

Chapter 8

Rangelands as Social–Ecological Systems

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Abstract A social–ecological system (SES) is a combination of social and ecological actors and processes that influence each other in profound ways. The SES framework is not a research methodology or a checklist to identify problems. It is a conceptual framework designed to keep both the social and ecological components of a system in focus so that the interactions between them can be scrutinized for drivers of change and causes of specific outcomes. Resilience, adaptability, and transformability have been identified as the three related attributes of SESs that determine their future trajectories. Identifying feedbacks between social and ecological components of the system at multiple scales is a key to SES-based analysis. This chapter explores the spectrum of different ways the concept has been used and defined, with a focus on its application to rangelands. Five cases of SES analysis are

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presented from Australia, China, Spain, California, and the Great Basin of the USA. In each case, the SES framework facilitates identification of cross-system feedbacks to explain otherwise puzzling outcomes. While information intensive and logistically challenging in the management context, the SES framework can help overcome intractable challenges to working rangelands such as rangeland conversion and climate change. The primary benefit of the SES framework is the improved ability to prevent or correct social policies that cause negative ecological outcomes, and to achieve ecological objectives in ways that support, rather than hurt, rangeland users.

Keywords Endangered species • Ranch economics • Restoration • Resilience • Climate change • Complex adaptive systems

8.1 Introduction: What Is a Social–Ecological System?

The dependence of humans on natural systems makes it essential to understand how human use and management affect the capacity of ecosystems to sustainably support human needs. Yet, too often, social and ecological systems have been studied as if they operate independently. There is a critical need for comprehensive, multidisciplinary approaches to understanding the social and ecological components, interactions, and processes that shape rangeland conditions, including the social, economic, cultural, and political attributes of the people and communities within rangeland systems. Environmental problems arise from failures in social processes as much as from ecological processes, and recognizing this, a common framework is needed for understanding and analyzing the drivers that lead to improvement or deterioration of natural resources (Ostrom 2009). The “social–ecological system” (SES) concept provides a framework for analyzing complex rangeland dynamics and identifying interventions that can increase rangeland sustainability and support the production of desired goods and services. Here we explore a spectrum of different ways the concept has been used and defined in research on rangelands.

Humans alter natural systems in an effort to increase human benefit. Some changes are dramatic, such as cultivation for crop production, but others are less obvious, such as vegetation changes caused over time by extensive livestock grazing. Human systems react to ecosystem changes in many different ways, as with the economic, demographic, and policy responses to drought, wildfire, or deforestation. While range science has developed sound techniques for examining both the ecological and social components of rangelands, there has been little progress so far in seeing them as integrated and interdependent, or in developing techniques to resolve potentially competing goals (e.g., species conservation, open land access, economic benefits) within a rangeland SESs. Range ecology research has traditionally focused on grazing regimes and ecological indicators with less attention paid to the needs and goals of the livestock owner or property manager. This neglects real-world

concerns about the finances, labor, limited time and information, and multiple goals of ranchers, pastoralists, and resource managers that influence *why* livestock are grazed in a certain way. Conversely, the social sciences have provided a wealth of information on who uses rangelands and why, but has been less successful at linking social, cultural, political, and ecological factors to ecological outcomes (Brunson 2012).

Purely technical interventions in rangelands often fail when researchers and managers do not consider their impacts on economic, political, cultural, and social well-being. To illustrate, introducing improved livestock to replace local breeds has at times been proposed to improve the livelihoods of pastoralists in developing countries. Some researchers have pointed out that improved livestock in such settings have had unintended consequences including increased financial risk, altered grazing patterns and gender roles, increased labor needs, and decreased income for women (Wangui 2008). Improving livestock breeds may do little to alleviate what might be the overarching problems of inadequate markets, government and industry land grabs, crop encroachment, and even climate change. In addition, the acceptability and practicality of a new technology for the people expected to use it must be considered. The goals of individual ranching enterprises may or may not mesh with those supposed by researchers and agency managers. In addition, drought, government policy, and livestock prices are external drivers affecting any proposed innovation at the ranch enterprise level, while personal beliefs and traditions, and family relationships, have implications for the ability and willingness to cope with change and adopt new technology. Rangeland research and management cannot afford to overlook human dimensions if the expectation is to contribute to the solution of real-world problems.

The social processes that sustain or degrade the ecosystem's current state, and the ecological processes that both drive ecosystem change and shape human use and benefits occur at multiple scales and are fraught with uncertainties. To improve the sustainability of natural resource use, managers need not only better or more complete ecological data, but also a clear understanding of where, when, and how resources are used and who gets to use them, and how and why use varies over time and across the landscape. The SES framework allows managers to treat all these interacting dynamics as part of a single integrated system (Fig. 8.1).

The notion that ecosystems and societies are shaped by one another is not a new idea (Norgaard 1994), but it has not been sufficiently emphasized in rangeland science. The edited book entitled "Linking Social and Ecological Systems" by Berkes and Folke (1998) was groundbreaking because it provided an integrated approach to simultaneously analyze both social and ecological systems for the purpose of natural resource management, and launched the term "social–ecological systems." Foundational work on the SES concept replaced the "view that resources can be treated as discrete entities in isolation from the rest of the ecosystem and the social system" (Berkes and Folke 1998, p. 2). Since the term emerged in the late 1990s, SESs have also, but less commonly, been called "coupled human–natural systems" to reflect the fact that both society and ecosystems have distinct internal dynamics

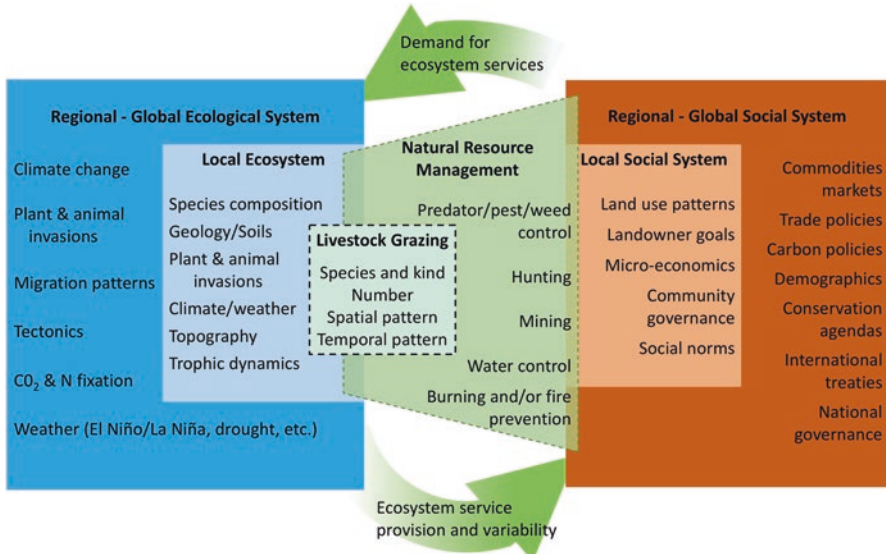


Fig. 8.1 Generalized diagram of a rangeland social–ecological system. Humans and the environment interact in countless ways outside of natural resource management, but the interactions are most directly planned, manipulated, and monitored in natural resource management activities. Local, regional, and global social processes can all shape natural resource use and management activities. While resource policy may be set at large geographical scales (e.g., national), management activities occur within a single ecosystem. Livestock grazing differs from other types of natural resource use in that it is indirect; rather than directly manipulating a rangeland ecosystem, livestock operators devote their primary attention to managing livestock, and the livestock interact directly with the rangeland (adapted from Reid et al. 2014)

but react in response to one another, sometimes in unanticipated ways (Liu et al. 2007a, b; Turner et al. 2003).

Much of SES research has focused on their resilience, describing various characteristics that allow an SES to persist and adapt to changing circumstances (e.g., Gunderson and Holling 2002; Berkes et al. 2003). This vein of SES scholarship is dominated by systems theory and treats SESs as complex adaptive systems that self-organize (e.g., Folke et al. 2005) and operate with feedbacks and thresholds (e.g., Walker et al. 2004). Drawn almost wholly from the natural sciences, this framing of SES has been critiqued by some social scientists on the grounds that such ecological principles cannot be so simply applied to social systems nor, by extension, to SESs (Olsson et al. 2015).

A challenge for applying the SES framework is in analyzing how social and ecological components of the system interact in iterative cycles. Too often, only single cross-system influences are emphasized in SESs, such as how changes in resource or social policy affect rangeland ecosystems, without following up to see how altered ecological processes feed back to affect the social system. While several conceptual models have been created for rangeland SES that might address this shortcoming (e.g., Fox et al. 2009; Walker et al. 2009), it is not always clear how to use them and they have not been widely applied.

8.1.1 *Conceptualizing SESs*

SESs are typically too large and complex to analyze all their structural and functional components at once. Creating a conceptual framework is one way of thinking through the complexity of SESs. The primary purpose of SES frameworks is the identification of specific components, processes, or feedbacks for analysis, and a metric for assessing their roles and interactions in the system. For example, who are the resource users, and do they share information about the resource with each other? How far is a population from where policy and management decisions are made, and how valued is their input about resource use? Policy makers or resource managers can create their own frameworks in order to analyze their resource systems of interest. The key is identifying the important variables, the scales on which they operate, figuring out how they interact, and then measuring them over time. When problems arise, trying to solve the “why” will often entail finding unexpected connections between multiple components within the SES. Understanding how the SES has reacted to perturbations in the past can be of great help in this effort. At best, the use of SES frameworks will spotlight where interventions are needed or possible to achieve management goals, and will detect system changes over time in a way that allows for some level of prediction.

One SES framework originating from political and economic science is meant to allow identification of SES components and interactions within systems of resource use such as fish, groundwater, or pastures. This framework divides an SES into seven categories for analysis: resource systems, resource units, governance, users, interactions, outcomes, and related (or adjacent) ecosystems (Ostrom 2007, 2009). Each of the seven categories is then subdivided into a set of components in order to identify causal relationships and drivers, so that different systems can be compared. A different framework focuses on the exposure of an SES to a particular hazard, and then tracks sensitivity and resilience of both social and ecological components with the aim of analyzing vulnerability (Turner et al. 2003). A third, called the Drylands Development Paradigm, aims to synthesize lessons from research on desertification and economic development, and to act as a template whereby each of the five key principles of SESs can be examined and tested in case studies (Reynolds et al. 2007). The Resilience Alliance has created its own framework specifically for assessing the resilience of an SES (Resilience Alliance). Each of these frameworks is intended for a specific set of contexts and types of resource use, but the underlying assumptions about the interdependency of SESs are the same (for a review of ten SES frameworks, see Binder et al. 2013).

Researchers and managers tend to focus on the components of an SES most likely to be influenced by a given change or intervention, or perhaps those most amenable to analysis or management based on their own discipline, as the methods and theories of their own discipline are most familiar to them. Team approaches that include social as well as ecological scientists can help to assure a more comprehensive approach. Three key characteristics critical for analyzing an SES—scale, feedback, and resilience—may be difficult to recognize and measure, and thus may be overlooked. A rangeland SES is profoundly affected by attributes such as the

system’s geographical location, social context, governance structure, management dynamics, uses of natural resources, and economic relationships. These attributes can all be helpfully analyzed according to their scale, feedback, and resilience in the SES.

8.1.2 Scale

Understanding of ecosystems and their response to use and management has often been hampered by a failure to appreciate the role of *scale* (Cash et al. 2006). Each scale, such as spatial or temporal, may have different dominant patterns and processes at different hierarchical levels (Fig. 8.2). For example, in considering sustainability of rangelands, at the level of a rangeland ecological site, the selectivity and distribution of grazing animals may be critical. At the regional level, the price of real estate and zoning laws may be the critical factors in rangeland sustainability. Although they are not always, hierarchical levels may be nested. For example, if conservation does not occur at the regional level, then there may be no rangeland

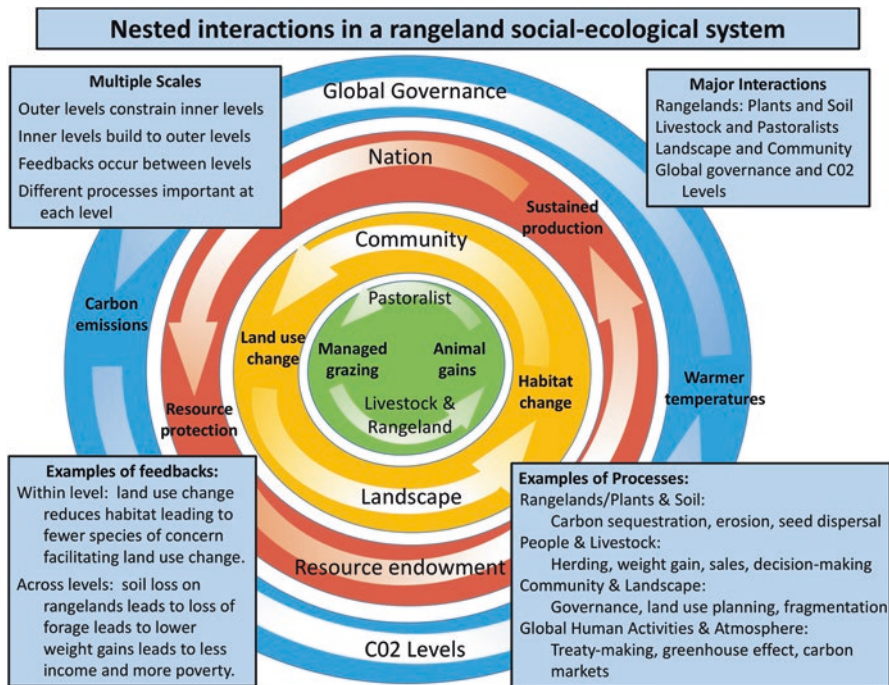


Fig. 8.2 An SES portrayed as a nested hierarchy illustrates how feedbacks occur across and within scales, and that different processes act as important system drivers at different scales. It also illustrates how some factors are largely outside the control of the pastoralist, for example national politics or drought and warming. On the other hand, outer levels are shaped by lower levels: without pastoralists, there is no pastoral community

ecological site left to manage (Chap. 5, this volume). Conversely, if ecological sites are not well managed, negative perceptions by the public may erode support for ranching, a possibility that lends support to the creation of regulations governing grazing use implemented at the regional or even national level. Temporal scale is similarly important, as processes may happen quickly or slowly, last only briefly, have a legacy effect influencing future processes, or persist for a very long time. Interactions among scales and levels are common and may cross social and ecological systems.

Unfortunately, monitoring or evaluating systems at multiple scales is often beyond the budget and knowledge of natural resource managers or scientific researchers. For this reason, some authors have recommended concentrating analysis on interactions of specific subcomponents (Roe et al. 1998), while others have suggested that social–ecological interactions are typically determined by a small number of “controlling variables” that should be the focal point of analysis (Holling 2001). In either case, the spatial or temporal scale of management may not be adequate to address the scale of ecological processes, a social–ecological mismatch leading either to mismanagement, ineffectual management, or an absence of management (Cumming et al. 2006). For example, a land manager might set a single stocking rate for an entire property based on average grass cover. Within that property, however, that stocking rate might result in overgrazing of some pastures and undergrazing in others. In this instance, the geographical level of management—the property—is too large for sustainable management of some individual pastures. On the other hand, some natural resource problems may occur at a larger level than the property, calling for a watershed-level approach that crosses property lines and involves understanding what drives cross-boundary cooperation. The challenge is to integrate and validate social and ecological data from multiple scales and levels when crafting policy and management prescriptions.

8.1.3 *Feedbacks*

A *feedback*, or feedback loop, is when a variable within a system changes in such a way that increases the likelihood and strength of further change (positive feedback) or decreases the likelihood or strength of future change (negative feedback). Positive feedback loops are self-reinforcing or amplifying, while negative feedback loops are self-regulating, or stabilizing. For example, conservation initiatives directed at ecological systems may alter the living situation or behavior of local social groups who might then increase or reduce their environmental impact as a result (Miller et al. 2012). As an example of a positive feedback loop, the sale of several ranches for residential development in an area formerly dominated by ranching can increase land values and alter community dynamics, causing more ranchers to sell their land to developers (Huntsinger 2009). Negative feedback loops dampen a particular effect or make an action less likely to be repeated. For example, in a natural system an overpopulation of herbivores reduces the forage available to each animal to the

point where reproduction slows and mortality increases, lowering the number of herbivores. In SESs, interactions between hierarchical levels may function as feedbacks (Gunderson and Holling 2002).

From the perspective of rangeland managers or policy organizations, feedbacks may act as both vulnerabilities and opportunities. Where positive feedback loops have negative consequences, such as the conversion of rangeland mentioned previously, extra precautions should be taken to prevent those feedbacks from taking effect. Where feedback loops create positive change, short-term expenditures may be justified by long-term benefits. For example, establishing venues for stakeholder meetings and management collaboration may require investing additional time and money but result in steadily increasing participation that reduces management costs and improves outcomes in the long run. Whether positive or negative, recognizing the presence of feedback is a crucial step.

8.1.4 Resilience and Adaptability

Rangeland management and science have increasingly focused on *resilience* of rangeland ecosystems, including the resilience of social actors. Resilience can be defined as the capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, identity, and feedbacks (Walker et al. 2004) (Chap. 6, this volume). Disturbances may originate in social or ecological subsystems and may occur slowly or rapidly (May 1977). A non-resilient SES may change or lose components and functionality when an unusual change, or perturbation, occurs in either the social or the ecological subsystem; a resilient SES will not only maintain function, but may also benefit from disturbance by reorganizing to further increase resilience (Gunderson and Holling 2002; Berkes et al. 2003). Resilient systems are those that can more readily adapt to new forces without losing functionality or transforming in fundamental ways. It is important to note that resilience is not an inherently good or bad quality. Degraded, unproductive rangelands or impoverished communities might be just as or even more resilient to change (i.e., improvement) than are more desirable and productive states (Cote and Nightingale 2012).

Resilience is not the same thing as stability. Stability is the ability of a system to return to an equilibrium state following a temporary disturbance (Holling 1973). Ecological stability has been challenged by alternative ecological models that reject the notion that ecosystems have a single equilibrium state (Westoby et al. 1989). Managers often attempt to create a stable flow of inputs and outputs from a managed system, because managing more variable systems requires frequent monitoring and the ability to rapidly alter resource-use patterns—both of which are expensive and difficult to carry out. Unfortunately, the resulting simplification of the managed system frequently results in reduced resilience (Holling 1973; Walker et al. 1981). The resilience concept does not preclude small changes or variation within the system, thus providing a better fit with dynamic, multi-equilibrium rangelands. For

example, the establishment of stocking rates at a rangeland's perceived carrying capacity may be assumed to foster stable, sustainable livestock production. Such a steady-state view overlooks the impact of variable rainfall and temperature on forage production, which may lead to undesirable grazing outcomes in above- or below-average years and ultimately result in loss of ecosystem functionality (Chap. 6, this volume).

Analyses of integrated rangeland SESs have tended to view rangelands as *complex adaptive systems* that should be managed to enable adaptation to ecological and social change (Walker and Janssen 2002; Walker et al. 2009; Huber-Sannwald et al. 2012). Complex adaptive systems have many components that adapt or learn as they interact (Holland 1992) (Chap. 11, this volume). For example, cheatgrass (*Bromus tectorum*) invasion of the US Great Basin has resulted in ecosystem shifts away from dominance by perennial grasses and shrubs to dominance by cheatgrass, an annual species. This has influenced both the biological and human components of the ecosystem. The monocultural stands now common in North America facilitate the spread of a native generalist fungal pathogen called “black fingers of death” (*Pyrenophora semeniperda*) that colonizes cheatgrass stands across a broad distribution (Meyer et al. 2008). Livestock operators have had to adapt their grazing regimes to fit the timing of cheatgrass productivity and the periodic loss of forage caused by increasingly frequent wildfires. The transition to cheatgrass dominance has altered wildlife habitat and reduced the populations of some species, spurring conservation and restoration efforts. Cheatgrass is thought to be spread by livestock grazing, but grazing also serves to reduce cheatgrass biomass and thus the likelihood of damaging wildfires (Knapp 1996). Grazing, restoration efforts, and wildfires all interact in the production of ecosystem services. Interventions by livestock operators, range managers, and policy makers may have an effect, but the ultimate outcomes are difficult to predict given the complex ecologic and climatic factors involved.

The ability to cope with disturbance and respond to change has been termed *adaptive capacity* (Plummer and Armitage 2010). Within a given SES, adaptive capacity may vary at different scales, for different processes, and for different organizations and individuals. An individual or community with many diverse resources may be better able to adapt to change. A multispecies rangeland is usually better able to maintain productivity despite fluctuations in weather or drought, or the introduction of a plant disease, because some species will thrive better than others in the new conditions. Similarly, some people may have the flexibility of mind to adapt to new life conditions while others may not.

Adaptation does not only occur after singular, discrete perturbations, however. The dynamic nature of both ecosystems and society entails a constant state of change, meaning that adaptation is a continual, iterative process (Rammel et al. 2007). Change can originate in either society or the ecosystem and does not necessarily result in a functional, or successful, adaptation by the other system. People and institutions may not perceive change or the necessity of change, may be unwilling to change, may be unable to adapt successfully, or may change in a way that does not help. In society, the ability to adapt and the options available for adaptation

are limited by power dynamics that are often overlooked or wishfully assumed to be less significant than they are. Adaptation should not be assumed to follow change, nor should it be assumed to be beneficial when it does (Watts 2015a). While it is common to hear of the need for society to adapt to climate change or other environmental forces in order to reduce vulnerability, it is rarely pointed out that the reason society is vulnerable and must adapt is because of the way the social–ecological landscape has developed. In many cases, society has created its own vulnerability to climate change and other environmental forces (Taylor 2014).

Ecological diversity and the presence of redundant components have also been highlighted as central for maintaining resilience (Walker 1995; Walker et al. 1999). While some theorists have proposed that a diversity of institutions and stakeholders in governance and management structures can benefit natural resource management, social scientists have questioned the extent to which such ecologically based notions can be extended to social systems. For example, some consolidated authoritarian regimes have proven to be remarkably resilient by monopolizing power and violently crushing any challenges (Agrawal 2005). Resilience was incorporated into ecology decades ago and is now ubiquitous in that field, but it has also emerged as a central feature in SES analyses, including rangeland SESs (Folke 2006; Reid et al. 2014). Despite the concept's recent prevalence in such institutions as the World Bank and the US military, many social scientists are critical about applying the concept in social contexts, including to SESs (Olsson et al. 2015). There are several key reasons for this critique.

First, by placing emphasis on resilience to disturbance rather than on disturbance itself, less attention is paid to the more politically sensitive questions of who is vulnerable and why, and how future disturbances might be avoided (Walker and Cooper 2011; Watts 2015b). Coming as it does largely from the natural sciences, resilience is often viewed as a rather mechanistic cause-and-effect process that does not account for human agency and goal formation (Davidson 2010). Furthermore, the formation of resilient livelihoods in SESs may be promoted by governments or other institutions but perceived by individuals or communities as radical, undesirable cultural change (Crane 2010). This is in part because what constitutes a social or environmental “problem” is highly subjective and frequently politically motivated (Castree 2001). The role of environmental shocks in driving social or SES change must be balanced by an awareness of the political and economic factors that create or allow “natural” disasters such as famines (Watts 1983). Despite these critiques, it is also true that the resilience concept has been adopted by many social movements around the world as a way to frame projects of social adaptation to new challenging circumstances (Brown 2014).

It must also be noted that the centrality of the system concept inherent in SES, resilience, and complex adaptive system frameworks is not without problems. The concept of a system inherently involves thinking about a multitude of components with coordinated actions and potentially even a unitary goal. In both human and ecological settings, who and what constitutes “the system” is by no means clear, and it would be inappropriate to assume that coordinated activity or collective goals are common outcomes of human interactions (Olsson et al. 2015).

8.2 Environmental Governance

The richly interconnected view of resource systems in an SES stands in opposition to strategies that attempt to reduce system complexity by focusing on only a small number of target resources, species, or indicators as is typical of maximum sustained yield and steady-state natural resource management (Holling and Meffe 1996). History has shown that these types of management strategies are often ecologically unsustainable because of unrecognized slow system change, sudden unpredicted disturbance, and/or unknown interconnections. On the social dimension, these approaches often fail as a result of an inability to understand what people want from natural resources, a lack of capacity to govern human resource use, and the broad perception of an accompanying policy or distribution of benefits as unjust.

Given the evolving nature of complex adaptive systems and their lack of predictability, much of the work on SESs in rangelands and elsewhere focuses on developing responsive policy and governance that supports system resilience (e.g., Walker et al. 2004; Armitage et al. 2009) rather than attempting to provide specific and relatively inflexible resource management prescriptions. Social groups do not maintain consistent or uniform relationships with their surrounding environment, but change in either social or ecological patterns cannot necessarily be attributed to a corresponding driver in the other system (Vayda and McCay 1975). Resource management and governance policies must therefore monitor and be responsive to ecological and social processes that may or may not create new drivers of change within the SES. It is the inclusion of both ecological and social variables within the frame of analysis that makes the SES framework useful for management. Changes in the price of beef or altered land tenure policies, for example, have to be considered alongside fluctuations in climate and vegetation composition when planning management actions or policies for a rangeland SES.

Problems that cross scales or levels within SESs can prove challenging for two reasons: *perception* and *communication*. First, the occurrence of a phenomenon at one level must be perceived as having been caused by a driver at another level. Second, that observation has to be communicated—persuasively—to the person or organization capable of solving the problem, and that person or entity has to decide to address the problem. Solutions involving changes in policy need to be effectively communicated to the affected population, ideally with buy-in from the affected populations. The perception problem can be met with a combination of thorough cross-scale monitoring and diverse information networks. Communication problems require adaptations to governance structures and strategies that facilitate information sharing and learning across sectors and hierarchical levels. An increasing number of groups, such as the Sustainable Rangelands Roundtable (<http://www.sustainablerangelands.org/>) and the California Rangeland Conservation Coalition (<http://carangeland.org/>) in the USA, are devoted to encouraging this type of communication about rangelands and range management.

Inclusion of various stakeholders in goal-setting, planning, monitoring, research, data interpretation, and decision making is one way that managers can create

improved integration of ecosystem management with the social system, and gather more information about the system. Various models and terms have been created for this type of process, including community-based natural resource management (Leach et al. 1999) and adaptive comanagement (Olsson et al. 2004). Through the inclusion of multiple stakeholders, a project can gain access to information about the social needs and dynamics of the SES and to traditional and local knowledge about the ecosystem, which optimally increases the benefits of management to both the social and ecological components of the SES (Olsson et al. 2004). Engaging stakeholders can start to build consensus around an initiative, constructing the social networks needed for implementation and adaptation across the many dimensions of an SES. One model for a participatory approach to increasing SES resilience involves collaboration between many stakeholders to define the bounds of the SES and the trajectory of progress desired, followed by scientific study to determine how resilience can be maximized under such trajectories, and lastly a collaborative assessment of policy and management implications (Walker et al. 2004). In this process, stakeholders can provide information and insights that managers or scientists cannot, while networks and relationships are formed that can foster the iterative learning central to adaptation.

Some social and ecological problems occur at extensive spatial scales which only organizations with broad jurisdiction may be equipped to handle, such as regulating the migration of livestock herds under transhumance (Turner 2011). Furthermore, participatory approaches must be tailored to the specific management context and be flexible in response to social needs and the respective strengths of different stakeholders, which may mean employing different collaboration techniques and reaching out to different stakeholders at different times (Stringer et al. 2006). Increased stakeholder participation can also prevent making timely or difficult management decisions, particularly regarding the curtailment of resource use. For this reason it is best to adopt governance strategies that incorporate stakeholder input without causing decision-making stalemates. Providing a process to sanction the decision-making authority helps to ensure that decision makers who do make nonconsensual management decisions remain accountable for those decisions, hopefully leading to fully participatory negotiations and decisions most of the time (Lebel et al. 2006) (Chap. 11, this volume).

One hurdle in the way of improving the management of rangeland SESs is that regulatory policies are usually enacted on the premise that the problem faced is homogeneous across different times and places and that a single policy applied consistently will solve this problem in all locations. Unfortunately, rangeland problems are rarely so consistent and neither are the agencies tasked with implementing government policy. The single agency, single policy type of policy implementation is an example of *centralized governance*. Centralized systems assume that all information can be routed through a single office and that solutions can come from that same office. In contrast, *polycentric governance* systems have multiple locations for collecting data and issuing and carrying out management actions. Polycentric

governance models do not rely on a single solution to a perceived single problem, but rather seek to coordinate activities working toward a common goal.

For example, rather than ordering a single government bureau to apply a herbicide to an invasive weed wherever it is found at the same time every year, a polycentric governance system might rely on some federal offices, some counties, and some local nonprofit groups to eradicate that same weed at the time and in the manner that work best in that area. Polycentric governance systems may be more difficult to coordinate logistically but they are more likely to account for local social and ecological differences in a manner that increases project efficacy (Nagendra and Ostrom 2012). Given their more diverse constituents, polycentric governance systems are also more open to different types of information than centralized systems, and may be more creative in finding solutions (Lebel et al. 2005). Polycentric systems may also find it more difficult to reach consensus among their constituents, which can slow down decision making and delay projects.

The recent turn toward adaptive management and comanagement models tends to feature government agencies, NGOs, and other institutions as the principle actors in SESs. This institutional bias risks excluding individuals or groups that lack the relevant job titles from having a voice in how resources are managed. This is especially problematic for politically marginalized groups, such as most mobile pastoralists, who may not be considered viable rangeland managers by governmental or international entities. The institutional bias in both the resilience and adaptive management frameworks works to overlook power imbalances between various stakeholders, encouraging the false assumption that resulting decisions are consensual. Even in community-based natural resource management models, which have been extensively deployed in sustainable development projects worldwide, the “community” is all too often assumed to be a singular, cohesive group with internally uniform characteristics and goals, when in reality this is seldom, if ever, true (Agrawal and Gibson 1999).

8.3 Case Studies

In the following case studies, each conducted by different authors of this chapter, the SES framework is used to focus on different aspects of the SES as they influence the adaptive capacity and resilience of the system. Some authors focus more on the ecological dynamics shaping the ability to adapt, while others are most attentive to the social components. The focal spatial scale ranges from entire regions in the USA’s Great Basin and Australia to a couple of counties in California, down to the village scale in China, and finally to the scale of individual enterprises in Spain. Each study intends to improve understanding and support of the social and ecological drivers of resilient rangeland SESs.

8.3.1 Adaptation to Climate Change by Australian Livestock Managers

In northern Australia, climate change is expected to lead to increasingly dry conditions (Marshall 2010; Marshall and Stokes 2014). These changes are anticipated to be unprecedented—projections suggest that the scale and rate of change driven by increasing concentration of greenhouse gases in the atmosphere will significantly alter the distribution and quality of rangeland resources (IPCC 2014). The most likely climate future for the North based on RCP4.5 and RCP8.5 model projections for 2030 and 2090 suggests that temperatures will be warmer and hotter, respectively, but no “most likely” future with respect to rainfall is suggested (www.climatechangeinaustralia.gov.au). Although Australian rangelands have historically been highly resilient to a range of environmental, economic, and social changes, climate change in northern Australia is expected to reduce forage production, livestock profit margins, and biodiversity. Rangeland livestock operations are already struggling to maintain profitability because of recent drought conditions (Marshall and Stokes 2014). If managers and operators are not able to adapt to changing conditions, the extensive lands currently utilized for grazing might be converted to other, less valuable, states. Should grazing cease, extensive areas may transition to new ecological states that provide fewer or less valued ecosystem services. This means that sustaining rangeland landscapes in Australia is tied to the profitability of rangeland operations compared to the alternative possible uses. This study uses the SES framework to highlight how changes to the ecological system must be matched by adaptive changes in the social system in order to maintain the resilience of these pastoral SESs.

The future of the Australian rangeland SESs depends on the capacity of managers to sustainably manage rangelands, and the employment of managers is dependent on the condition of the rangelands (Marshall et al. 2011, 2014). Occupying some 70 % of the Australian landmass (Stafford Smith et al. 2007), rangelands are sparsely populated and of spatially and temporally variable productivity due to erratic rainfall. High variation in weather and seasons means that droughts are “normal” across the country, and drought declaration can occur more often than 3 years in 10 (McKeon et al. 2000). Livestock managers have had to cope with drought against an existing backdrop of conventional economic, biophysical, institutional, cultural, and political pressures and uncertainties (Howden et al. 2007). It is uncertain whether livestock operators have the adaptive capacity to adjust grazing practices to the altered conditions of a changed climate and remain both ecologically sustainable and economically viable (Marshall and Stokes 2014).

Environmental degradation on Australian rangelands can occur when, in an attempt to minimize the costs of a drought, livestock managers mismanage stocking rates, exacerbating pressures on already stressed grasslands (McKeon et al. 2004). One way for Australian livestock managers to adapt to climate change would be through making the most of good years and avoiding losses and reductions in resource condition in drought years (McKeon et al. 2004). Knowing when to alter

stocking rates, when to supplement with outside feed, when to move livestock to other properties, when to burn, and when to alter water supplies, for example, can differentiate between those producers likely to be successful in the long term and those that are not (Hansen 2002). If stocking rates are too high at the onset of drought, for example, soil compaction and erosion will reduce productivity in future years (McKeon et al. 2004). In order to avoid damaging rangelands in bad times but reap rewards in good times, livestock managers have to remain flexible by having backup plans and the ability to quickly adapt grazing plans to match present conditions. They need to balance economic, environmental, and social trade-offs, and manage their system as an SES, rather than attempting to make the system profitable every year. However, not all managers in Australia have the vision or capacity to maintain rangeland resilience (Marshall and Smajgl 2013).

Adaptive capacity in people or organizations is typically associated with creativity and innovation (Holling 2001); testing and experimenting (Folke et al. 2005); effective feedback mechanisms (Adger et al. 2011; Cumming et al. 2005); adaptive management approaches (Briske et al. 2008); flexibility (Cumming et al. 2006); reorganizing given novel information (Marshall et al. 2013); managing risk (Howden et al. 2007); and having the necessary resources at hand (Marshall and Stokes 2014). These characteristics are critical at all scales. On Australian rangelands, the adaptive capacity of individual managers has been conceptualized and operationalized as comprising four main dimensions; (1) how risks and uncertainty are managed; (2) the extent of skills in planning, learning, and reorganizing; (3) financial and psychological flexibility to undertake change; and (4) anticipation of the need and willingness to contemplate and undertake change (Marshall 2010; Marshall et al. 2014). A livestock manager who ranks highly in all four dimensions is thought to be more able to adapt to changing circumstances, in other words possess greater adaptive capacity. These four dimensions have been used to examine the adaptive capacity of managers to sustainably manage rangelands (Marshall and Smajgl 2013). Based on a survey-based evaluation of these dimensions, only 16 % of managers across northern Australia have the capacity to meet the challenges of a changing climate, and the remaining majority may be unable to maintain successful grazing operations into the future (Marshall et al. 2014). Vulnerability was assessed as a function of both adaptive capacity and climate sensitivity, where managers who were assessed as more dependent on the grazing resource were assumed to be affected by smaller changes in local climate. The northern beef industry as a whole was regarded as vulnerable particularly because of poorly managed operational risk, weak support networks, and low strategic skills or interest in changing behavior by managers (Marshall et al. 2014).

The SES concept recognizes the link between the continuation of a specific ecological system and the continued socioeconomic viability of the livestock industry. By 2030, some areas of northern Australia will be experiencing more droughts and lower summer rainfall (Cobon et al. 2009). Livestock managers need support in accepting that they must adapt and in developing and implementing effective adaptations. Possible avenues for intervention might be in teaching managers about

climate change, disseminating up-to-date climate and ecological data, determining appropriate stocking rates for new climatic conditions, assisting with financial tools to support rapid sales or purchases of livestock when conditions change, and improving the monitoring strategies or adaptability of grazing plans more generally. By providing knowledge of the different types of vulnerability of resource users, vulnerability assessments can enable decision makers to prioritize their efforts, provide a basis for early engagement, and tailor a range of adaptation approaches to most effectively accommodate and support the divergent requirements of the different categories of resource users. Given the coupling of social and ecological systems, maintaining rangeland resilience across scales by supporting human adaptation processes is likely to be an essential strategy for adapting to the challenges of the future.

8.3.2 Climate Change and Forb Restoration in the Great Basin, USA

The SES framework was used to understand factors that impeded the use of herbaceous broad-leaved plants, or forbs, in restoration of cheatgrass (*Bromus tectorum*) invaded Great Basin sagebrush steppe ecosystems of the western USA. Most of these ecosystems are managed by federal agencies, in particular the Bureau of Land Management. Forbs are an important component of biodiversity in these ecosystems (West 1993) and increasing native forb species richness can enhance resistance to invasive plants (Pokorny et al. 2005) including cheatgrass. By providing fine-textured, combustible fuels, cheatgrass increases susceptibility to wildfires, and wildfires have been growing in frequency and severity across the Great Basin (Brooks et al. 2004), a trend that is expected to continue as a result of climate change (Abatzoglou and Kolden 2011). Yet when rangeland managers choose seed mixes for restoring native plant communities after a wildfire, forbs are often underutilized. While reduced forb abundance after wildfires is a local- to regional-scale ecological issue, applying an SES framework revealed that it stems partly from higher level processes that affect agency budget choices, as well as individual variation in how managers perceive and interpret scientific information about rangelands and climate change. The SES framework accounts for factors, relationships, and feedbacks among scales that influence the relationship between forb restoration, climate change, invasive plants, and manager decision making. An SES-based analysis of key drivers of manager decision making helped to understand the limitations to the adaptive capacity of managers.

Land managers may know which plant species to reseed after wildfire to suit past conditions, but predictions of future climate in these regions suggest more variable and extreme weather events, longer droughts, and increasing summer high temperatures (Ackerly et al. 2010; Polley et al. 2013). Part of this study was to evaluate the effect of summer warming on forbs to test the assumption that forb species choices for postfire rangeland seedings might need to be adapted to suit

future climate conditions (Whitcomb 2011). Summer air temperatures at the soil surface are predicted to increase +4.5 to +6 °C in the Great Basin by the year 2100 (Jiang et al. 2013). A field experiment was conducted over 2 years at an experiment station near Logan, Utah, in which selected native and non-native forbs were grown to test their responses to increases in air temperature (Post and Pederson 2008). As hypothesized, the different plant species responded differently to warming, indicating that changes in species fitness and ultimately composition under warming conditions are likely. If managers are to effectively implement postfire seeding practices for these new conditions, they need to have the adaptive capacity to try new seed mixes, despite concerns about costs and uncertainty about propagation (Sheley and Half 2006).

Land management decisions were examined in order to assess the interactions and factors shaping postfire rehabilitation practices. Most Great Basin public land is managed by natural resource professionals who are expected to be responsive to the interests of the public and to use scientific information, admittedly in short supply, to manage sustainably. In this case, information about the prospect of climate change and the response of different species *should* have driven managers to choose rehabilitation methods that anticipate climate change effects on the ecosystem. The available climate and ecological information suggests that forb rehabilitation should be prioritized in management decisions, and that using seed mixes that are adapted for climate change will increase the likelihood of diverse forb communities over the long term. Yet knowing which species are more likely to survive in a warmer climate is only part of the management picture.

Using the SES framework it became apparent that managers' attitudes toward using available scientific information were influenced by broader scale US political debates about the existence, causes, and appropriate response to climate change. Research has shown that the best predictor of viewpoints about climate change is personal value orientation (Leiserowitz 2006). Managers employed by government agencies are partially influenced by the policies and norms of the agencies that employ them, but personal values also can affect management decisions (Richards and Huntsinger 1994). To understand how these social factors influence rangeland rehabilitation decisions in a sagebrush steppe SES, managers employed by various agencies across the region were interviewed regarding their opinions whether local weather events are indicators of larger climate trends; their concerns about the risks associated with climate change in their jurisdictions; current management activities to address future climate predictions; and perceptions about the role of forbs in ecosystem resilience.

Insights from 20 usable interviews conducted in May 2010 found that managers may not use available data about temperature changes or forb responses when choosing species for seed mixes. Thirty-year climate data showed that precipitation had declined at 18 of the 20 locations where the interviewees worked, with an average decrease of 12 %, and maximum temperatures overall had increased. Yet when asked whether the climate was changing locally or not, only about half had noticed changes. Those who thought that the climate was changing typically had spent more time in that location than those who did not think so. This finding may indicate that

managers with local experience based their answers on personal experience, while more recent arrivals relied instead on general beliefs about climate change. Managers in both groups stated that while their organizations had policies in place that encouraged consideration of climate change in management, they were hesitant to do so without more specific guidance about how to use climate change information in their decision making. This range of responses demonstrates the complexity of managerial decision making and the unpredictable array of variables that influence adaptive capacity.

Further limitations to adaptive capacity were revealed in the interviews. Some managers were uncertain about the role and status of native forbs in their jurisdictions. Most reported using custom seed mixes that included native forbs as well as grasses, but forb diversity was low with only one or two species included, typically due to the generally high cost of forb seed. As wildfires become more frequent and severe across the region, managers struggle to obtain the resources needed to keep up with postfire rehabilitation needs. Budget shortages also inhibit the ability to take the risks needed to successfully adapt to changing conditions. Together with a lack of firm conviction about the occurrence of climate change, a choice *not* to change practices could be easily made.

Considered in its entirety, analysis of the social context suggests that many rangeland managers were unprepared to adapt to climate change when implementing postfire rehabilitation seedings. Over time, such a failure in adaptability, if it continues, could lead to the transition of more areas of sagebrush steppe to alternative ecological states, which in turn would affect land-use practices by local communities. The SES framework made it possible to examine how local land management practices are affected by large-scale social and ecological forces that do not seem directly related, but are linked and mediated through manager perceptions.

One might conclude that the key to changing seed choices is to influence manager beliefs about the importance of forbs to ecosystems and the reality of climate change. Yet climate change beliefs are highly related to personal values, and value-based attitudes are highly resistant to change (Eagly and Kulesa 1997). Manager beliefs are also shaped partially by prevailing opinions in the local community (Kennedy et al. 2001), and these may be even more resistant to change. A more fruitful intervention might be to provide specific agency-wide guidance for the use of new seed mixes, framing the need not in terms of climate change, but as related to problems managers experience directly such as non-native species invasions, higher fire frequencies, and drought. Facilitating communication between managers who are actively preparing for climate change and those who are not may clarify the benefits of adaptation measures and enhance adaptive capacity. Increasing budgets to increase purchasing power and devoting more resources to identifying new seed sources and seeding technologies would also help to improve manager ability to use native forb seeds effectively in future conditions.

8.3.3 *California Black Rail Habitat in the Sierra Nevada Foothills*

Concerns about the welfare of a rare bird, the California black rail (*Laterallus jamaicensis coturniculus*), led to a study of the SES that sustains the small wetlands that are its primary habitat in the Sierra Nevada foothills. More than two-thirds of the wetlands in the area are fed primarily by irrigation water, either by irrigation runoff or through leaks in earthen irrigation canals and ditches, and are scattered within grazed annual grasslands that are mostly in private ownership. Wetlands fed by irrigation water are also more consistently wet and had greater bird use than those subject to seasonal water variations (Richmond et al. 2010). Designing the study and analyzing research results using an SES framework revealed that many wetlands are functionally “accidental” and have little impact on land use or productivity from the landowner perspective. They are largely ignored by landowners, and while this benign neglect is to some degree why they have served as black rail habitat for decades, changing environmental and economic conditions could lead to their demise. In this study, the SES framework linked factors outside of the land manager–ecosystem relationship to strong impacts on the potential for conserving rail habitat, and revealed a need for governance that facilitates feedbacks from rail habitat conditions to water districts.

The secretive black rail is a small ground-dwelling marsh bird, and was known only from large marshes in San Francisco Bay and along the lower Colorado River until it was “discovered” in the Sierra foothills of Yuba, Nevada, Placer, and Butte counties in 1994 (Richmond et al. 2008). The SES framework enabled researchers to conceptualize and model the ecosystem service of rail habitat provision as a product of the interaction of humans and environment, rather than a service provided by the ecosystem alone (Huntsinger and Oviedo 2014). Researchers hypothesized that the interaction of landowners and environment is driven mostly by water scarcity, fears of mosquito-related illness, ranching activities, water price, and landowner goals for their land (Fig. 8.3).

To understand how landowner decisions influenced black rail habitat, landowners within the bird’s habitat distribution were surveyed about water and land management goals and practices in 2014. Results showed that about half the landowners purchased irrigation water from a water district. Water districts are local government institutions that supply water to farms and homes in a rural area. They typically serve hundreds to thousands of properties. While many respondents reported having a small wetland that could be rail habitat on their property, few survey respondents reported any management of such wetlands, with about 9 % reporting draining a wetland in the last 5 years, and 9 % reporting that they created a wetland during the last 5 years. About half said that they valued wetlands as wildlife habitat, about a quarter thought that the green forage was useful for livestock, but about a quarter reported not doing any management because the wetlands simply did not “bother” them.

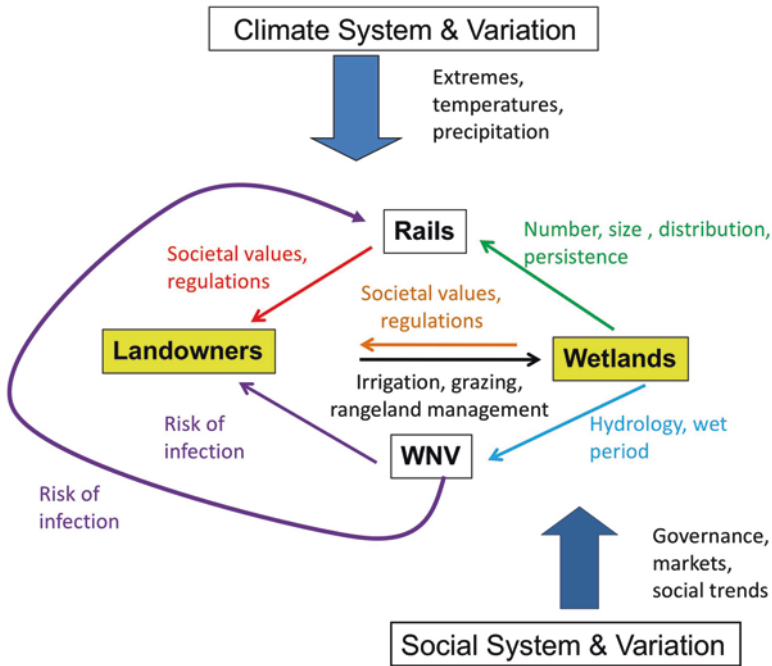


Fig. 8.3 Initial model of the SES proposed by researchers for California black rail in the Sierran foothills (Hruska et al. 2015). Much of the focus was on the relationship between landowners and wetlands. While the focus of this excerpt is on the social element, researchers also studied bird ecology, epidemiology, and hydrology as part of the study

The history of real estate appreciation in the area has also influenced water use. Because of strong competition for water allocations from water districts, it is often difficult to get a new allocation or increase an old one, but once granted, allocations are rarely taken away. As a result, landowners who get an allocation keep purchasing that amount of water every year, whether they can use it or not, to avoid losing their allocation. Having an allocation makes a property more valuable. Under these conditions there is little motivation to conserve water. Despite the fact that California was in the third year of severe drought, in 2013–2014 water district water purchasers were more likely than non-purchasers to respond in the survey that they had plenty of water for their property. Water districts buffer the drought for their customers, maintaining existing flow largely without reductions. Using water district water apparently changes the timing and nature of feedbacks to management from drought—it took 4 years of drought before water districts began cutbacks and landowners felt the impacts in our study area. While the lack of reduced water use during drought is a problem from a water conservation standpoint, it is positive for maintaining rail habitat.

Researchers learned that water districts and their policies have an extraordinarily important role in determining how people use water, especially during droughts.

This finding came despite the fact that, because they are so diverse, numerous, and little understood, water districts were not included in the initially proposed SES. The two most common actions respondents said that they would take if water districts increased prices substantially would be to reduce or cancel water purchases, or to reduce or eliminate irrigated pasture, two actions that would strongly affect rail habitat. Similarly, many respondents reported that they would reduce the size of irrigated pastures or decrease their irrigation frequency if water districts provided less water. Interviews with water districts revealed that while there are feedbacks between landowners and water districts, there seem to be no feedbacks from wetlands to water districts—in general, water districts have no legal or political motivation to consider the impacts on habitat from water conservation or water delivery practices (Fig. 8.4). In addition, state policy is encouraging water districts to conserve water, and districts are now making substantial investments in their infrastructure to prevent leaks and seeps, both water sources that create rail habitat. Water conservation efforts throughout California will be translated to many landowners and wetlands via the water districts.

The SES framework made crucial “weak links” in sustaining habitat for the rail quite clear: state water policy, local water districts, and landowners are unaware of

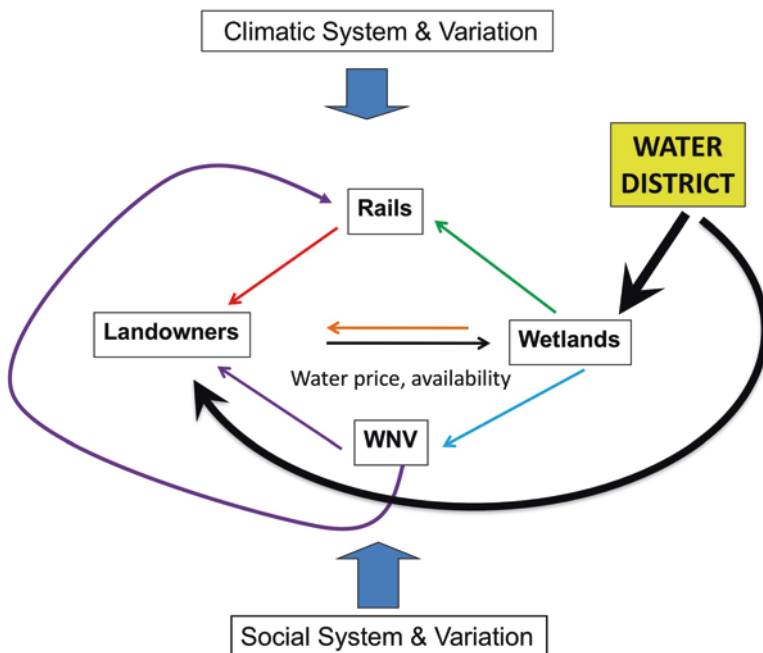


Fig. 8.4 A modified SES for California black rail habitat in the Sierran Foothills. New, critical players were identified as the study progressed and the areas where interventions would be important were located. Landowners only have an indirect effect on water districts, and at a different scale—in the aggregate. Water districts are directly affected by climate and regulations, both larger scale processes

any reason to consider impacts of management decisions on small wetlands. In conclusion, maintaining the resilience of the SES will require finding points of leverage for influencing water district actions, a process that will involve changes in governance. Given that most rail habitat is on private land, improving the resilience of wetlands must also incorporate outreach to landowners and water districts, a process that would require collaboration between multiple organizations throughout the SES. The fact that landowners expressed a strong interest in wildlife will help guide outreach activities.

8.3.4 Nomad Sedentarization Project in Xinjiang, China

Grassland covers 41.7 % of China and is home to some 17 million registered pastoralists and agro-pastoralists. Most pastoralists are ethnic minorities that have traditionally moved mixed herds of livestock up and down an elevation gradient on a seasonal basis, or across large distances to avoid drought and seek good weather and range conditions. Mobile livestock management buffers the spatially and temporally variable conditions in arid rangelands and is deeply intertwined with social and cultural practice and traditions (Roe et al. 1998; Li and Huntsinger 2011). Mobility and opportunistic grazing, common adaptive strategies in arid land pastoralism, are important components of the resilience that has enabled pastoralists to persist in environments with unpredictable forage production. The SES framework can be used to assess the resilience of pastoralist SESs in response to development policies, in this case sedentarization projects that decrease mobility of livestock herds. State-driven nomad sedentarization projects in China are intended to improve household income while decreasing grazing pressure on local grasslands (Harris 2010). By examining sedentarization at multiple spatial scales—village, county, and water catchment—researchers found that these projects have met objectives at some scales and in some locations but not others. An SES approach revealed how new patterns of resource use created by sedentarization policies have had significant environmental consequences, weakening the resilience of pastoralist communities in the study area within Xinjiang Uyghur Autonomous Region (hereafter Xinjiang).

Since 2006, the Chinese Government has enacted a series of Nomad Sedentarization Projects (NSP) throughout the country's six largest pastoral areas. The NSPs in China are designed to provide improved social services to herders, including construction of houses with tap water and electricity, and development of alternative livelihoods, and to restore grasslands by reducing grazing pressure through decreased stocking rates and the planting of supplemental fodder near settlements. The projects are funded directly by the central government, with annual budgets sometimes exceeding the equivalent of 200 million US dollars (Ministry of Finance 2011). In contrast to previous studies of sedentarization that focused only on individual villages, this study sought to examine the effects of sedentarization on the pastoral SES across different spatial scales: economic and rangeland conditions at

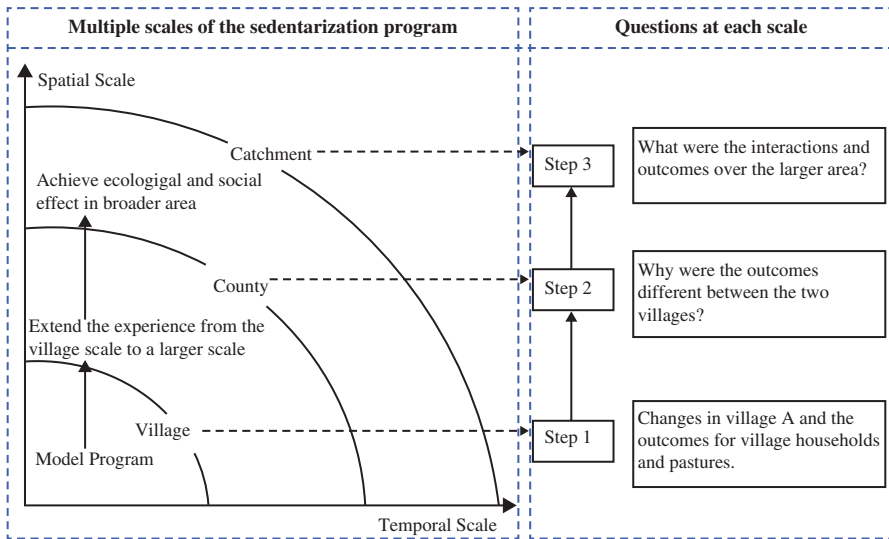


Fig. 8.5 Questions developed based on the SES framework for two sedentarized villages in Xinjiang Province, China (from Fan et al. 2014)

the village scale, social and economic processes at the county scale, and ecological processes at the catchment scale (Fig. 8.5). This allows analysis connecting management impacts at one scale to unexpected consequences or feedbacks to smaller or larger scales (Pelosi et al. 2010).

In Jinghe County of Xinjiang, sedentarization of mobile pastoralists began in the late 1990s and was completed in 2007, by which time 98 % of pastoral households had settled. Jinghe County lies within the Ebinur Lake catchment, and the two study villages are both within the county and within 50 km of the lake’s shore. Given the low precipitation at the catchment floor of only 60–80 mm per year, the snowmelt-fed lake and associated wetlands play an important role in sustaining the regional ecology.

Researchers surveyed herder households in two villages, here referred to as Village A and Village B, to document household income and herder opinions on sedentarization’s effect on grassland health and livelihoods. Prior to sedentarization, all households had annually moved livestock through four seasonal pastures and had similar standards of living, though households in Village A owned more livestock (406 ± 142) than those in Village B (308 ± 142). As part of sedentarization, all households built permanent homes in their former autumn pastures and were allotted adjacent land for cultivation. Access to traditional pastures was limited, allowing for only a two-season (summer–winter) rotational cycle, with livestock spending more time near residences. Importantly, Village A was allotted 13.4 ha of private land per household by the government whereas Village B received only 5.4 ha per household due to a new protected area nearby. Though livestock husbandry still accounted for approximately three-quarters of total income, new

income sources included renting out land, government grassland subsidies, agriculture, and outside employment. While the pattern of sedentarization was quite similar for the two villages, its effect on household livelihoods was not. Village A was a local success story and held up as a model of modernization, while Village B struggled to meet household needs.

In Village A, all 23 surveyed households reported preferring their new sedentary life because they liked the improved housing and access to services, and the overall “more convenient” lifestyle. Nearly all had increased livestock numbers, with a new average herd size of 1002 ± 548 . These larger herds were given supplemental feed grown on household agricultural plots or purchased from outside the community, decoupling them from the variable rangeland productivity. Households built barns and warming sheds that maintained greater livestock body weight during the winter, allowing for earlier lambing with higher survival rates and heavier lamb weights at the time of sale. In the summer, livestock were grazed on traditional summer pastures and also on summer pastures rented from neighboring townships. Despite this, only one household thought that pasture quality was improving over time, with most linking pasture condition to rainfall. At the village level, ecological conditions were not believed to have improved because of the policy.

Sedentarization in Village B was significantly different. Due to smaller and more dispersed household allotments, few households were able to irrigate their land or rent it out to professional farmers. Village B was unable to rent additional summer pasture land, as Village A had. Households could not increase their livestock numbers, and average income is now 50 % of that of Village A. Households in Village B were unable to make comparable investments in infrastructure and supplemental feeds. Many households required bank loans just to meet household expenses. Thus, while both villages turned to agriculture and supplemental food and settled in permanent housing, the two villages had significantly different outcomes in terms of household income, herd size, and use of irrigation. At the county level, the sedentarization created inequitable outcomes among villages which could ultimately destabilize the social system.

At the catchment level, there have been dramatically increased rates of groundwater withdrawal for irrigated agriculture, especially cotton. The nearby Ebinur Lake is shrinking rapidly and local river flows are decreasing or disappearing entirely. The lake now has half the surface area that it had in 1950, with steady declines marked since 2003, correlating with the increased area under cultivation (Sun and Gao 2010). Human activity is held responsible, with most of the water used for crops (Qian et al. 2004; Cheng and Hong 2011). Survey respondents remarked that it was becoming increasingly difficult to get drinking water from shallow wells, as the local water table was dropping. Sedentarization has had significant ecological impacts at the catchment scale that may undermine the resilience of the SES of all villages in the watershed, even the more successful Village A.

The SES framework reveals that environmental policy has both social and ecological effects, and that they may be different at different spatial scales. Ecologically, water limitations at the catchment scale seem likely to feed back to the village level, making the current agricultural uses that resulted from sedentarization unsustainable.

Declining pasture conditions may lead to more reliance on irrigated crops, feeding back to increased water demand, and worsening water loss at the catchment level. The disparity in economic impacts apparent at the county level may destabilize the SES socially by creating feelings of inequity at the village level. Sedentarization has undermined the resilience of these pastoral communities by generating social and ecological tensions at multiple spatial scales. By becoming aware of the interconnections of social and ecological systems, and considering outcomes at multiple spatial scales, managers in this case would be better equipped to establish development policies that sustain households and villages, pastures, and watersheds.

8.3.5 Environmental Accounting for Spanish Private Dehesa Properties

Oak woodland *dehesa* is an ancient and extensive agro-sylvo-pastoral system in southwestern Spain's Mediterranean climate zone that produces multiple products, including cork, acorns, and wood from oaks; forage for diverse breeds of cattle, sheep, goats, and bees; habitat for game and mushrooms; recreation and scenery; and acorns for Iberian pigs. The characteristic pattern of well-spaced oaks with a mostly herbaceous understory is shaped by human management. Landowners enjoy many nonmarket ecosystem services (also called private amenities) from the land, including a beautiful setting, recreation, the status of owning a large property, hunting, a traditional lifestyle, the rewards and challenges of stewardship, and the possibility of passing the property on to their heirs. Woodland ecosystems actively managed as *dehesa* have notably high biodiversity, higher than similar systems under alternate land uses (Bugalho et al. 2011). *Dehesa* is threatened by abandonment because of the low prices for commodities such as cork and by competition from agricultural intensification and development. The SES framework is applied here to explore the feedbacks between the environment and the individual *dehesa* enterprise to understand factors shaping the persistence of the *dehesa* system at the household level.

Like ranches in the USA (Oviedo et al. 2013), *dehesa* properties command higher prices than can be explained solely by income from commercial production. Commercial income is often low and governmental subsidies supplement the operations. However, the cultural and ecological nonmarket ecosystem services consumed by *dehesa* owners partially explain why they chose to pay expensive *dehesa* land prices, just as they have been used to explain why ranchers in the USA persist in ranching when other investment choices might show greater monetary returns (Smith and Martin 1972; Oviedo et al. 2012) (Chap. 14, this volume). In this study, researchers sought to quantify these nonmarket landowner benefits in order to determine how much *dehesa* owners “earn” from nonmarket ecosystem services compared to commercial income. This comparison would make it possible to consider these services, as motivators for land ownership, when making land use policy. In this case study, an “agroforestry accounting system” (Campos 2000) is used at

the property level to monetize some of the nonmarket benefits to the landowner from dehesa, and to place them into a fuller accounting of income to the landowner. Presented here is a summary from the detailed study of Oviedo et al. (2015a, b).

The Agroforestry Accounting System (AAS) is a framework developed to overcome the limitations of conventional income accounting by incorporating, among other things, ecosystem amenity benefit streams in economic analysis (Campos 2000). Though this approach can be used to estimate the economic value of the ecosystem to society, here we focus on benefits to the landowner as the focal environmental feedback to the SES. The AAS includes capital gains, with land appreciation as its main component. Land appreciation is part of landowner income because the landowner will realize this value when the property is eventually sold. As with land valuation more broadly, land appreciation of dehesa is better explained by nonmarket ecosystem service amenities available to dehesa owners than by commercial income potential (Oviedo et al. 2015b). The study differs from previous economic analyses of dehesa and other agroforestry ecosystems in that both market commodities and nonmarket ecosystem services are calculated together to create a more complete ledger of total income equivalents for dehesa owners.

The “ecosystem services” concept originated with the idea that land-use decision making would be improved if the nonmarket benefits from ecosystems could be quantified in monetary terms (Chap. 14, this volume). For example, a municipality might develop a forest watershed and gain tax dollars, but it might trade off substantial water filtration and provision services, erosion control, and recreation opportunities. Recreation and water are sold in various markets, and the prices can be used to generate an estimate of those monetary values, but erosion risk, for example, is difficult to value. “Nonmarket” benefits such as aesthetic beauty or cultural heritage values are even more difficult to monetize. One method often used is “contingent valuation analysis” (CVA), where people who benefit from a particular environmental feature, such as a stand of trees used for walking or communing with nature, are asked how much money they would be willing to pay to maintain the existence of, or receive in compensation for the loss of, that feature (Mitchell and Carson 1989; Campos et al. 2009).

Data from three different sources was integrated in the AAS methodology. One source was a contingent valuation survey of 765 landowners used to obtain estimates of the value of nonmarket ecosystem service benefits to landowners (Oviedo et al. 2015b). A second source was the nominal cumulative land revaluation rate for Spanish dry natural grassland for the period 1994–2010 (MARM 2011), used to roughly approximate land appreciation value. Third, commercial income data for three sample dehesas was gathered from account books, in-depth interviews, and field data (Oviedo et al. 2015a). Government net subsidies were not included here because they are temporary, and depend largely on the varying European economic context.

In all three dehesas, commercial activities alone result in negative operating income. Capital gains from land appreciation are positive in all cases and make up some, but not all, of the difference between expenditures and revenue. The inclusion of the nonmarket ecosystem services consumed by dehesa owners and quantified by CVA makes the income for all three dehesas positive, and in fact makes up a higher share of total income than commercial activities. As the principal drivers of

appreciating land values, landowner nonmarket ecosystem services are doubly important in this accounting.

When the low or negative commercial income, positive income from capital gains, and value of owner-consumed ecosystem services are factored together, real total profitability ranges from 3.2 to 5.6 % (Oviedo et al. 2015a). If conventional income accounting were applied, the feedback from the ecosystem to the landowner from nonmarket ecosystem services would be overlooked, and our understanding of the interactions, or feedbacks, between landowners and the dehesa ecosystem would be less complete.

Dehesas would not be “profitable” for landowners without the ecosystem services they provide, making nonmarket ecosystem services consumed by the landowner a positive feedback that should strengthen the landowner’s bond to the property. As these are nonmarket benefits and do not produce cash, the landowner must be able to afford, and be willing to pay, property expenses in order to acquire them. This capacity is key to the ecological sustainability of dehesas and implies that dehesas must be owned by people either with substantial savings or with monetary income from other sources. When considered in the larger portfolio of income streams from dehesas, having nonmarket sources diversifies the operation, increasing the resilience of ownership in the face of unpredictable and changing markets for the more tangible products.

The translation of nonmarket benefits to the landowner into monetary terms allows us to better understand when subsidies or other interventions are needed to maintain the integrated “profitability” that motivates landowner choice in this SES. It also highlights the need to maintain the production of landowner-consumable ecosystem services in order to motivate ownership and management investment. This is critical in Spain, for while land use controls inhibit conversion of dehesa to other uses, they do not sustain the active dehesa management necessary to preserve the considerable benefits of the system to Spanish society, including wildlife habitat, carbon sequestration, watershed protection, and scenery. The governmental subsidies that are provided to landowners reflect an appreciation of these values. An open question is whether any of these nonmarket goods and services can eventually find a nongovernmental market (Caparrós et al. 2013). Environmental accounting provides insight into how regulations, social pressures, significant ecological change, or other factors that reduce the nonmarket ecosystem services a landowner can consume from their property may put the dehesa at risk as much or more than low commercial profits.

8.4 What Can Be Learned from These Case Studies?

It has been suggested that resilience, adaptability, and transformability are the three related attributes of SESs that determine their future trajectories (Walker et al. 2004). Resilience and adaptability figure prominently in the case studies, but the third, transformability, or the ability of a system to transition to a new SES, has been

less studied and is not found in the case studies. In each, the SES framework was used to locate key interventions needed to maintain or increase the resilience or adaptive capacity of the system (Table 8.1). The SES framework revealed multi-scalar feedbacks and drivers that otherwise likely would have been overlooked, and helped to understand at least some of the relationships that influence the resilience of complex systems. Each of the case studies reveals certain weak points in the SES that are either being neglected or exacerbated by current management strategies, and which may threaten the long-term persistence of the SES.

The focal SES in each case study was found to have vulnerabilities that threaten to cause significant shifts in the landscape and the resident social groups. By analyzing each of the case studies as an SES, it was possible to identify threats as well as points where adaptive capacity and resilience were low, in essence revealing the weakest link in the chain of interactions and the point at which intervention should be made. Unfortunately, the synthetic research that went into each of the case studies is rare in natural resource management, and underscores the need for a large amount of information in order to create sound policies and management prescriptions. Since it would likely be expensive and time consuming for any one agency or actor to gather all the necessary data individually, gathering together people from many different sectors of the SES may be the best way to detect threats and how they could be avoided.

8.5 Future Perspectives

Writing about the need for global action to respond to the profound changes in ecosystems caused by human activity, Carpenter and others state, “The challenge of sustainable development is to ... transform social-ecological systems to provide food, water, energy, health and well-being in a manner that is economically, ecologically and socially viable for many generations in the future and for people in all parts of the world” (2012). The Millennium Ecosystem Assessment published in 2005 identified gaps in current knowledge linking ecosystem services and human well-being, including the need to understand how SESs evolve over time and respond to policy interventions, trade-offs among different ecosystem services, and how to integrate the expectation of nonlinear and abrupt changes into policy and planning (MA 2005). The SES concept is still relatively new to range science, and it has yet to be widely applied. It is acknowledged that social factors deserve more attention and more in-depth research in range management, but research to date on the interactions of society and rangelands has rarely been able to escape the bounds of a single discipline (Brunson 2012). Most range research has tended to focus on the ecology, management strategies, or economics of rangelands, but has rarely synthesized these different components.

Table 8.1 Overview of the SES framework and five case studies

Case	Problem	SES highlights	Interventions
Adaptation to climate change by Australian livestock managers	Lack of adaptive capacity in the face of anticipated climate change leads to poor management decisions and reduced economic resilience to climate change Scale: Region and enterprise	Ranching collapse would cause undesirable social and ecological change. Feedbacks between climate change and rangeland productivity are connected to ranch economic welfare	Education and support for rancher adaptive capacity, and mission-oriented research into rancher needs to guide education and outreach
Climate change and forb restoration in the Great Basin	Limited manager adaptive capacity in developing postfire seeding practices that anticipate climate change, leading to decreased ecosystem resilience Scale: Region and administrative units	Individual and community values limit personal adaptive capacity, costs and uncertainty of successful regeneration constrain management adaptive capacity	Support receptivity to learning; problem should be stated in terms other than adapting to climate change; financial support to reduce risk is needed
The California black rail and small wetlands in the Sierran foothills	Small wetland habitats for a rare bird are at risk from climate change and nonadaptive water conservation policy Scale: Individual landowners and water districts	Policy at the state and local scale inadvertently threatens small-scale wetland habitat for a rare bird. A lack of feedback to local or state policy makers about wetlands because they are “invisible”	New governance or policies for water districts are needed; outreach to landowners about maintaining small wetlands as wildlife habitat
Sedentarization of pastoralists in Xinjiang	Sedentarization and irrigated agriculture put the grassland SES at risk ecologically and socially due to economic inequality and overuse of water Scale: Household, village, county, and catchment	Understanding of the multiple scales of an SES and how they interact can be used to assess resiliency; impacts to and feedbacks from processes at the broader scale undermine resilience at the household scale	Programs should be revised using SES assessment of impacts at multiple scales, including equity of outcomes; development plans should be altered to fit environmental constraints
Environmental accounting for dehesas in Spain	Reasons for owning traditional woodlands producing many ecosystem services are not recognized by policy, yet support resilience to fluctuating prices of agricultural products Scale: Individual landowners, ecosystem	The consumption of ecosystem services by landowners acts as a positive feedback on the resilience of regionally valuable dehesa	Understand and support feedbacks that enhance landowner commitment to maintaining dehesa enterprises, including landowner-consumed ecosystem services

Rangelands around the world operate under a broad array of governance systems and property rights regimes. Thus far the SES concept has been used far more effectively to analyze past and present situations than in providing clear steps for future work. Future research should go further in determining how these different components are linked, and further suggest policy improvements that might better support ranchers, pastoralists, and rangeland managers. The effect of large-scale economic and political forces on local environments lends itself well to SES analysis. For example, in the USA, zoning laws discourage conversion of private rangeland to other uses within certain geographical areas, but ranch conversion is not otherwise prohibited and ranches are rarely the most profitable land use. Alternatively, many European countries have national laws that ban the conversion of certain agricultural lands—including *dehesa*—to nonagricultural uses. In the western USA, there is growing interest in conserving “working rangelands”—rangelands that produce ecosystem services as well as commodities. Yet there has been little research to date comparing the effectiveness of various national land policies on maintaining working rangelands or supporting their active management at the household scale. Comparing the effects of land-use policies on the ecology of working rangelands would provide needed policy-relevant information.

At a recent national workshop on “usable science,” participants, including scientists, livestock operators, and land managers, ranked 142 identified issues proposed by five working groups (water, animals, vegetation, soils, and socioeconomics). The number one-ranked issue overall came out of the Socio-Economics Working Group: understanding and managing for variability (climate, drought, fire), adaptation, and recovery (Brunson et al. 2016). This topic is admittedly broad, but the SES approach is a good fit for analyzing key components: ecosystem change, adaptive capacity, and resilience in rangeland systems. Rangelands are subject to high variability of climate, vegetation, and market influences of livestock and feed prices, and dealing with such variability is a constant challenge for livestock operators and land managers. SES frameworks might productively be used to increase the resilience of working rangelands by identifying beneficial ecological traits but also by constructing social and economic support systems for livestock operators and land managers. Research exploring the use of SES frameworks to help practitioners and managers anticipate and manage variability and change in environment and society is a needed contribution.

Trade-offs and synergies among the various goods and services derived from rangelands need more attention in general. On public lands, agency interventions on specific allotments could have impacts on entire landscapes: examining these cross-scale effects, and the trade-offs among them, requires greater attention. Designation of a park or preserve may be of great benefit in meeting conservation and recreation needs, but might have devastating effects on individual livestock operators, and lead to a transformation in nearby communities with various ecological and social outcomes at diverse scales. SES analysis could help anticipate these effects, providing a fuller picture of the opportunities and trade-offs of the change. This type of research is hampered, however, by the difficulties of cross-disciplinary research. SESs are inherently interdisciplinary, but different disciplines use different research

methods, and the multiple geographic scales used by SES researchers require multiple researchers to work together in different places. Greater emphasis is necessary to integrate and balance multidisciplinary programs and projects addressing rangelands, including the use of multiple research methods.

Finally, as pointed out earlier, transformability as an SES characteristic has not received enough attention from SES researchers. Yet transformations are occurring in rangelands in many parts of the world. In China, when does a sedentarized nomad community shift to a different SES and what does that mean for the well-being of the people in the community? In the USA, many ranching communities have experienced an influx of new residents working in businesses related to mining and tourism, or seeking a place to retire, vacation, or telecommute. When does a ranching community transform to another type of community or SES altogether? What does this mean for the economy and the environment? The SES framework could be used to assess the impact of such transformations in a comprehensive way, and to analyze the resilience and adaptability of the new SES.

8.6 Summary

An SES is a combination of social and ecological components that shape each other in profound ways. For example, a grassland landscape is radically altered when it is converted to agriculture. The natural components of that system are affected by farming and land management practices, water use, infrastructure, etc. Farming communities are impacted by the productivity of the soil, by precipitation and temperature, and by the multitude of plants and animals they either rely on (for pollination or soil health) or compete with (crop pests or predators). Similarly, livestock operators graze their animals and conduct management activities in ways that shape rangeland ecology, but also respond to changing ecological conditions such as invasive plant species or variable productivity caused by irregular rainfall. Larger scale patterns such as climate change, demographic trends, and global meat prices also affect rangelands both directly and by altering land-use patterns.

The SES concept is not a methodology for research or a checklist to identify problems. It is a conceptual framework designed to keep both the social and ecological components of a system in focus so that the interactions between them can be scrutinized for drivers of change and causes of specific outcomes. Furthermore, change may cross back and forth between the social and ecological subsystems in ongoing feedbacks. Most research and land management policies are based predominantly on either ecological or social phenomena and problems. This type of single-discipline thinking leads to policies which either fail to address the problem or cause unintended consequences. SES analysis requires a great deal of information from multiple disciplines and often at multiple sites, which is logistically challenging and has served as a barrier to widespread use of the SES framework until recently.

SESs exist because human life depends on ecosystems, and human actions perpetually affect ecosystem components and functions. Rangeland managers work at the intersection of human enterprise and rangeland ecosystems. Managers must remain flexible and adaptive enough not only to tailor grazing and management activities to suit unpredictable environmental conditions, but also to respond to changing policy, economics, demands for ecosystem services, and management capacity. Such flexibility and adaptability constitute a serious challenge especially given climate change and decreasing profitability of range-fed livestock. If we as a society want to continue to have working rangelands, policies to promote more cross-disciplinary research and education, flexible land use, and novel economic programs to satisfy multiple objectives for rangelands are sorely needed.

It has been suggested that resilience, adaptability, and transformability are the three related attributes of SESs that determine their future trajectories. Resilience can be defined as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks (Walker et al. 2004). In the face of a disturbance, a resilient SES will not only maintain function but may even use the disturbance as an opportunity to reorganize and further develop resilience (Gunderson and Holling 2002; Berkes et al. 2003). Disturbances can originate in social or ecological systems and can happen rapidly or gradually (May 1977; Chap. 6, this volume). The ability of the SES to adapt to change is a key to resilience. If change overwhelms the resilience and adaptive capacity of an SES, it will transform to a new type of SES. SES analyses should strive to identify the interactions that lead to resilience, adaptation, or transformation.

The application of the resilience concept to social settings and, to a lesser degree, the use of the SES concept itself have been critiqued for overlooking the role of human autonomy, cultural values, social heterogeneity, and power relations among actors in SESs. An overemphasis on institutions as environmental managers and decision makers all too often obscures the role of individuals and loosely affiliated groups in social–environmental relations. In the future, range SES analyses could be improved by better accounting for social difference among stakeholders and their ability to take part in political and decision-making processes.

Components of SESs that figure prominently into their analysis include scale and feedbacks. Understanding of ecosystems and their response to management has often been hampered by a failure to appreciate the role of scale. Different patterns and processes are characteristic of different temporal and spatial scales. Research too often focuses on a single scale, overlooking processes that occur primarily at larger or smaller scales, but which nonetheless critically impact the components of the focal SES. Identifying feedbacks between social and ecological components of the system at multiple scales is a key to SES-based analysis. For example, household economics may be affected by international meat prices or a consolidation of the meat-packing industry. Droughts that occur only once a decade can have lasting effects on rangeland ecology, herd sizes, management strategies, and local poverty.

Five case studies using the SES concept were presented. In each, the SES framework was used to locate key interventions needed to maintain or increase the resilience or adaptive capacity of the system. Analyses identified important processes and

interactions at scales from the personal values of an individual to region-wide watershed impacts. The SES framework revealed multi-scalar feedbacks and drivers that otherwise likely would have been overlooked, and helped to understand at least some of the relationships that influence the resilience of complex systems. Each of the case studies revealed weak points in the SES that were either neglected or exacerbated by current management strategies, and which may undermine the long-term persistence of the SES, causing significant shifts in both landscapes and social groups. By analyzing each of the case studies as an SES, it was possible to determine how the ecological and social components of the systems were affecting each other. This allowed for an assessment of how the SES was being threatened, where adaptive capacity was low, and when resilience was breaking down, in essence revealing the weakest link in the chain of interactions and the point at which interventions should be made.

Unfortunately, the synthetic research that went into each of the case studies is rare in natural resource management, and indicates the need for a large amount of information in order to create sound policies and management prescriptions. Since it would likely be expensive and time consuming for any one agency or actor to gather all the necessary data individually, gathering together people from many different sectors of the SES to share information and collaborate on solutions may be the best way to detect threats and how they can be avoided. Research is needed on integrative metrics for cross-disciplinary projects, the on-the-ground impacts of social interactions and processes, the policy interventions that support resilience, and evaluating trade-offs and synergies.

One hurdle in the way of improving the management of rangeland SESs is the fact that regulatory policies are usually enacted on the premise that a problem is consistent across different times and places and that the policy will solve this problem when applied everywhere uniformly. Unfortunately, rangeland problems are rarely so consistent and neither are the agencies tasked with implementing government policy. The single agency, single policy type of policy implementation is an example of centralized governance. Centralized systems assume that all information can be routed through a single office and that solutions can come from that same office. In contrast, polycentric governance systems have multiple locations for collecting data and issuing and carrying out management actions. Polycentric governance models do not rely on a single solution to a perceived single problem, but rather seek to coordinate activities working toward a common goal.

Managers should aim to maximize the resilience of both the ecological and social elements of a desirable SES, which calls for favoring diversity and adaptability over maximizing yield and efficiency (Holling 1973; Holling and Meffe 1996). Given that rangeland managers typically have very limited control over the social components of range SESs, increasing participation and cooperation between managers, other invested actors, and the public to maximize information sharing, cooperation, and adaptive capacity of management activities would likely improve outcomes of rangeland SES management (Walker et al. 2004; Gunderson 2001; Olsson et al. 2006). Adaptive comanagement has become a common prescription for ecosystems and for SESs, and may include collaboration among agencies whose jurisdictions intersect in a particular SES, or participatory efforts with diverse stakeholders

(Stringer et al. 2006). Adaptive management also has relatively high information needs and institutional costs, making it difficult for many agencies to undertake (Jacobson et al. 2006). Increasing the involvement and number of stakeholders may improve monitoring of SESs and generate more viable alternatives and solutions, but it does not itself constitute a solution. Some stakeholders inevitably have more power than others in shaping how an SES functions.

Rangeland managers and policy makers would be well advised to keep the following points in mind when creating management plans for SESs:

1. Ecological diversity and redundancy of components are beneficial for resilience, and should be preserved through management activities. Feedbacks may support or weaken resilience. Undesirable states can also be resilient.
2. Stakeholders in any system are typically stratified throughout several hierarchical levels of geographical scale and legal authority. These hierarchical levels do not have the same motivations nor are they affected by the same processes. Interactions between them are complex.
3. All SESs are complex, and changes within them may be difficult or impossible to predict. Management plans should thus be adaptive, with changes contingent on consistent monitoring to guide both short- and long-term planning. Governance systems should likewise be adaptive, for similar reasons.
4. Uncertainty within the system can be minimized through the inclusion of all relevant stakeholders in the management process. Genuine inclusion implies that stakeholders have a chance to affect outcomes and receive benefits while acknowledging that authority and benefits are rarely shared equally and that action must usually be taken based on incomplete information and a lack of consensus. When successful, stakeholder inclusion increases information gathering and feedback and decreases uncooperative behavior and unpredicted behavioral change (Armitage et al. 2009).
5. SES research teams should include both social and ecological scientists. Unbalanced funding and emphasis can lessen the prospects for a successfully interactive project. Funding agencies need to emphasize this balance in granting programs.

The primary benefit of the SES framework is the improved ability to prevent or correct social policies that cause negative ecological outcomes, and to respond to ecological problems in ways that support, rather than hurt, social actors. By utilizing an SES analysis, rangeland managers and policy makers can create beneficial feedback loops such that society benefits from sustainable utilization of rangelands, and ecological objectives are met in ways that benefit livestock operators and the broader society. Managing solely for social or ecological objectives has a long history of unintended consequences, including ecosystem collapse and social unrest. While information intensive, conceptually complex, and logistically challenging in the management context, the SES framework can help overcome intractable challenges to working rangelands such as climate and land-use change.

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