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Articles

An Integrated Social, Economic, and Ecologic Conceptual (ISEEC) Framework for Considering Rangeland Sustainability

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Currently, there is no standard method to assess the complex systems in rangeland ecosystems. Decision makers need baselines to create a common language of current rangeland conditions and standards for continued rangeland assessment. The Sustainable Rangeland Roundtable (SRR), a group of private and public organizations and agencies, has created a forum to discuss rangeland sustainability and assessment. The SRR has worked to integrate social, economic, and ecological disciplines related to rangelands and has identified a standard set of indicators that can be used to assess rangeland sustainability. As part of this process, SRR has developed a two-tiered conceptual framework from a systems perspective to study the validity of indicators and the relationships among them. The first tier categorizes rangeland characteristics into four states. The second tier defines processes affecting these states through time and space. The framework clearly shows that the processes affect and are affected by each other.

Keywords ecological, economic and social indicators, rangeland, sustainability

The development of standard approaches to assessing sustainability in rangeland systems has led to the review and implementation of indicator programs designed to monitor trends in these landscapes. However, accurate implementation of indicator programs requires a thorough understanding of the interactions of ecosystem functions and processes in both the biophysical and socioeconomic subsystems. Praxis, the general art of applying conceptual frameworks to real-world concerns, frequently leads ecologists and social scientists to employ models dependent upon less-than-perfect empirical representations to describe highly complex systems. One legitimate employment of this process has been to portray applications of the concept of sustainable development. Sustainable development refers to the ability of a nation or state to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987).

Since 2001, representatives from conservation and commodity organizations, local, state, and federal agencies, universities, and tribal governments have been engaged in an ongoing program to identify, validate, and promote indicators of sustainable rangeland management. The group calls itself the Sustainable Rangelands Roundtable (SRR)[1] (Rowe et al. 2002). These indicators create a common language for reporting the status of rangelands and aid decision makers in allocating scarce financial and workforce resources to monitor rangeland conditions (Maczko et al. 2004). To validate selected indicators and examine the relationships between them, we, as a subgroup of SRR, produced a conceptual model called the Integrated Social, Economic, and Ecological Conceptual (ISEEC) framework, which is presented here.

Conceptual frameworks based on multiple disciplines can be built by applying disciplinary perspectives to a given subject or by focusing on a particular issue and determining how the disciplines can define the related processes. The ISEEC framework was created by focusing on rangelands and the social, economic and ecological forces that affect its condition. As a part of this process, the disciplines have shed their assumptions of system equilibrium, have dealt with the complexities of local conditions that may not be expressed at larger aggregations of analysis, and have grappled with understanding uneven temporal rates of change. Although these three disciplines are often isolated from each other, building the ISEEC framework has shown the remarkable similarity among the conceptual and methodological orientations of inquiry.

Integrating Ecology and Social Sciences with Sustainability

Holling et al. (2002) showed that issues associated with the complexity of sustainable development are not singularly limited to social, economic or ecological paradigms, but instead must be integrated across all three. Traditionally, however, attempts to integrate disciplinary paradigms have ended with one or more being shortchanged (Holling et al. 2002). Previous indicators of sustainability, such as maximum sustained yield or other measures of rangeland resources, have largely been based upon reductionist views. Traditional reductionist science seeks to break complex systems into constituent components and deal with them individually, often without referring to the whole system, and then establish principles based upon fixed cause and effect laws (Flood 1999). This approach to understanding nature tends to promote unidimensional, discipline-based thinking, which in effect makes disciplines separate elements of logic and often causes dislocation between the disciplines. If true, these fixed laws would tend to modify social behavior because the responses of natural systems would be predictable.

Analyses of dynamic natural and social systems, however, have shown reductionist approaches to be ineffective in articulating system complexities. As von Bertalanffy (1950) explained, the existence of an organism cannot be understood solely in terms of behavior of some fundamental parts; instead, a whole organism behaves in a way that is more than the sum of its parts—it exhibits synergy. To focus on only one aspect of rangeland use, management, and sustainability is to look at an incomplete picture. Thus, previous sustainability indicators have been inadequate because of the limitations and constraints of approaches such as reductionism (Coleman, Swift, and Mitchell 2004).

"Wholeness" must be viewed as the interrelatedness of events through both space and time, with an understanding that emergent self-organization is occurring that can lead to new states (Flood 1999). Integrated human and ecological systems are nonlinear and complex with unpredictable persistent states derived from multiple and interacting feedback loops (Costanza et al. 1993). The challenge of understanding whole ecosystems is seldom fully addressed and requires the integration of both ecological and socioeconomic factors. Key questions include: (a) How do the factors affect one another? (b) Are assumptions of interrelatedness valid? (c) Can a suite (or suites) of indicators be developed to meet those assumptions?

Ecological and social science conceptual frameworks emphasize explanations of change over time and space. There remains an ongoing debate regarding the driving forces of natural systems between supporters of equilibrium-based and non-equilibrium-based theory (Vetter 2005). Considerable rangelands research around the world continues to demonstrate the difficulty in recognizing equilibrium dynamics in complex systems such as rangelands (Wiens 1977; Connell and Sousa

1983; DeAngelis and Waterhouse 1987; Briske, Fuhlendorf, and Smeins 2003; Briske, Fuhlendorf, and Smeins 2006). The ecological sciences have focused significant efforts on explaining the processes by which natural systems progress from one state to another through the development of "state and transition" models (Westoby, Walker, and Noy-Meir 1989; Archer 1989; Laycock 1991). This concept, which challenges traditional perspectives of the directional progression of natural systems, states that the dynamics of natural systems are characterized by temporally persistent states separated by potentially rapid transitions. Traditional views hold that natural systems move toward some "climax" state in which perturbations only interrupt or temporarily reverse the rate of movement to an ultimate climax equilibrium (Dyksterhuis 1949).

A primary assumption guiding the process discussed here is that ecological and social systems (including markets) do not have inherent tendencies toward equilibrium. Consequently, understanding the causes and consequences of any change is contingent on recognizing both endogenous and exogenous conditions. An ancillary assumption is that change can, and likely will, be expressed unevenly over a given area of land. Therefore, geographic scale is an essential component of the ISEEC framework. It is also assumed that rangeland ecosystems and associated social systems do not necessarily return to their previous conditions following a perturbation. Moreover, it is assumed that different elements of a system may change at different rates, and changes can be continuous or punctuated in both time and space. Recognizing the nonlinearity of both natural and social systems, development of a conceptual framework to integrate across such systems must provide the flexibility to address change through both spatial and temporal scales.

Integration of ecological and socioeconomic processes through a conceptual framework also provides an avenue for addressing the concept of compensating feedback, the phenomenon where well-intentioned interventions result in system responses that can offset the benefits of the intervention (Senge 1990). Ultimately, the integration across disciplinary boundaries provides a systematic means for "seeing through the complexity to the underlying structures generating change" (Senge 1990). In essence, using a systems approach to develop the conceptual framework has provided a means not to ignore complexity (Holling, 2001), but instead to organize the complexity into a logical "story," as described next.

An Overview of the ISEEC Framework

Ecological systems and processes provide the biological interactions underlying ecosystem health and resilience. Socioeconomic infrastructures and processes provide the context in which rangeland use and management occur, and rangeland health and resilience shift. All these systems and processes interact and affect one another over time and space. Therefore, to adequately assess and monitor rangeland sustainability, integration of social, economic, and ecological perspectives is needed.

In the ISEEC framework, the world is categorized into four states: (1) current biophysical conditions, (2) natural resource capital, (3) social capacity and economic capital, and (4) current human condition (Figure 1). As indicated by the large downward arrows in Figure 1, the four states are acted upon by ecological and natural resource processes and by social and economic processes. The results of the various processes acting upon the states and conditions existing at time period$_0$ result in a modified set of states and conditions existing at time period$_1$. The ecological and

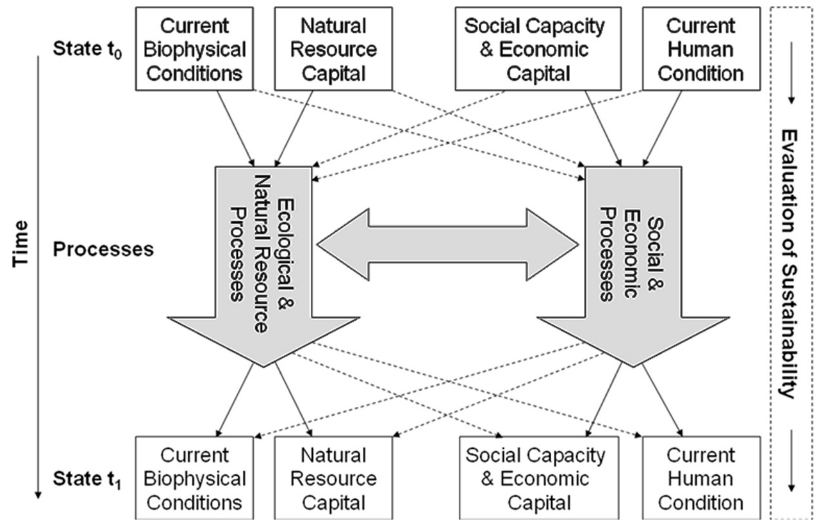

Figure 1. Tier 1 rangeland sustainability evaluation framework.

natural resource processes and the social and economic processes then act upon those modified states and conditions, resulting in new states and conditions in the next time period. The framework is intended to be dynamic and is accomplished by representing the ecosystem as a continuous series of states and conditions being acted upon by processes to create further modified states and conditions over time.

The oval in the center of the framework in Tier 2 (Figure 2) shows interaction between the ecological and socioeconomic subsystems. The framework asserts that

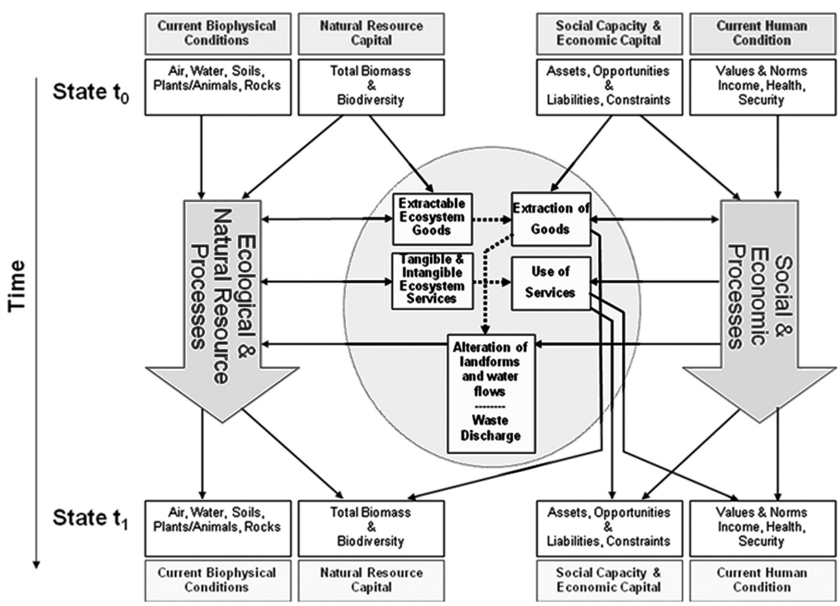

Figure 2. Tier 2 rangeland sustainability evaluation framework.

ecosystem services are the vehicle by which ecological and socioeconomic systems interact. Specifically, interactions occur by way of extraction of ecosystem goods, use of ecosystem services, waste discharge, and alteration of landforms and water flows.

"Ecosystem services" is a concept that is broadly accepted, although what compromises ecosystems services and how best to categorize them is debated (Daily et al. 1997; Millenium Ecosystem Assessment 2003; National Research Council 2005; and others). For this article, ecosystem services and their uses are considered to be the primary vehicle by which social and economic states and processes interact with ecological states and processes. As the debate and concepts evolve, the flexibility of the ISEEC framework will allow for the accommodation of refined knowledge. Regardless, ecosystem services remain a primary bridge between the ecological and socioeconomic sides of the framework.

In what follows we describe the state and condition boxes in practice. We briefly describe the ecological and natural resource processes and the social and economic processes. However, our primary focus is on the interactions between the biophysical and socioeconomic components of the framework.

States and Conditions in the ISEEC Framework

The four boxes shown at state t_0 and again at t_1 represent conditions existing at two different points in time. Two of the boxes at each state are labeled as types of "capital." Economists and sociologists emphasize the capacity to both organize and use existing resources to meet human needs over time. Certain aspects of these capacities are often referred to as "capital." Broadly, capital can be defined as assets that generate benefits and can include, but are not limited to, physical capital (buildings, machinery, roads, and communication systems), natural capital (stocks of natural resources that can be extracted or otherwise used by people), and human capital (the capacity of humans to realize their potential which is affected by age, health, knowledge, and skills among other factors). The concepts of social capacity can also be integrated into this line of thought.

Current Biophysical Conditions. These conditions include the state and status of all the biota comprising rangelands, as well as the environmental conditions that influence and are influenced by the biota—in other words, the rangeland ecosystem. It is determined by all of the biotic and abiotic components that constitute a particular rangeland, such as air and water quality, condition of the soil, and level of biodiversity in the rangeland ecosystem, among other things. *Natural resource capital* is the total biomass present in the ecosystem—both plants and animals. This represents the stock of resources existing in the biophysical environment.

Social Capacity and Economic Capital. Social capacity refers to the mixture of human capital and the capacity for social networks to maintain or transform social systems, which represents the opportunities and constraints afforded by the existing organization of society. Contained in this category are individual or community social and support networks and the institutional structures of society, including regulation and the educational, governance, legal, and market systems, as well as the inclusion of human populations. Economic capital represents the productive assets present in the economy. *Current human condition* as a category represents human well-being—the state and status of individuals, groups, and society. It includes cultural orientations associated with values and norms present in a society, as well as economic conditions, such as employment and unemployment, income distribution within society, and growth rate of the economy. The distribution of factors affecting societal well-being (e.g., population structures, educational status, wealth, quality of social interactions, and community cohesiveness and integration) can affect economic and social capacity to maintain or change a social system.

Processes in the ISEEC Framework

The processes represented in Figure 1 comprise the actions (or flows) taking place in the ecological and socioeconomic subsystems between states t_0 and t_1. For this article we define *process* to be a system of operation in the production of an output. For example, the process of nutrient cycling refers to the movement of an element or nutrient through the ecosystem from assimilation by organisms to release by decomposition; this process often produces biomass. Production of goods and services is a process on the social/economic side of the framework, as are governance and regulation, both of which affect the production process, as all three processes respond to norms and preferences expressed by society.

Biophysical and Natural Resource Processes

These processes represent functions that produce biomass, either through primary production via photosynthesis or through consumption and conversion to other biomass. They also include the variety of processes that continuously cycle finite biospheric elements via the carbon, water, and nutrient cycles. Such processes are performed or mediated by the rangeland biota, and they in turn set the conditions for the functioning of the biotic world. This cycling of matter results in some of the natural resource stocks present in the next period in time.

Other ecological processes include dynamics like succession, migration, adaptation, competition, and soil genesis/erosion; disturbances like flood, drought, and fire are also considered to be ecological processes within the framework. Ecological processes interact with and affect each other. The processes are driven and controlled by *current biophysical conditions*, and the outcomes become the *current biophysical conditions* in the next time period.

Ecological and natural resource processes are influenced and modified by various intentional human activities, such as the extraction of rangeland products (e.g., forage, other biomass, and water); alteration of landforms and water flows; and investment in management practices leading to such things as environmental mitigation and restoration. These processes are also influenced by intended and unintended consequences of human actions, like the release of waste products into the environment and careless behaviors.

Social and Economic Processes

Economic processes include demand, the production of goods and services, trading, investment, and consumption or use of goods and services. Production of goods and services is broadly defined, to include "household production" (such as meals, outdoor recreation, etc.) (Becker 1965, 1974; Lancaster 1966) as well as manufacturing processes. Social processes include management and social regulations that reflect social policies pertaining to the use and management of natural resources, for example, pollution standards or controlling invasive species (Cook et al. 2007). Demographic processes on the socioeconomic side of the framework include birth, migration, aging, and morbidity. Other social processes that affect the right-hand side of the framework include governance, education, and social integration and interaction versus stratification and social differentiation. These processes determine the organization of society. Taken together, all these processes result in *social capacity and economic capital* and *current human condition* at the next point in time.

Interactions Among Social, Economic, and Ecological States and Processes

Previous efforts to address natural resource sustainability have, with few exceptions (National Research Council 2005), failed to adequately consider both social and economic factors. Consideration of the dynamic two-way interactions between biophysical and socioeconomic factors and how these interactions affect sustainability is critical to a well-informed assessment of their sustainability. We envision three primary pathways of interaction: ecosystem goods and their extraction, tangible and intangible ecosystem services, and waste discharge and alterations of landforms and water flows.

Ecosystem Goods and Their Extraction

On rangelands, the traditional extraction that occurs is consumption of forage by livestock and wildlife. In addition, various plants are extracted for purposes such as fuel, construction materials, herbal and medicinal uses, and landscaping. Increasingly important is the extraction from rangeland ecosystems of water for irrigation and consumption. Such extracted ecosystem goods are demanded by people and enter into production processes for consumable, tradable, or otherwise usable goods and services, which then contribute to social capacity and economic capital or to the current human condition. Obviously, extraction also affects the stock of natural resource capital. By-products of extraction and the extraction process factor into the current biophysical conditions through mechanisms such as soil erosion and vegetation dynamics.

A more subtle form of extraction of ecosystem goods is related to recreation and "spiritual" or "aesthetic" goods. Natural environments produce goods that are extracted not as commodities but as experiential opportunities. Such extracted goods enhance the human condition by promoting experiences of wonder, majesty, and scenic beauty, or as a backdrop to life activities. They can also enter as inputs to a household production process and contribute to leisure and recreation activities. Such extractions have by-products that can affect, positively or adversely, the natural environment—appreciation may lead to protection or restoration; overuse may lead to degradation of habitat; and careless use may lead to wildfire or expansion of invasive species. This overlaps with the concepts of tangible and intangible ecosystem services.

Tangible and Intangible Ecosystem Services

Many ecosystem goods enter into our framework through extraction and productive processes; often they are more commodity-oriented. The focus of the *tangible and intangible ecosystem services* and *use of ecosystem services* boxes is to represent those services that do not explicitly enter by way of extraction and productive processes. These ecosystem services are used by humans, whether humans recognize it or not, and contribute to human well-being.

Ecosystem services refer to a wide range of conditions and processes through which natural ecosystems and their constituent species help sustain, support, and fulfill human life. These services can be tangible or intangible, but they are nevertheless critical for sustaining human well-being. Examples include trees and grasses cooling streets and buildings, forests reducing stormwater runoff, and lakes adding recreational opportunities and aesthetic amenities. Ecosystem services maintain biological diversity and support the production of ecosystem goods like forage, timber, biomass fuels, natural fibers, precursors to many pharmaceuticals and industrial products, and wildlife. Ecosystem services also support and enhance life through core ecosystem processes that help purify air and water, mitigate droughts and floods, generate soils and renew their fertility, detoxify and decompose wastes, pollinate crops and natural vegetation, control many agricultural pests, protect from the sun's ultraviolet rays, partially stabilize climate, and provide opportunities for recreation and leisure activities, aesthetic beauty, and intellectual stimulation (Daily et al. 1997).

Waste Discharge and Alteration of Landforms and Water Flows

Wastes are discharged into the ecosystem as byproducts of several processes, and they can have both positive and negative effects. For example, release of biosolids onto rangeland has been shown to increase primary production (Jurado and Wester 2001). By contrast, biosolids can have adverse effects on plants and aquatic biodiversity through acidic leaching, and nitrate losses can be problematic for maintaining water quality (Dalton and Brand-Hardy 2003).

Perhaps the greater effects of waste discharge, though, result from human use of biophysical goods and services. These include discharges from production and manufacturing processes, by-products of burning fossil fuels, and wastes resulting from consumption and use of goods and services (such as discarded packaging). Some of the wastes are recycled back into productive processes while others are discharged into the ecosystem. Released wastes are, in turn, acted upon by (or interrupt and otherwise alter) natural processes, and result in changed conditions of natural resource capital and current biophysical conditions.

A more subtle effect of human society that might be included in a broad conception of "waste discharge" is by-products of human behavior that adversely affect the environment. Besides the burning of fossil fuels and introduction and spread of exotic and invasive species, careless or malicious behaviors can also result in environmental or ecosystem damage. Such by-products of society affect both current biophysical conditions and natural resource capital.

Another way that humans and human behavior can directly affect rangeland ecosystems is by altering landforms and water flows. Some alterations have positive or neutral effects on the environment while others have negative effects. Increasing and migrating human populations encroach on rangeland, with land use changing from grazing and open space to subdivision and residential development (Mitchell, Knight, and Camp 2002). Results include habitat fragmentation and basic changes in the composition of species as development occurs, landscaping replaces native plants, and exotic and invasive species may be introduced and spread. Native wildlife species may become pests and nuisances, leading to their removal from parts of the ecosystem.

Completing the ISEEC Framework

Absent from the ISEEC framework, as discussed, is any notion of scale, either spatial or temporal. Rangeland ecosystems can be considered at multiple spatial scales. One might think in terms of a particular river basin or a single tributary. Alternatively, one could consider rangelands at the national or ranch scale, or anywhere in between.

Issues of scale become important when developing and collecting data about indicators of rangeland condition. While there is merit in being able to assess conditions at a national scale, the dynamics of some indicators are masked at higher levels of aggregation and only have meaning at finer grains. Some indicators are not associated with nested systems, so sampling and data aggregation will fail to capture the emergent properties of the entire system (Wright et al. 2002). Erosion, for example, is defined in terms of soil moving off a specified site. While this is clearly measurable at a site scale, soil might be moving from one site to another at the watershed scale with no net erosion occurring. Indicators for measuring soil erosion at these two scales would differ. In another example, changes in an empirical measure of fragmentation might be trivial at the global scale but critical at the local scale. Thus, indicators used to assess rangeland sustainability need to be evaluated in terms of the most appropriate scale for the question being asked.

This variation is also true for time scales. Life histories of various biota are highly diverse, so changes in elements contributing to natural resource capital occur with different frequencies, varying from weeks to decades. Different processes within the ISEEC framework will be affected at different points in time. In response to a particular stimulus, Process A might show a change in Period $t+1$ while Process B might not show a change until Period $t+5$, and Process C might show a response only in Period $t+20$.

The ISEEC framework is flexible in that it can be used in the context of different and multiple spatial scales and time horizons. It is also flexible in terms of the level of detail that can be considered. More detail can be incorporated into any of the states or processes represented in the ISEEC framework. In this way, the ISEEC framework provides an opportunity to "drill down" into any of the component parts to reveal more about the workings of particular states or processes. For example, the nutrient cycle can be understood at a broad level; nutrients are cycled and recycled as they are consumed and broken down by a variety of organisms and chemicals. For other purposes one may need to understand the details of how certain bacteria change nitrites back into nitrates, which are then usable by plants or animals. On the social–economic side of the framework, for some purposes it may suffice to know that people place a high value on a particular area of public land, but for other purposes it may be necessary to understand details about how that value would change in response to different management actions. Qualitative information, for example, could be collected to enhance understanding of a process, or relationships between processes, gained from quantitative studies. Such multi-methodological drilling down can be performed for any of the disciplinary-based boxes/arrows or to gain more detailed understanding of the relationships and interactions between ecological phenomena and socioeconomic phenomena.

Illustrating the ISEEC Framework Concept

To demonstrate how a natural disturbance or change in management might concurrently influence states and processes within the ecological and socioeconomic subsystems of the ISEEC framework, we use the example of an alien plant species, spotted knapweed (*Centaurea maculosa*), invading a rangeland ecosystem (Sheley et al. 1998). The perturbation can be considered at any scale—management unit, national forest, or even at the regional level (Pauchard, Alaback, and Edlund 2003). It can also be initiated as either a biophysical or a socioeconomic disruption: for example, an uncontrolled fire or extended drought versus a reduction in a county weed budget or a revised weed control regulation.

We start by assuming that spotted knapweed is introduced into the ecosystem under consideration. The species would first show up at time t_0 as an altered current biophysical condition, as manifested in the area of infestation of invasive plant species of concern. As knapweed populations expanded, their presence could be detected in changes in the population status and geographic range of rangeland-dependent species and the annual productivity of forage species (Watson and Renney 1974).

Changes in forage species composition would be expected to alter other basic ecological processes, including water flow, soil erosion, and stream sedimentation (Lacey et al. 1989). These in turn would lead to changes in ecosystem services like the number of wild animals and domestic livestock on rangeland, as well as scenic beauty (Hirsch and Leitch 1996).

When the status of ecosystem services is changed, so are the uses of ecosystem goods and services, subsequently modifying socioeconomic processes and conditions. These include the value of forage harvested from rangeland by livestock, rates of return on investment for range livestock enterprises, and expenditures for restoration activities. Use of ecosystem goods and services, in turn, impacts both current human condition and social capacity/economic capital at time t_1.

During the subsequent time period, t_1 to t_2, changes in management (Emery and Gross 2005) and social regulations could modify extraction processes, which would subsequently affect ecological processes on the left side of the framework and production, consumption, and use of ecosystem services on the socioeconomic side. Possible socioeconomic indicators responding to these dynamics might include sources of income from rangeland, livestock production, and employment diversity in rangeland-dependent counties (Haynes 2003), professional education and technical assistance opportunities for landowners, and funds expended for invasive species research (Lodge et al. 2006). The indicator parameters at time t_2 would then serve as initial conditions for the next framework iteration.

As this illustration shows, using the conceptual framework provides a mechanism for policymakers and research program leaders to derive strategies for management activities that incorporate an integrated understanding of the ecological, social, and economic factors modified by natural and human-caused system disturbances.

Conclusions

In their disciplinary-based research, sociologists, economists, and ecologists have traditionally assumed that systems from disciplines other than their own are given and constant. The reality is that systems are dynamic with heterogeneous rates of change for components. The ISEEC framework is an attempt to rigorously integrate the ecological component with the social and economic components of rangeland sustainability. Three primary pathways of interaction are suggested between social, economic, and ecological factors related to rangeland sustainability: (1) Human impacts on the state and status of the ecosystem are filtered through ecological processes, (2) ecosystem effects on the human condition are filtered through social and economic processes, and (3) ecosystem effects on the human condition flow through the use of ecosystem services.

As discussed in the introductory section of this article, the ISEEC framework had its roots in an effort to design an integrated system of indicators to assess rangeland sustainability. A system of indicators was designed, and it includes social, economic, and ecological-based indicators. The framework can be used to think about indicators and whether those proposed to date are complete or the best choices. More interestingly, the framework provides a context in which to think about how indicators affect and are affected by each other, and how ecological states and processes interact with social and economic states and processes. Much work remains to be done to characterize and empirically document those interactions. Considering ecosystem services and uses of ecosystem services to be the vehicle by which those interactions occur is a significant step toward understanding how ecological states and processes affect and are affected by social and economic states and processes.

While we do not claim that the conceptual framework presented here addresses all questions from previous efforts, it does provide a starting point for discussion among a wide range of researchers and practitioners to develop a more comprehensive, integrative framework for evaluating and monitoring rangeland sustainability, and while the ISEEC framework was developed in the context of rangeland sustainability, it can be generalized to address other ecosystem types. Finally, multidisciplinary endeavors that create the opportunity for practical and transdisciplinary conceptual frameworks are necessary. It is the hope and intension for SRR to build upon this model in ways that might engage the promises of transdisciplinary knowledge.

Note

1. For more information about the SRR, see its Web site at http://sustainablerangelands.warnercnr.colostate.edu

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