Sustainability Research for Rangelands

JOHN E. MITCHELL

Author is a rangeland scientist at the Rocky Mountain Research Station, Forest Service, USDA, in Fort Collins, Colorado 80526

Abstract

In the past, rangeland sustainability research and reporting focused upon condition and trend of range sites. Patterns like condition and trend estimated at local scales cannot be aggregated to the national level because processes existing at small scales often have no meaning at large scales. Scale refers to the extent relative to the grain of a variable within a space-time framework, and it is fundamental to hierarchy theory. Extent and grain limit the degree of data aggregation within nested hierarchies; aggregation in non-nested hierarchies is more difficult because the data do not capture the emergent properties of the broader system. SRM, the Ecological Society of America (ESA), and the Forest Service have led activities over the past decade to evaluate the scientific basis for sustainability. The ESA Sustainable Biosphere Initiative, begun in 1991, called for increased fundamental research in global change, biological diversity, and sustainability of ecological systems. ESA also conducted two forums on science and sustainability that underscored essential linkages among physical, biological, and socioeconomic systems, along with need to interface science and policy, in assessing sustainability. In 1993, the SRM Research Affairs Committee sponsored a symposium on research strategies for providing sustainability to a nation's rangelands. Among the goals enumerated in the symposium was the necessity to better understand societal values in relation to rangelands. The Rocky Mountain Research Station undertook an analysis of the 67 indicators of sustainable development of temperate forests included in the Montreal Process, and found most to be applicable to rangelands.

Introduction

The status of rangelands in the United States has long been of interest to the Congress and American people. Until two decades ago, however, perceptions of rangeland sustainability focused primarily upon range condition in relation to livestock grazing. Early scientists had documented that plant succession was an indicator of misuse (Sampson 1919), but a monitoring framework was not in place to document sustainable management. By 1934, our country was facing a grazing crisis on the public domain caused by drought, the depression, and conflicts between sheep and cattle interests that led to the first assessment of its rangelands. This assessment found that much of the U.S. public rangeland base outside of Forest Reserves, especially in the Southwest, was being persistently overgrazed. Nearly 600 million acres were estimated to be excessively eroding, thereby reducing soil productivity and watershed function. Nonetheless, the report stated that 99 percent of the western rangeland was "available" for livestock grazing (Secretary of Agriculture 1936). Three decades later, the Public Land Law Review Commission documented our country's continued interest in viewing rangeland use and sustainability primarily in terms of maximizing livestock grazing (Public Land Law Review Commission 1970).

In recent years, federal land management agencies and other organizations have started considering sustainability in terms of both amenity and commodity resources, involving ecological, economic, and social measures at multiple scales. This shift became socially acceptable, in part, when research demonstrated that future increases in demand for red meat could be largely met by private forage sources (Joyce 1989). At the same time, social scientists began to show how a region's sustainability must be linked to "communities of place" and the human, social, natural, and financial capital needed by these communities (Flora 1999).

The 1992 United Nations Conference on Environment and Development, held in Rio de Janeiro, first formalized the joint importance of environmental protection and economic and social development for achieving sustainability at a national scale (Johnson 1993). Specific criteria and indicators (C&I), founded on this triad, have been accepted for temperate and boreal forests through the Montreal Process (Coulombe 1995). C&I for rangelands are now being developed by the Sustainable Rangeland Roundtable (SRR). The purpose of this paper is to describe the research basis for discerning the sustainable management of U.S. rangelands.

Scale Issues

Dealing with issues of scale may be the central research-related problem associated with deriving C&I for sustainable rangeland management. When trying to incorporate multiple scales in relation to indicators of sustainability, it is important to understand principles of hierarchy theory. According to this theory, three important scale-dependent attributes of data are grain, extent, and frequency behavior. The threshold between the smallest discernable data features and those that are too small to be observed is known as the grain of an observation. For example, a 5-ha meadow cannot be distinguished using remotely sensed AVHRR data having a pixel size of 1 km^2. The threshold between the largest describable feature and those that are too big is called the extent of an observation. As Allen and Hoekstra (1992) said, “That is why one cannot conduct a full study of trees through a microscope.”

The cycle time of unperturbed behavior of a system is directly related to its level of organization. Thus, there is a continuum of natural frequencies from the top to the bottom of a hierarchy (see Fig. 1). An example of different natural frequencies would be the rapidity in which ecological sites can change their successional status in comparison to the slow changes vegetation undergoes at a national scale (Mitchell 2000). Such theoretical bases for scaling and integrating ecology makes it difficult, if not infeasible, to aggregate hierarchies from local to national levels.

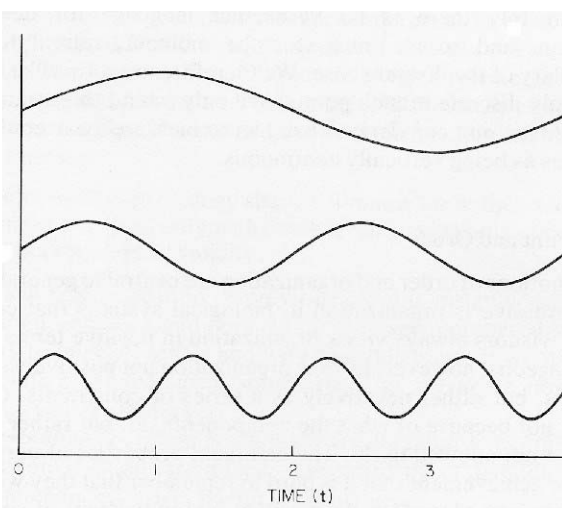

Figure 1. Relationship between systems scale and natural frequency distributions. Compare the relative changes of the lowest and highest scales between time 1 and time 3 (from Allen and Starr 1982).

Because of the importance of scale in developing and evaluating indicators of sustainable rangeland management, the SRR has created a Scale Working Group headed by Dr. Paul Geissler of the U.S. Geological Survey (see http://www.pwrc.usgs.gov/brd/srrscale.htm).

Biological Thresholds

Thresholds, or discontinuities, are manifested in a number of ecological indicators of forest and rangeland sustainability. The concept of thresholds declares that the state of an ecological system can change abruptly, and sometimes irreversibly, in response to a continuous and even change in some driving variable. Understanding threshold values adequately to relate them to sustainable management is difficult, at best, because of a number of uncertainties and limitations. Perhaps foremost, the delineation of a threshold depends upon the spatial and temporal scale in which it is considered (Levin 1992).

Ecological thresholds for ecosystem resilience and ecosystem function in response to biodiversity have been advanced by both theoreticians (May 1973) and scientists using empirical data (Tilman 1996). For example, the redundancy hypothesis maintains that ecosystems can lose a number of species because others will substitute for them as a result of niche overlap. However, at a certain point, the loss of another species can trigger a functional breakdown (Walker 1992). Tilman et al. (1997) later established that plant productivity and plant nitrogen are positively correlated with species diversity in a pattern consistent with this premise. A meta-analysis of 171 studies showed both non-linear and positive patterns between species richness and productivity to be more or less prevalent, depending upon scale (Mittelbach et al. 2001). However, no studies have verified a unmistakable discontinuity in ecosystem stability or function in relation to changing diversity, in part because the science of ecology is too complex to enable predictions of ecosystem-level outcomes of changing biodiversity. In addition, the idea of ecosystem resilience is imprecise as best, relating to two general concepts, the ability to recover to a pre-existing state following a disturbance and the ability to exist in the form of alternate ecosystem states (Grimm and Wissel 1997).

Ecosystem fragmentation has been studied at length in relation to biodiversity. Some authors have hypothesized a discontinuous correlation between these two variables, resulting in a threshold level of fragmentation, above which habitat suitability, and thus biodiversity, declines abruptly (Bascompte and Solé 1996).

Invasions by non-native plants are known to adversely affect both biodiversity and productive capacity at multiple scales (Vitousek et al. 1996). Whether a discontinuity or threshold mechanism applies to ecosystem responses to invasive species is not known; however, one would expect triggering nonlinear feedback mechanisms to be present (Gonzalez-Andujar and Hughes 2000). The interactions between alien annual grasses and fire constitute one well-documented altering ecosystem processes at local and, perhaps, regional levels (Young and Longland 1996). Their applicability to broader scales deserves investigation.

Sustainability as Expressed by Forms of Capital

In many ways, the concept of sustainable development and sustainable rangeland management at a national scale is tied to economic theory. Capital goods are entities existing in the present but which serve to provide a source of income or consumption opportunities in the future. In other words, capital has investment value. Capital has historically been considered in terms of goods and services having known market value, but recent advancements in ecological economics and sociology have led to consideration of other forms of capital, including natural capital and human/social capital (Flora 1999). Sustainability can be considered to be attained when the combination of all kinds of capital provide for the needs of present and future generations. An optimal level of sustainable development is achieved when no change in policy can make any group better off without causing another group to lose without just compensation, an economic condition called Pareto optimality. Regardless, one foundation of sustainability is that financial/built capital, natural capital, and human/community capital are all indispensable components.

The idea of substitutability represents a key provision for achieving and assessing the joint production of multiple forms of capital. A great deal of research has gone into both theoretical and applied aspects of substitutability. Collectively, economists have tended to stress the ability of markets to allocate resources efficiently, a process that requires a high degree of substitutability between natural and other forms of capital. Ecologists, alternatively, by and large contend that minimum thresholds of natural capital exist, and tradeoffs with financial/built capital become less and less feasible as risks of unsustainable, and potentially irreversible, outcomes from losing natural capital increase (Toman 1994). Unlimited substitutability is inclined to be viewed from an anthropocentric perspective while a total lack of substitutability is aligned with an ecocentric viewpoint. Some authors have called for those studying sustainable development to take a anthropogenic outlook, a more centrist condition where values of nature become overriding as they approach some minimum safe standard (Folke 1995). Thus, the notion of thresholds is not limited to biological criteria when it comes to considering sustainability.

Intergenerational equity comprises an crucial part of analyzing sustainability. The economics and social literature on this subject is long and complex, often including issues of fairness, ethics, and irreversibility. Authors have fiercely debated various discount rates and intergenerational social welfare functions (Vojnovic 1995). Ultimately, our understanding of equity is coupled to a hierarchy of social values and objectives, which in turn have purpose because of basic held values (Mitchell et al. 1995).

Previous Rangeland Sustainability Investigations

A number of research forums and reports concerning the sustainable management of rangelands have been conducted during the past decade. The Ecological Society of America's (ESA) Sustainable Biosphere Initiative (SBI) called for increases in basic research on sustainability of ecological systems to help improve the management of natural resources (Lubchenco et al. 1991). The SBI emphasized the importance of ecological knowledge in monitoring and evaluating ecosystems. It likewise recognized the importance of scale when it posed the same question facing the SRR Scale Working Group; that is, "How do patterns and processes at one spatial or temporal scale affect those at other scales?" Two national-level research items in the SBI are effects of changing land use patterns on ecological processes and feedbacks between ecosystem and atmospheric processes. Since it's establishment, SBI has served to fortify the link between science and policy through projects bringing together academics, agency representatives, local and tribal governments, and NGO's through various projects. Thus, ESA participation in the SRR falls logically within the purview of their SBI Project Office.

At least two forums on interrelations between environmental quality and economic growth have been published in *Ecological Applications*. The first forum (Ecological Applications 3:545-589), entitled "Science and Sustainability," was based upon a paper published in *Science* by Ludwig et al. (1993). Its contributors recognized that the term "sustainability" is not well understood, even though it has received a great deal of attention. What sustainability entails is the ability to manage ecosystems under uncertainty, while paying heed to the linkages among physical, biological, and socioeconomic systems, as well as to the juncture between science and policy.

The second forum (Ecological Applications 6:12-32) was entitled "Economic growth and environmental quality." It, too, was prompted by a prior article in *Science*, one that examined feedbacks between measures of these two variables (Arrow et al. 1995). The conclusion that economic growth always leads to a country's environmental improvement was seen as inconsistent, at best. Ecologists do not commonly understand economic concepts like substitutability, but ecologists generally maintain that basic ecosystem services (natural capital), such as clean air and water, decomposition of wastes, etc., cannot be considered as substitutable. Several authors acknowledged difficulties associated with using thresholds as ecological indicators of carrying capacity and ecosystem resilience (see section above). Research was seen as needed to obtain models and other information upon which thresholds and limits could be based.

In 1993, the Society for Range Management (SRM) held a symposium sponsored by its Research Affairs Committee (Vavra 1995). The symposium examined research strategies for providing sustainability to U.S. and other rangelands. Speakers suggested that scientists need to build upon past successes and involve the public in forging new research programs. Participants identified six goals for future work: provide water, develop efficient and environmentally compatible livestock grazing systems, maintain/enhance riparian and wetland systems, develop vegetation management schemes that ensure ecosystem integrity, provide quality wildlife habitat, and understand the needs and direction of society in relation to rangelands. The symposium did not address scale issues or C&I for sustainability.

At about the same period, another SRM committee reported upon its work for evaluating rangeland sustainability at the management unit level (Task Group on Unity in Concepts and Terminology 1995). The Task Group concentrated upon the importance of soil as the basic resource, and sought agreement among land management agencies in defining ecological sites and site conservation ratings (sustainable and unsustainable). In doing so, it highlighted the importance given to thresholds in appraising ecological sustainability; in this case, site conservation thresholds of ground cover, below which unacceptable soil erosion rates will occur. Erosion has also been deemed as an important indicator of soil and water conservation at a national level; however, it will be much more complex to assess (unpublished SRR notes).

Applicability of Montreal Process C&I to Rangelands

A meeting of Rocky Mountain Research Station scientists was held in October 1997. Its goal was to advise the Station Director on the status of rangeland monitoring and priorities for future research on this subject. The participants recommended a mechanism for doing so that tied the need for new knowledge about rangeland monitoring to the issue of sustainable rangeland management. They reached this conclusion, in part, because the Forest Service had already adopted the seven Montreal Process criteria and 67 indicators as the means for assessing the sustainable management of forests at a national level. As a result of the meeting, the Station Director asked a group of scientists to prepare a series of papers, one for each criteria, examining the applicability of the Montreal Process C&I to rangelands. The papers addressed the following questions:

1. Are the indicators developed for assessing sustainability of temperate and boreal forests applicable for rangelands? If so, which ones are most critical?
2. Are approaches and data available to assess, monitor, and integrate the indicators?
3. What research is needed to implement the Montreal Process C&I on rangelands?

The papers were to be written for a refereed journal, in order that assumptions and conclusions contained therein would be subject to peer review. They were subsequently accepted by *The International Journal of Sustainable Development and World Ecology*. Papers covering the first five criteria were published in 2000, and the last two are in press (Appendix A).

In general, the authors found all seven Montreal Process criteria to be essential for evaluating rangeland sustainable management at a national scale. Many of the indicators were considered very important, while a number do not seem to apply to rangelands as they do to forests; for example, economic indicators dealing with production, consumption, and employment have surrogates among the other six criteria or they are not nearly as vital from a macroeconomics perspective as for forests.

A number of research obstacles were identified in the Montreal Process papers. Many definitions were seen as ambiguous. Data and methodologies were judged to be inadequate. Work to clarify definitions, design and validate monitoring systems, and test critical assumptions will be necessary to implement a comprehensive framework of rangeland indicators, according to most of the authors.

Sustainability Science: A New Discipline

An internet-based Forum on Science and Technology for Sustainability has been initiated. The Forum considers sustainability science to be an emerging discipline having a purpose of understanding the nature of interactions between nature (ecology) and society (social and economic factors). It grew from discussions at the Friibergh Workshop on Sustainability Science, held in Őrsundsbro, Sweden on 11-14 October 2000 and is now managed as an activity of the Initiative on Science and Technology for Sustainability (see http://sustsci.harvard.edu/). Like ESA's SBI, the Initiative has goals of expanding the role of science in considering and achieving sustainability, as well as improving the connection between science and policy.

The framers of the Forum have envisioned seven core questions that must be taken up under the banner of sustainability science (Kates et al. 2001). Four of these core questions directly apply to goals of the SRR. They are: What determines the vulnerability or resilience of the nature-society system in particular kinds of places and for particular types of ecosystems and human livelihoods? Can scientifically meaningful "limits" or boundaries be parameterized that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation? How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability? How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning?

Conclusions

A number of common threads are woven among results from research directed at rangeland sustainable management. First, the concept of sustainable management or sustainable development is not precisely defined. However, broad agreement exists over its importance, and that the concept involves the confluence of biophysical, social, and economic elements.

Tenets of hierarchy theory are ingrained in sustainability research. Attributes and issues of scale have been a fundamental aspect of hierarchy theory. The scale of data, both spatially and temporally, must be consistent with the level and frequency dynamics of the system being monitored.

Understanding thresholds, although a key factor of several rangeland sustainability indicators, faces serious problems. The magnitude, sensitivity, and consequences of ecological and economic thresholds at a national scale are poorly understood.

Sustainability can be evaluated in the currency of human/social, natural, and financial/built capital. Taken collectively, assessments of sustainability will depend upon the values and perceptions of the beholder; therefore, no single "Dow Jones" of sustainable management can exist.

C&I for sustainable rangeland management fit within the larger R&D framework for monitoring rangelands by facilitating advances in national monitoring systems, thus promoting a feedback mechanism between monitoring and assessments.

Literature Cited

Allen, T.F.H., and Thomas W. Hoekstra. 1992. Toward a unified ecology. Columbia University Press, New York, NY.

Allen T.F.H., and Thomas B. Starr. 1982. Hierarchy: perspectives in ecological complexity. The University of Chicago Press, Chicago, IL.

Arrow, Kenneth, Bert Bolin, Robert Costanza, Partha Dasgupta, Carl Folke, C.S. Holling, Bengt-Owen Jansson, Simon Levin, Karl-Göran Mäler, Charles Perrings, and David Pimentel. 1995. Economic growth, carrying capacity, and the environment. Science 268:520-521.

Bascompte, J., and R.V. Solé. 1996. Habitat fragmentation and extinction thresholds in spatially explicit models. Journal of Animal Ecology 65:465-473.

Coulombe, Mary J. 1995. Sustaining the world's forests: the Santiago Agreement. Journal of Forestry 93(4):18-21.

Flora, Cornelia Butler. 1999. Sustainability of human communities in prairie grasslands. Great Plains Research 9:397-419.

Folke, Carl. 1995. Ecologists and economists can find common ground. BioScience 45:283-284.

Gonzalez-Andujar, J.L., and G. Hughes. 2000. Complex dynamics in weed populations. Functional Ecology 14:524-526.

Grimm, V., and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. Oecologia 109:323-334.

Johnson, Stanley P. 1993. The earth summit: The United Nations Conference on Environment and Development (UNCED). International Environmental Law & Policy Series. Graham & Trotman, Ltd., London, United Kingdom.

Joyce, Linda A. 1989. An analysis of the range forage situation in the United States: 1989-2040. Gen. Tech. Rep. RM-180. Rocky Mountain Research Station, Fort Collins, CO.

Kates, Robert W. and 22 others. 2001. Sustainability science. Science 292:641-642.

Levin, Simon A. 1992. The problem of pattern and scale in ecology. Ecology 73:1943-1967.

Lubchenco, Jane, and 15 others. 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72:371-412.

Ludwig, Donald, Ray Hilborn, and Carl Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17, 36.

May, Robert M. 1973. Stability and complexity in model ecosystems. Monographs in Population Biology 6. 2nd ed. Princeton University Press, Princeton, NJ.

Mitchell, John E. 2000. Rangeland resource trends in the United States: a technical document supporting the 2000 USDA Forest Service RPA Assessment. Gen. Tech. Rep. RMRS-GTR-68. Rocky Mountain Research Station, Fort Collins, CO.

Mitchell, John E., Deborah J. Shields, and Larry R. Rittenhouse. 1995. A hierarchical model of ecosystem management, p.322-342. In: Joyce Elma Thompson [compiler]. Analysis in support of ecosystem management. USDA Forest Service, Ecosystem Management Analysis Center, Washington, DC.

Mittelbach, Gary G., and 8 others. 2001. What is the observed relationship between species richness and productivity? Ecology 82:2381-2396.

Public Land Law Review Commission. 1970. One third of the Nation's land: a report to the President and to the Congress by the Public Land Law Review Commission. Superintendent of Documents, Washington, DC.

Sampson, A.W. 1919. Plant succession in relation to range management. U.S. Dep. Agr. Bull. 791. Washington, DC.

Secretary of Agriculture. 1936. The western range. Senate Document 199. U.S. Government Printing Office, Washington, DC.

Task Group on Unity in Concepts and Terminology. 1995. Evaluating rangeland sustainability: the evolving technology. Rangelands 17:85-92.

Tilman, David. 1996. Biodiversity: population versus ecosystem stability. Ecology 72:350-363.

Tilman, David, Johannes Knops, David Wedin, Peter Reich, Mark Ritchie, and Evan Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. Science 277:1300-1302.

Toman, Michael A. 1994. Economics and "sustainability": balancing trade-offs and imperatives. Land Economics 70:399-413.

Vavra, Martin [ed.]. 1995. Rangeland research: strategies for providing sustainability and stewardship to the rangelands of America and the world. Rangelands 17:199-214.

Vitousek, Peter M., Carla M. D'Antonio, Lloyd L. Loope, and Randy Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468-478.

Walker, Brian H. 1992. Biodiversity and ecological redundancy. Conservation Biol. 6:18-23.

Vojnovic, Igor. 1995. Intergenerational and intragenerational equity requirements for sustainability. Environmental Conservation 22:223-228.

Young, James A., and William S. Longland. 1996. Impact of alien plants on Great Basin rangelands. Weed Technology 10:384-391.

Appendix A: Papers published by Rocky Mountain Research Station scientists evaluating the applicability of Montreal Process criteria and indicators to rangelands.

Mitchell, J.E., and L.A. Joyce. 2000. Applicability of Montreal Process biological and abiotic indicators to rangeland sustainability: introduction. Int. J. Sust. Dev. World Ecol. 7:77-80.

Flather, C.H., and Carolyn Hull Sieg. 2000. Applicability of Montreal Process criterion 1 – conservation of biological diversity – to rangeland sustainability. Int. J. Sust. Dev. World Ecol. 7:81-96.

McArthur, E.D., S.G. Kitchen, D.W. Uresk, and J.E. Mitchell. 2000. Applicability of Montreal Process criterion 2 – productive capacity – to rangeland sustainability. Int. J. Sust. Dev. World Ecol. 7:97-106.

Joyce, L.A., J.E. Mitchell, and S.R. Loftin. 2000. Applicability of Montreal Process criterion 3 – maintenance of ecosystem health – to rangelands. Int. J. Sust. Dev. World Ecol. 7:107-127.

Neary, D.G., W.P. Clary, and T.W. Brown, Jr. 2000. Applicability of Montreal Process criterion 4 – soil and water conservation – to rangeland sustainability. Int. J. Sust. Dev. World Ecol. 7:128-137.

Joyce, L.A. 2000. Applicability of Montreal Process criterion 5 – maintenance of rangeland contribution to global carbon cycles. Int. J. Sust. Dev. World Ecol. 7:138-149.

Mitchell, J.E., and A. Hill. 2002. Social, economic and legal indicators for the sustainable management of rangelands. Int. J. Sust. Dev. World Ecol. (in press)

Shields, Deborah, and E.T. Bartlett. 2002. Applicability of Montreal Process criterion 6 – long-term socio-economic benefits – to rangeland sustainability. Int. J. Sust. Dev. World Ecol. (in press).

Woodmansee, R.G., and J.E. Mitchell. 2002. Applicability of Montreal Process criterion 7 – legal, institutional and economic framework – to rangeland sustainability. Int. J. Sust. Dev. World Ecol. (in press).