-ecological system to drought and winter storms increased.

A project was implemented to address issues of poverty and environmental degradation and to help preserve the traditional culture in the Sonid Left Banner area of Inner Mongolia, located on the south-eastern part of the

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Mongolian Plateau (Dalintai et al. 2012). The climatic risks and uncertainties remained as in the past; however the overgrazing had heightened environmental risks which were compounded with greater economic risks. This project attempted to nuance the land tenure structure to bring back the traditional ways but with a new structure that meshed with the land tenure and market systems. Cooperatives were created to facilitate a collective approach for the use of the grassland and a cooperative division of labor. The boundaries of land units from several households were merged, with the households still retaining ownership of the land. All animals were herded together. Herders were encouraged to take on the responsibility to restore the grassland. Collective decisions on grazing methods drew on traditional ways and information provided by research ecologists collecting data and working with the herders. The collective purchasing and marketing of products was an attempt to reduce the economic risks as well as improve market negotiation skills. Herders recognized that reducing the costs of a disaster is in its own way a kind of income. Project scientists realized that lowering the risks to herder production operations was more practical than attempting to increase their incomes. The cooperative's main problem is learning how to adjust to the government's grassland protection policies to better meet the local needs of the herders (Dalintai et al. 2012). The breadth of decisions that the local herders can take on directly affects the final performance of the community-based grassland management projects. Eventually, the restoration of the arid ecosystem and incomes both increase with greater local decision making.

The grand challenge for vulnerability assessments in rangeland systems and in getting adaptation on the ground is to connect awareness of vulnerability with the potential for adaptation across ecological, socioeconomic, and institutional systems. An assessment could identify the level of risk, urgency of action, efficacy, and cost-effectiveness of adaptation options, and engage and empower stakeholders, including vulnerable populations, in adaptation planning (Salinger 2005; Marshall and Johnson 2007; Joyce and Millar 2014). Processes that facilitate collective learning in the vulnerability assessment could help to identify adaptation approaches that most effectively accommodate and support rangeland managers and enterprise owners.

15.4 Resilience in Heterogeneous Systems

15.4.1 Resilience in Socio-Ecological Systems

Resilience has emerged as an important concept to guide and support more inclusive and effective approaches to the management of combined social and ecological systems (Ludwig et al. 1997; Berkes and Folke 1998; Levin et al. 1998). Resilience

was first characterized as persistence of ecological systems and described as their ability to absorb change and disturbance and still maintain the same relationships among component parts (Holling 1973; see Chap. 6, this volume). At this time, human and natural systems were treated independently and it was implicitly assumed that ecosystems responded to human use in linear, predictable, and controllable ways (Folke et al. 2002). The concept of resilience has since gained substantial momentum through recognizing the complexity and variability of natural and social systems (Gunderson 1999; Walker and Janssen 2002; Davidson-Hunt and Berkes 2004). For example, social and natural resource systems are intrinsically linked through intricate and dynamic cycles that are, by their very nature, adaptive (Holling and Meffe 1996; Holling 2001). These linked systems continually face interventions or disruptions that “reset” the natural cycles of recovery, growth, and adaptation (Holling 1996). Adaptive systems are flexible, continually change, and can cope and reorganize. Change and adaptation are now understood to be integral features of the dynamics of socio-ecological systems and have replaced the previous concept of ecological stability (Holling 1973; Folke et al. 2002).

The concept of resilience is especially apt when rangelands are envisioned in a socio-ecological context. Rangelands will have to continually adapt to climate-induced changes, including drought, heat waves, wildfires, flooding, greater weather variability, and shifts in rainfall and seasonal patterns (Walker and Schulze 2008), and increased pests and diseases (Volney and Fleming 2000). In addition, rangeland systems will have to address cultural change, including the acceptance and adoption of new best practices, and technology that enhances adaptation to climate change and reduces greenhouse gas emissions (Darnhofer et al. 2010; Fleming and Vanclay 2010; Marshall et al. 2016). In some instances, these climate-induced changes may be so severe or adaptive capacity very limited, that climate-related regulatory change through governance or social institutions will also need to be addressed (Cabrera et al. 2006).

Management of socio-ecological systems involves the maintenance of system properties and feedbacks that confer resilience without compromising the ability to cope and adapt to future change (Holling and Meffe 1996). Specifically, successful adaptation on the rangelands means that landowners and their enterprises will remain viable through time despite an increasing volatility within social and ecological subsystems (Fig. 15.1). Remaining viable depends not only on maximizing productivity during any one season, but also on minimizing negative consequences to future productivity (McKeon et al. 2004). Climate change requires that landholders make the most of good years and avoid losses and reductions in resource condition in drought years to an extent as yet unprecedented (Hobbs et al. 2008). If stocking rates are too high at the onset of drought, for example, soil erosion will be accelerated and the productivity of future years will be diminished (Watson 2004; 2008). These decisions involve trade-offs between short-term profit maximization and risk avoidance (Hammer et al. 1996; Hammer 2000; Hansen 2002; Hertzler 2007).

15.4.2 *Variations in Adaptive Capacity of Landowners*

Natural systems have an inherent adaptive capacity that has evolved from responding to past disturbances including climate. Adaptation has previously focused on the manipulation of natural resources, and economic resources. However understanding social heterogeneity among enterprise owners is important for effective management of rangelands and climate adaptation planning (Emtage et al. 2007). Adaptive capacity is the ability to convert existing resources—natural, financial, human, social, or physical resources—into a successful adaptation strategy (Marshall et al. 2014). Characteristics that contribute to adaptive capacity include creativity and innovation for identifying adaptations; testing and experimenting with various adaptations; recognizing and responding to effective feedback mechanisms; employing adaptive management approaches; possessing flexibility; being able to reorganize given novel information; managing risk; and having necessary resources at hand (Marshall et al. 2010).

We emphasize that adaptive capacity is not solely dependent on having financial or ecological resources. On rangelands, and at the landowner scale, adaptive capacity has been more comprehensively operationalized according to four measurable attributes reflecting landowners' and managers' skills, circumstances, perceptions, and willingness to change (Marshall et al. 2012). These have been described as (1) how risks and uncertainty are managed; (2) the extent of skills in planning, learning, and reorganizing; (3) the level of financial and psychological flexibility; and (4) the anticipation of the need and willingness to contemplate and undertake change (Marshall 2011; Park et al. 2012). While other measures have been developed in other contexts (e.g., Cinner et al. 2009) these four dimensions have served as the basis from which several studies on rangelands have examined adaptation processes (Marshall et al. 2011; Webb et al. 2013; Marshall and Stokes 2014).

Australian enterprise owners, as a group, exhibited highly heterogeneous levels of adaptive capacity (Marshall and Smajgl 2013). In fact, of the 16 possible combinations describing adaptive capacity on rangelands, all combinations were represented to some extent. Only some individuals had the capacity to respond successfully to policies and practices that enhance climate adaptation. This suggests that the current social heterogeneity in adaptive capacity will profoundly limit the extent to which landowners in Australia can respond to lower summer rainfall and increasing drought projected to occur in 2030 (Cobon et al. 2009).

Landowners that can anticipate or effectively react to the effects of climate change are more likely to adapt to new climate conditions. Landowners with a higher adaptive capacity tend to display consistent characteristics that have enabled researchers to more clearly define or describe what makes for a higher adaptive capacity (Marshall 2010). While management actions cannot eliminate risks of impacts from climate change, management can increase the inherent capacity of ecosystems to adapt to a changing climate (Settele et al. 2014). For example, humans can select adaptation actions that guide the transition or transformation of

a socio-ecological system toward an alternative system that may be more resilient to novel climatic conditions (Hobbs et al. 2013). Understanding social heterogeneity across enterprise owners could help tailor climate adaptation planning.

15.5 Management Responses to Past Change

15.5.1 Drought

Human activities can fundamentally alter the social-ecological interactions within rangeland systems (Stafford Smith et al. 2007), particularly as enterprise owners and managers respond to biophysical drivers such as climate, or socioeconomic drivers such as local, regional, and international markets (Reynolds and Stafford Smith 2002; Reynolds et al. 2007; Chap. 8, this volume). Semiarid and arid rangeland systems may be among the most tightly coupled socio-ecological systems because of the high degree of climate variability and dependency among system components (Stafford Smith et al. 2007). We look to studies of past management response to change for insights that could benefit climate change adaptation.

Drought is a normal part of climate and, although common in arid and semiarid rangelands, drought can occur in all types of climate (Thurow and Taylor 1999; Wilhite and Buchanan-Smith 2005). Drought is referred to as a slow-onset natural hazard, where effects of drought accumulate slowly over time. This slow onset, and the temporary nature of drought, often leads to a lagged response by landowners and managers. Drought impacts can be costly, with reductions in water supplies, forage, and livestock productivity. Herd liquidations, one response to drought, often occur on the downside of the price curve for livestock and restocking on the upside of the price curve (Bastian et al. 2006), resulting in financial challenges for the landowner (Torell et al. 2010).

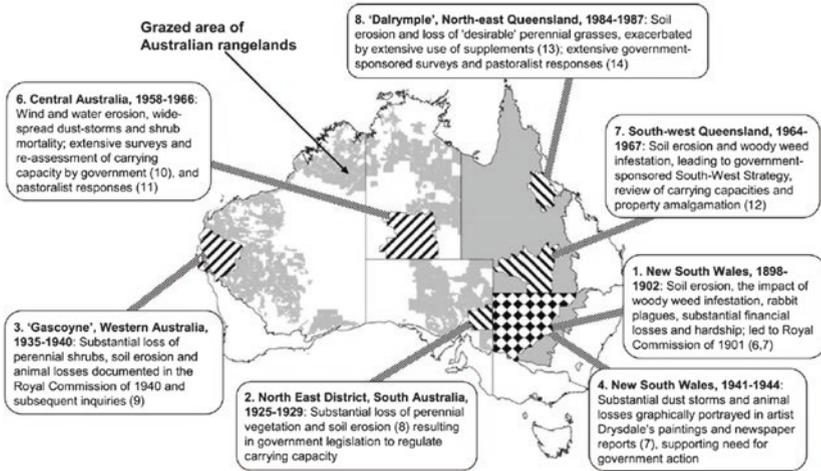
Drought has been a learning experience at the scale of an individual livestock enterprise; however, some enterprises may still be underprepared for subsequent droughts. Over 500 cattle ranchers in the state of Utah were surveyed after the 1999–2004 drought, described as the sixth most severe drought since 1898 in Utah (Coppock 2011). Herd size varied from less than 5 brood cows to over 300 head and grazed ecosystems included desert, grassland, and high-elevation grasslands. Only 14% of cattle enterprises were prepared for the 1999–2004 drought. The experience of this drought increased the number of ranchers that self-identified as being better prepared for subsequent drought to 29% when they were surveyed in 2006. A negative experience in the 1999–2004 drought and the perception that another drought was inevitable were primary motivations for increasing drought preparedness. The most common risk management actions put in place by ranchers after the 1999–2004 drought included improving water for livestock, and diversifying family income (Table 15.2). While adaptive capacity for drought improved with this experience, still greater than 50% of the livestock operators were only somewhat prepared or not prepared for the next drought. This lack of adaptive capacity ensures that crisis drought management will begin again when the next drought occurs.

Table 15.2 Risk-management actions used by Utah ranchers in 2009 for drought preparedness (Coppock 2011)

Tactic	Percentage of respondents saying “Yes, I am doing this” (%)
Improving water for livestock	76 ± 4.0
Diversifying family income	68 ± 4.4
Improving irrigation for hay production	67 ± 4.3
Improving land management	57 ± 4.5
Reducing stocking rates	56 ± 4.9
Enrolling in government disaster compensation programs	55 ± 5.0
Increasing capacity for hay production	53 ± 4.4
Purchasing feed insurance	38 ± 3.9
Seeking extension information	37 ± 3.8
Using Internet drought forecasts	31 ± 4.2
Using forward contracting for livestock sales	30 ± 4.2
Increasing capacity for hay storage	29 ± 3.8
Planning to use grassbanks	26 ± 3.7
Renegotiating bank loans	17 ± 3.5
Other (19 tactics). Most common: (1) expanding grazing land and investing in improved grazing systems (seven), (2) researching drought and drought management (two)	9 ± 2.3
Using forward contracting for hay purchases	8 ± 2.5

Total survey response was 96.7%, resulting in 509 responses

Managers of rangelands enterprises also confront volatility in the meat and fiber market, in addition to climatic variability, and these two events are often interrelated. Using a series of historical drought episodes in Australia (Fig. 15.5), Stafford Smith et al. (2007) identified the linkages between operator decisions and broader social and economic developments. During every drought, a common set of events occurred: (1) good climatic and economic conditions for a period, leading to local and regional social responses of increasing stocking rates, setting the preconditions for rapid environmental collapse, followed by (2) a major drought coupled with a market decline making destocking financially unattractive, further exacerbating grazing impacts, and then (3) permanent or temporary declines in grazing productivity, depending on follow-up seasons coupled again with market and social conditions. One conclusion authors drew from this study is that learning from climate and economic events is often temporally mismatched. Decisions were driven by short-term economic cycles. However, the return times of some climatic events were outside of the life spans of enterprise operators, which limited this information from influencing the short-term decisions. In addition, institutional and government responses, including monitoring and post-drought surveys, were too slow to stop the degradation. Drought management responses require information sharing among managers, industry,



D. Mark Stafford Smith et al. PNAS 2007;104:20690-20695

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Fig. 15.5 Drought episodes in Australia were used to describe the interactions between the ecological and the social processes in socio-ecological rangeland systems (from Stafford-Smith et al. 2007). Shading indicates pastoral areas (sheep or cattle), forward hatching indicates episode regions with longer droughts, and back hatching indicates shorter droughts (diamonds indicate that New South Wales had one of each)

science, and institutions at regional and multigenerational scales. Drought-monitoring systems put in place after widespread drought, such as the national monitoring in Australia, or the National Integrated Drought Information System (NIDIS) and the Drought Portal in the USA, offer real-time information about drought as well as local and regional climate.

Drought planning for enterprise operators on rangelands is readily available through government and academic institutions and long-term management strategies for climate variability have been developed. Yet few enterprise operators employ risk management strategies such as conservative stocking or flexible stocking. The use of flexible grazing management that fluctuates with favorable and unfavorable years can produce greater economic return than a set conservative strategy (Torell et al. 2010). However, the return on this approach was highly dependent on the accuracy of seasonal climate forecasts and a careful trade-off analysis of stocking and destocking. Enterprise operators were hesitant to use near-term climate forecasts unless they saw economic and environmental benefits associated with seasonal forecasts (Marshall et al. 2011) or forecast tools were tailored specifically to users' needs (Dilling and Lemos 2011).

Management actions to address proactively as well as during drought are widely available through extension agents, consultants, or professional organizations. Further, governments, industries, and communities have introduced a range of

economic and policy initiatives. These have included regulatory instruments, educational instruments, and voluntary and market-based instruments (Moon and Cocklin 2011). However, these efforts have been variable in their success (Sankey et al. 2009; Briske et al. 2011). Research suggests that a significant part of the reason that sustainable practices are not adopted by rangeland enterprise owners is that policies and practices are typically founded on the “average” or “typical” resource user and do not appreciate the extent of diversity among these populations (Marshall and Smajgl 2013; Briske et al. 2015; Roche et al. 2015). Implementing resource-protection strategies without sufficient knowledge of the capacity of people to cope and adapt to them may impose levels of stress upon individuals and communities to such an extent that their ability to adapt, tolerate, or prosper under the new conditions is compromised. Strategies that generate stress and conflict are also likely to result in poor compliance and leave the natural resource unprotected (May 2004).

The greatest challenge under a changing climate may not necessarily be the identification of specific management options, but rather the need to encourage human behavioral changes to sustain the socio-ecological rangeland system. Drought intensity and duration are likely to increase under climate change (Dai 2011, 2013). Few past strategies incentivized human behavior toward management to sustain resilient ecosystems (Marshall and Smajgl 2013). Future management may need to be responsive to the decision-making processes that rangeland owners and operators use. Four distinct patterns of decision making in drought were identified in surveys of cattle ranchers in western USA. The patterns encompassed using a long-term strategy dealing with climatic uncertainty, facing drought by building efficiency into the operation and relying on strong local ranching networks, second-career perspective with reliance on outside income and conservative stocking, and, last, an experimental approach to ranching using evidence-based adaptation to drought (Wilmer and Fernández-Giménez 2015). Outreach by extension or academia to these different patterns of decision making cannot rely on one approach, but rather needs to reflect on decision-maker ways of knowing.

15.5.2 The Influence of History in the Human Response to Change

We close this section with four case studies that identified motivations and adaptive responses to different types of socio-ecological disturbances: environmental change caused by human activity in the Solomon Islands; economic change resulting from closure of a timber mill in Canada; political, social, and economic change in a multiethnic rural village in Romania; and responses to policies for adapting to sea-level change in Australia (Fazey et al. 2015).

Change in each of these case studies was occurring daily; however, the adaptive responses to sudden change were influenced by historical legacies. In the mill closure case study, one community had previously experienced several economic changes (fur trading to mining to timber) and, given this experience, could cultivate

a new economy with the mill closure, a contrast to the community without this historical legacy. In the sea-level policy development, the past practice of compensating for damage and current favorable attitudes toward private property rights facilitated the influence of a minority group on resisting change.

Change and the response to change can accelerate further change. On the Solomon Islands, population pressure resulted in subsistence resources dwindling, and the initiation of cash cropping practices, which reduced or moved food gardens from the more fertile areas, increasing pressure on the ecological systems. The increasing numbers of people attempting to respond to this need also resulted in an acceleration of change in the community.

Connections among ecological, economic, and social processes constrained and enhanced the likelihood of success in the multiethnic community. Power in this community was intertwined with conforming to the social norm of a combination of subsistence agriculture and cash-making activities. Political power and education allowed one ethnic group to work outside the village accumulating cash. Newly arrived immigrants creatively adapted; however, their ways did not conform to society's expectations, particularly in subsistence agriculture. Consequently, they were unable to gain important political capital and integrate into village life according to the prevailing social norm.

The development of future adaptation approaches/strategies will need to consider underlying socio-ecological assumptions, values, and principles, and how understanding past change can provide inspiration for new and transformative futures (Fazey et al. 2015). It is recognized that past disturbances influence the response of ecological systems to future disturbances. Equally important, adaptation planning for climate change must recognize that the legacy from historical events influences how individuals and a community will respond to current events and plans for the future.

15.6 Developing Adaptation Options

As we have previously noted, the emphasis on adaptation planning has shifted from a narrow focus on biophysical vulnerability to a broader vision of social, economic, and biophysical vulnerability, including the capacity of humans to respond. Broadly, adaptation needs have been defined by the Intergovernmental IPCC as those circumstances requiring action to ensure safety of populations and security of assets in response to climate impacts (Agard et al. 2014). Effective adaptation planning requires an assessment of the risk of climate-related impacts and hazards, and the vulnerability and exposure of human and natural systems as impacted by socioeconomic and climate drivers (Fig. 15.4). Ecosystem services such as food security, clean water, biodiversity, and disease and flood control are dependent upon ecological processes within the socio-ecological system. Consequently, biophysical needs include sustaining these systems and resources under climate change. Social needs

include sustaining financial, human, social, and cultural assets (Noble et al. 2014). In the socio-ecological rangeland system, social needs can involve addressing financial flexibility in a livestock enterprise, risk perceptions of rangeland managers, cultural patterns of grazing, or psychological stresses related to extreme events such as wildfire or drought.

Adaptation options can be classified as structural and physical, social, and institutional (Noble et al. 2014). Within structural and physical, engineering options for drought management could include new or enlarged reservoirs to store water, more efficient water delivery systems, and communications technology as cell phones and drought or flash flood warning systems. Physical adaptation also includes management of ecosystems and watersheds such as enhanced invasive species management, minimized soil erosion, and restoration of ecosystems after natural disturbances (Millar et al. 2007). Social adaptation options could include changes in the enterprise operation such as supplemental feed, conservative stocking, and changing type of livestock (Joyce et al. 2013) as well as options to improve the adaptive capacity of enterprise owner (Marshall and Smajgl 2013).

The private sector and local institutions will bear the greatest responsibility for developing and implementing adaptation strategies and practices (Noble et al. 2014). Livestock enterprise owners and industries associated with these enterprises will be motivated to protect their financial investments under a changing climate—productivity of their land, value of their genetic stock, infrastructure supporting markets, as well as the markets themselves. Local institutions will be key actors in adaptation, as they attempt to implement the top-down flow of policy, such as programs to address responses to extreme climatic events. However, limited availability of funding and resources, especially in developing countries, and the lack of national government support will challenge the ability of the private sector to implement adaptation options. Goals of private sector adaptation actions may not be consistent with local and national adaptation policies (Noble et al. 2014); similarly governmental actions in response to extreme climate events could further exacerbate local adaptation efforts (Fernández-Giménez et al. 2012).

All adaptation is local and no single adaptation approach works in all settings (Noble et al. 2014). Management actions rarely have been motivated by a single objective; consequently, adaptation options have been identified for managing plants, animals, and ecosystem processes along the lines of no-regret, low-regret, and win-win strategies. The motivation here is that these strategies may make ecological and economic sense locally in the current climate and may provide a means of protection as climate continues to change (Millar et al. 2007, 2012; Joyce et al. 2013). For example, in the face of an impending stress such as heat waves or drought, management would focus on actions that protect the existing assets and maintain what humans currently value in ecosystems. Protecting existing animals during increasing temperatures might imply implementing some type of heat stress management. Maintaining what humans value might imply off-enterprise employment to supplement expenses incurred by drought and other weather extremes. These strategies might be considered no-regret or low-regret strategies as heat waves and

drought are frequent challenges on rangelands. A more intensive response to impending climate stresses could focus on ensuring that current ecosystems can regenerate or recover after disturbances such as drought or wildfire. These options could involve aggressive invasive species management, alternative feed strategies during drought, or planting after disturbance events—all focused on keeping the ecosystem resilient and sustaining ecosystem services and the current enterprise structure.

As climate continues to change, incremental adaptation actions may not suffice (Kates et al. 2012; Joyce et al. 2013) and, in some cases, may institutionalize management practices that are maladaptive under the continually changing climate (Dilling et al. 2015). Enabling socio-ecological rangeland systems to adapt may be a desired strategy. This approach would assist climatically driven transitions to future novel states while mitigating and minimizing undesired and disruptive outcomes, such as loss of ecosystem productivity, or socioeconomic welfare in the community. Given that shifts in climatic trends and variability will continue into the future, adaptation planning represents an iterative process where climate-related risks and hazards must be continually reevaluated.

Where socio-ecological systems have been resilient in challenging environments, collective learning is likely at the core of that resilience. This collective learning occurs as societies deal with the variability across the biological and socioeconomic environments. Strategies in rangeland communities range from diversifying use of plants and habitats and income opportunities, migration of herds and households, flexibility in social organizations and livelihood strategies, grass banking or grazing reserves, and institutions of reciprocity and exchange (Fernández-Giménez et al. 2012). In Mongolia, the “otor” is one such strategy that has developed over time. Here herders and a portion of the household migrate to fatten animals in the fall, to seek better pastures in a drought or to flee bad weather and poor forage in a dzud. The mobility of herders is somewhat restricted by government policy but not always monitored or checked. However, Fernández-Giménez et al. (2012) concluded that while household units were well prepared for a dzud through the use of otor, these households became vulnerable when immigration of livestock from other communities occurred. Further, short-term government relief aid in response to these extreme events minimizes loss of life and impoverishment, but it may contribute to social vulnerabilities in the long term, such as lack of individual initiative (Fernández-Giménez et al. 2012; Chap. 17, this volume). Under climate change, adaptation will be a continual process, as individuals and communities seek to adapt to new environmental conditions that arise gradually or through abrupt change.

Collective learning can also occur where local and diverse groups come to realize the challenges that they face, such as the threat of development and rangeland fragmentation (Case Example 15.3) or concern that regulation or legislation will be put in place to protect wildlife or habitat on which the private sector depends (Case Example 15.4). In some cases these groups can self-organize to begin the process of addressing their concerns. In other cases, the group can be motivated by a third party who has little or no stake in the environmental or economic concerns.

Box 15.3: Self-Organizing Community Linking Management and Science: Malpai Borderlands Group in Southwest, USA

A group of private landowners identified the threat of fragmentation from subdivision and development on their landscape in the southwestern corner of New Mexico and the southeastern corner of Arizona. Residential development expanding from urban areas had already resulted in subdivision of some ranches. Additional landscape fragmentation and woody species encroachment of grasslands could permanently limit future options for sustaining rural livelihoods as well as affect ecosystem productivity and biodiversity. The Malpai Borderlands Group (MBG), formally organized in 1994, is a collaborative effort with environmental groups and state and federal agencies, built around goals shared by neighbors within the community and directed at protecting and restoring ecological diversity and productivity of around 324,000 ha. The Board of Directors includes local ranchers, scientists, and other stakeholders. The landscape includes about 57 % private land, 20 % state trust lands, 11 % National Forest, and 7 % Bureau of Land Management-administered land.

The Group's goal is "To preserve and maintain the natural processes that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant, and animal life in the borderlands region (<http://www.malpaiborderlandsgroup.org/>)." To help facilitate this goal, the MBG incorporated as a 501(c)(3) nonprofit organization, and was therefore capable of accepting tax-deductible contributions and holding conservation easements. The MBG has protected 32,000 ha of private land through conservation easements. These easements have had the indirect effort of easing management challenges by enabling ranchers to consolidate properties through purchase of additional properties and for other ranchers, the opportunity to avoid defaulting a mortgage or avoid the need to take a mortgage (Rissman and Sayre 2012). These easements have strengthened the social networks among landowners with easements and the MBG that holds the easement. The resources available for easement owners, such as financial incentives, have promoted increased management on these protected lands.

One of the more innovative projects devised by MBG is the concept of a "grassbank." Originated by the Animas Foundation, owner of the Gray Ranch and a partner in MBG, a grassbank is a concept in which grass on one ranch is made available to another rancher's cattle in return for the conveyance of land-use easements prohibiting subdivision. Grassbanking experiences of three ranchers changed their perceptions of grazing effects and resulted in 30–65 % reductions in their stocking rates on their ranches, a reduction not stipulated in the grassbanking arrangement (Rissman and Sayre 2012).

From the beginning MBG has been strongly committed to using the best available science and technology to achieve their objectives. The Group draws upon the input of a Science Advisory Committee to establish priorities and seek resources. This collaborative effort has resulted in a number of conservation treatments, enabling 28,000 ha of prescribed burn. The collaboration among the MBG and scientists from a wide array of disciplines and affiliations has resulted in enhanced science and management to support adaptation on the ground.

Box 15.4: Adapting to Climate Change with Social Learning: Gunnison Basin, Colorado, USA

The Nature Conservancy, a global nongovernmental organization that emphasizes conservation, began to engage community members in the Gunnison Basin, Colorado, USA, about climate change. A workshop was held in 2009 to explore the potential effects of climate change, using climate scenarios and a structured vulnerability assessment. Many questions about the potential effects remained within the community. The Nature Conservancy and several other organizations formed a working group which began the process of exploring the potential impacts of climate change (<http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/Colorado/science/climate/gunnison/Pages/default.aspx>). Building on this interest, in 2011, the Gunnison Climate Working Group was officially formed as a chartered partnership of 14 public and private organizations in Colorado's Upper Gunnison Basin (<http://southernrockieslcc.org/project/gunnison-climate/>). Goals of the Gunnison Climate Working Group are to (1) increase understanding and awareness of threats posed by climate change to species, ecosystems, and the benefits they provide to the people of Gunnison Basin; (2) identify and prioritize strategies and techniques for helping people and nature cope with climate change; and (3) promote coordination, collaboration, and effective implementation of strategies.

The US Fish and Wildlife Service's Southern Rockies Landscape Conservation Cooperative (LCC) provided funding to the Nature Conservancy, on behalf of the Working Group, to (1) complete a comprehensive vulnerability assessment to identify species and ecosystems most at risk to climate change; (2) develop a set of adaptation strategies for priority species and ecosystems; (3) design and begin implementation of a local adaptation demonstration project; and (4) document tools, methods, and lessons learned to share with others across the Southern Rockies LCC through a climate adaptation learning network.

The Climate Change Vulnerability Assessment for the Gunnison Basin is a first attempt at identifying ecosystems and species of the Gunnison Basin, Colorado, that are likely to be affected by climate change and why they are at risk. Climate projections suggest that the natural environment, ecosystems, and species of the Gunnison Basin will change significantly over the coming decades (Neely et al. 2011). The results indicate that many of the natural features of the Basin (50% of ecosystems and 74% of species of conservation concern) are susceptible to loss, degradation, or other changes associated with warming temperatures. This report provides a foundation for the Gunnison Climate Working Group's next step: developing social-ecological adaptation strategies to support resilience of social-ecological systems, including species, ecosystems, and human livelihoods in the Gunnison Basin.

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The tools, methods, and findings of the Gunnison Basin vulnerability assessment go beyond habitat adaptation strategies applied to support populations of Gunnison sage-grouse. The new tools build ecosystem resilience and support the Gunnison Basin agricultural and recreational economies. The vulnerability assessment provides a scientific foundation for a robust decision-making process which can be carried out over a larger landscape to inform and direct conservation delivery mechanisms for use by multiple partners.

Following completion of the vulnerability assessment, the Gunnison Climate Change Working Group applied for Wildlife Conservation Society funding to design and implement an on-the-ground climate adaptation demonstration project. Wildlife Conservation Society funds, matched by the US Fish and Wildlife Service grant, enabled the Working Group to complete the first phase of a priority strategy. This strategy was considered to be one of no-regrets because it is considered to be effective in the face of a range of future climate change projections. The goal is to enhance ecosystem resilience of wetland and riparian habitats to increase the adaptive capacity to manage for Gunnison sage-grouse. After completing a spatial analysis to identify sites for treatment, the team selected 12 potential sites based on local expertise and conducted rapid field evaluations to determine the top two private land sites for work in 2012. Simple restoration treatments, including one-rock dams, were designed to help retain water in impaired drainages. Partners designed and completed construction of over 100 rock structures on private lands to improve or restore wet meadows—which function as brooding habitat for the Gunnison sage-grouse. This vulnerability assessment and field project demonstrates an approach that facilitated collective learning by a group of diverse users who then went on to implement an adaptation project on the ground.

Many adaptation options have been suggested for the management of ecosystems and socioeconomic systems. Often, these options have been broad, such as drought management planning. In other cases, the options focus on ecosystem management and not the corresponding needs of the resource manager or enterprise owner. In most cases, adaptation options have not been specific enough in terms of the how, the who, and under what conditions these actions can be implemented (Heller and Zavaleta 2009). Further adaptive capacity is influenced not only by physical and economic resources, but also by social factors, factors missing in many of the early papers on this topic. Perhaps the most serious drawback in many of the currently proposed adaptation options is the lack of a linkage across the socio-ecological system. Adaptation in one part of the socio-ecological system, such as energy policy encouraging bioenergy crops, can reduce the adaptive capacity of another part of the system, shifting cropland to bioenergy and reducing food security. What is needed is an organizing framework that can identify key vulnerabilities and risks and integrate adaptation actions across the

socio-ecological system. In this manner, the adaptation strategies can be constructed to develop a response to the social, economic, and ecological vulnerabilities. The next section discusses development and application of a risk-management framework for adaptation planning.

15.7 Managing Climate Change Risks Through Adaptation

Rangeland systems have coped or adapted to a wide range of past extreme events, lowering the risk of these events in the future. Risk is quantified as the product of the probability of occurrence of hazardous events and the impact of these events. Climate change could increase the risk of loss of rangeland ecosystem functions such as regeneration and recovery, soil development, and nutrient cycling, and the risk of loss of biodiversity including domestic as well as native plants and animal species. Climate change, coincident with resource management, could increase the risk of degradation or desertification. Future extreme weather events could enhance the risk of loss of infrastructure (buildings, fences, equipment, water systems), enterprise assets (livestock including genetic stock, resource productivity through soil erosion and degradation), and social networks (transportation, informational, and financial). While many risks can be identified, the challenge is to identify those risks that are most important to the sustainability of the socio-ecological system in the future.

Key risks to rangelands are those that portend potentially adverse consequences for humans and social-ecological systems resulting from the interaction of climate-related hazards with the vulnerability of societies and systems exposed. Identifying these types of climate-related risks involves framing the risk as resulting from the interaction of vulnerability, exposure, and hazard (Fig. 15.4). Risks in this climate-related context are considered “key” due to high hazard or high vulnerability of societies and systems exposed, or both. In this framework, emergent risks, not previously considered, can arise from indirect impacts of climate change. For example, encouraging the production of bioenergy crops may decrease food security by reducing the land area producing food crops. The following are identified as key risks (Oppenheimer et al. 2014): risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings; risk of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semiarid regions; and risk of loss of terrestrial and inland water ecosystems, biodiversity, and ecosystem goods, functions, and services they provide for human livelihoods.

Risk perception influences human behavior. Risk perception of owners and managers of rangeland systems builds from past management of drought, wildfire, and extreme heat; however, social considerations, rather than physical vulnerability to climate change (e.g., availability of water), are known to determine managers’ perception of the risk of climate change (Marx et al. 2007; Moser and Ekstrom 2010;

Safi et al. 2012). For ranchers and farmers in Nevada, their risk perception of climate change was greater the more dependent their enterprises were on agriculture as their primary income. However, general beliefs about the causes of climate change and linking locally observed impacts to climate change were found to be the factors that most influenced their risk perception of climate change (Safi et al. 2012). Risk perception, informed by collective learning, can be motivation for action (see Case Example 15.4).

Managing climate change risks through adaptation is about planning for the future even though the future is uncertain. In fact, there is a strong link between managing future risks and managing for uncertainty. The extent to which landowners can manage for uncertainty and the associated risks of dealing with uncertainty is one of the more important determinants of the adaptive capacity that landowners possess (Marshall 2010). While some landowners will be unable to develop plans for their enterprise without solid knowledge of what the future may hold, other landowners will be able to develop plans that take into account that the future is unknowable. An important premise in managing uncertainty on rangelands is that they represent complex nonlinear systems which do not always have a definite or repeatable cause-and-effect relationship. Developing the skills to manage under such conditions may be a singularly important strategy for landowners to develop if rangeland systems are to be sustained. Inaction has been shown to be more detrimental than assessing risk and making decisions based on that risk calculation (Howden et al. 2007).

A constructive approach for climate adaptation planning is to plan for a range of plausible climate scenarios, and take the path of “least regrets,” which accounts for a range of uncertainties about the future. Uncertainty in the future climate of a region can be ascribed to several sources. We identify six here, each of which need to be explicitly addressed if the risks of climate change are to be effectively managed (www.adaptnrm.org):

1. Natural variability—uncertainty will exist around the ecological conditions, and the spatial and temporal variation in these conditions within a period of time and geographical area.
2. Observation/data error—observation error is the failure to properly observe, measure, or estimate processes and quantities. It results both from imperfect methods of observation, or overlooking key factors, and from sampling error.
3. System uncertainty—system understanding is limited by the understanding of all the links—thus, even with complex models, any projections (qualitative or quantitative) will have uncertainty.
4. Inadequate communication— inadequate communication relates to the difficulty of effectively conveying information between scientists, managers, and stakeholders. When communication is ineffective, information is lost, which can manifest itself as uncertainty.
5. Unclear objectives or lack of goal setting—unclear management objectives are ones that are expressed vaguely, not fully conceived, scaled improperly, or difficult to quantify, and enhance uncertainty within the system.
6. Outcome uncertainty—when actions are not implemented properly and it is not clear whether the model was incorrect or the practices themselves.

The achievement of greater adaptation action will require integration of climate change-related issues with other risk factors, such as climate variability and market risk, and with other policy domains, such as sustainable development (Howden et al. 2007). Dealing with the uncertainties among all aspects of rangeland life will require a comprehensive and dynamic approach covering a range of scales and issues. For example, landowners and managers will need to work with policy makers, practitioners, scientists, and others in their social networks to better assess the climate-related risks and hazards and to establish efficient means to respond to them.

15.8 Knowledge Gaps

This chapter has identified a number of areas where scientific knowledge is limited, quantitative methods are needed to capture ecological and social processes to bound uncertainty, and interdisciplinary research is needed to integrate the ecological and the social components of rangeland systems. Vulnerability assessments and adaptation planning must recognize the variation in the adaptive capacity of both ecological systems and the adaptive capacity of human systems. The previous section identified areas where uncertainty needs to be quantified and bound in order for risks associated with climate change to be identified and prioritized. This is a key area for knowledge development.

One area where very little research is ongoing is the experimentation of proposed adaptation management actions. Adaptation strategies are built on current understanding and practice, but they must recognize and attempt to incorporate future change. Field experimentation testing different proposed adaptation actions would provide a greater understanding of the likely success as well as offer comparisons of how natural systems might respond to the changing climate without adaptation treatments.

15.9 Summary

Climate change adaptation has evolved since the early 1990s and will continue to evolve as the scientific, management, and policy communities grapple with key vulnerabilities, risks, and strategies to adapt to climate change. The greatest learning may take place within the private sector and in local institutions where the greatest responsibility for adaptation may reside. The private sector will be highly motivated to protect their assets and maintain their positions in markets. Local institutions will likely be required to implement top-down adaptation policy developed by regional or national government institutions that may not be consistent with adaptations implemented by the private sector in response to local climatic extremes.

All adaptation is local and no single adaptation approach works in all settings. Understanding the key vulnerabilities and climate risks within the local setting is critical and the base on which adaptation strategies are developed. These vulnerability assessments must connect the understanding of ecological, economic, and social vulnerability with the potential for adaptation. The assessment must provide insights that can assist in the development of land management strategies for rangeland resilience; engage vulnerable populations early in the process; and guide development of strategies that enable decision and policy makers to tailor a range of adaptation approaches that most effectively accommodate the divergent requirements of various resource users. As part of this process, vulnerability assessments must recognize that just as the adaptive capacity of rangeland ecosystems varies across geographic regions, the adaptive capacity among resource managers and owners also varies greatly.

Collective learning is the basis for development of collective action among diverse resource users to tackle shared problems. This learning occurs when information emerges from experience and human interaction such that different goals, values, and knowledge are made explicit and questioned to accommodate conflicts. The challenge for developing and implementing adaptation actions is how to incorporate these learning opportunities into public processes so that underlying ecological and social assumptions about management of the socio-ecological system can be collectively visualized. Getting adaptation options on the ground may be closely tied to the success of such opportunities.

Adaptation requires an intentionality to address the effect of climate change. Specific consideration of how management actions need to respond to projected climate change is a part of the adaptation management strategy. The lack of drought planning in the past suggests that the current adaptive capacity is insufficient to sustain livestock enterprises under more frequent and intense drought in the future. Adapting to future change will require a different strategy than coping with past climatic events; the greatest challenge may be to encourage human behavioral changes to sustain the socio-ecological rangeland system. Just as past events influence future ecosystem development, past events in human communities influence future choices in response to day-to-day activities as well as to sudden and drastic events. The diverse history, experiences, and goals of individual managers represent a heterogeneous adaptive capacity that will greatly affect adaptation planning and the strategies selected and implemented. Adaptation strategies and policies need to reflect this heterogeneity, rather than managing for the average enterprise. Landowners may have different perceptions of risk, administrative or financial skills, access to trusted social networks, dependency to sense of place, or willingness to experiment with novel management practices. Landowners may have different ways of knowing and different past experiences that influence current and future decisions.

Adaptation to climate change will be a continual and iterative process. Landowner enterprises must remain viable as the productivity of the land varies through time. Managing for socio-ecological resilience on rangelands is related to the maintenance of system properties that confer resilience without compro-

misgiving the ability to cope and adapt to future change. Near-term responses may be incremental; however as climate continues to change, these actions may not suffice and transformative changes in the socio-ecological system may be needed.

Adaptation will need to occur within a system that is complex and where there are not always definite or repeatable cause-and-effect relationships. In addition, adaptation plans will need to occur under significant uncertainty of the future. Uncertainty exists not only within the natural system, but also within the models and modes of understanding of how the system works. Different sources of uncertainty, including uncertainty in other aspects of managing rangelands such as market risk, all need to be managed such that efficient responses can be identified and pathways of “least regrets” can be realized.

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