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# Rangeland ecology and management in a changing world

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**Key points:** Rangeland ecological science and management over the past century has emphasized external human actions to supplement and direct natural ecological processes in the hope of achieving sustained production. The focus has usually been on an improved efficiency of production, generally achieved by adding fossil fuel based inputs, to increase consistency of harvest. The results have been relatively benign in the more mesic and fertile rangelands and unsuccessful to disastrous in the more arid and infertile areas. We suggest a broader view of the interactions of humans and rangelands, one that includes people as a vital component within the system, might be a more realistic approach to achieving economic, ecological and social sustainability. An increased emphasis is necessary to develop new tools for capturing, organizing and communicating information and to provide testable hypotheses that can advance rangeland ecological science and management.

**Key words:** ecological site descriptions, state and transition models, multiscale management, ecological disturbance

**The ecology of rangelands: people are really important** Rangelands are often defined as any lands that are not considered arable or forest, and capable of providing support for human well-being from the native or naturalized vegetation (SRM 1989). Estimates of the global extent of rangelands generally range from 60% ~75% of total land area, with occurrence on every continent other than Antarctica. Although definitions and inventory procedures vary somewhat, several aspects of the ecology of rangelands emerge.

All rangelands, both by their nature and our definition, are managed. Regardless of the broader context of social and economic system within which they exist, there are no rangelands beyond influence by human decisions. Even in seemingly remote areas where it may be difficult to detect direct human influence, the historical impact, as well as the current influence on the global climate and atmospheric chemistry, link people and rangelands inextricably. Thus, the concept of pristine' may be academically interesting, but is of little use to people in inventorying, planning and assessing rangelands.

Rangelands, in addition to the managerial definition, are also defined functionally by their limitations, generally low and/or erratic rainfall, infertile or rocky soils, difficult topography or inaccessibility. These limitations are important because they define what we can expect from rangelands. Too often, these limitations are ignored and humans suffer because of it. From a management perspective, the greater and more varied the limitations, the more unlikely rangelands are to respond to inputs, especially those based on increasingly expensive fossil fuels. The history of rangeland science and management is littered with schemes predicated on the erroneous belief that these limitations could be overcome with enough inputs, either management or fossil-fuel based.

Three related themes emerge as the critical elements in the ecology of extant rangelands and, it should follow, in the conduct of research and management. First is the realization, acknowledgement, acceptance and integration into research, development and management of the idea that human actions, regardless of their motivations, result in the disturbance of rangelands (Archer and Stokes 2000). These new disturbance regimes are not recreations of natural' disturbance regimes, but are wholly human in their origin and effects. Regardless of how closely anthropogenic disturbance regimes try to mimic our perceptions of nature, they are limited both by our ability to interpret nature and by our ability to recreate what we have interpreted. Regardless of intention, these new disturbance regimes do have a similar effect as natural regimes in that they govern the rate and magnitude of ecological processes that drive ecosystem behavior and determine the array of goods and services that can be extracted.

Second, rangeland management is a multiscale endeavor, and understanding and management at the landscape and regional scales are just as important as what occurs at the community scale (Pringle and Tinley 2003). Multi scale complexity, a product of the interactions of geology, climate, past and present vegetation, as well as current and historic management also contribute to the unique ecology of rangelands. Although this complexity could logically be included among the many limitations of rangelands, it is also very much a defining factor in developing strategies for extracting rangeland ecosystem services. Croplands and forests are largely homogenized at mesoscales (ha to $km^2$) by human inputs. At the more mesic and fertile end of the scale, potential returns warrant investments to enhance the mesoscale homogeneity of rangeland plant communities, but often at the expense of ecological functions at more extensive scales. For the arid and semi arid rangelands that are most common around the world an emphasis on homogeneity becomes not only counterproductive, but wholly unrealistic. Because of the wider range of interests that have emerged in rangeland goods and services and new tools that are available for study, our understanding of cross-scale ecological processes has taken on greater importance (Havstad et al 2007).

Finally, it is clear that while ecology may be at the core, rangeland science encompasses many disciplines, among them agronomy, geology, animal science, soil science, economics, wildlife science, rural and urban sociology, anthropology and forestry . Emerging fields are those that consider society's involvement in the management of rangelands , from both a policy and a human dimension standpoint . Among the most important of these may be geography , both cultural and physical . Clearly , how scientists provide information to assist in decision making and how managers use that information in the future will be determined how well our profession can integrate and apply varied physical , social and economic aspects of the ecology of rangelands . In the end , without application we are left without relevance (Reynolds et al . ,2003) .

**The ecological basis for rangeland R & D : the world is our plot** Given the extensive human use and reliance on rangelands globally , it would be illogical to view rangelands as anything other than human manipulated systems . However , it would also be mistaken to assume that rangelands can be intensively managed like croplands and forestlands . For better or worse , the condition of rangelands will be determined by how well humans indirectly manage and/or impact ecological processes . Thus , research and development to benefit rangelands must be focused on the interactions of humans and rangeland ecological processes . From a research and development perspective , the impact of humans on rangelands is best viewed in a framework of ecological disturbance . For the first century of rangeland research , scientists focused their attention on the orderly progression of plant communities through time from post disturbance simplicity to the increasing complexity associated with lack of disturbance . Disturbance (fire , overgrazing , frequent or severe drought) may have caused dramatic alterations but the change was reversible once the disturbance was removed . Disturbances were viewed as degrading to ecosystem processes and protection from disturbance allowed processes to return to a normal , stable range . In essence , anthropogenic disturbance was viewed as external to rangeland ecosystems and human decision making was relegated to the narrow framework of how to best simulate nature . Through a combination of observation and experimentation , ecosystem processes have been shown to exhibit much more complexity than simple linear succession (Vavra and Brown 2006) .

Just as important as the human imposition of new and novel disturbances is the human influence on existing disturbance regimes . For decades , rangeland research pursued the elusive goal of stabilizing productivity through the application of a combination of fossil-fuel based (fertilizer , herbicide , reseeding , fencing , water developments , supplements) and management (rotational grazing , herding , distribution) . These novel , anthropogenic disturbance regimes were intended to enhance efficiencies by stabilizing species composition to favor forage species , enhancing forage production and to improve harvest . In the more mesic , fertile rangelands , these technologies were relatively successful . But in the more arid and infertile ecosystems , which encompasses the bulk of the world's rangelands , the attempts to stabilize production of livestock products generally resulted in degradation , loss of stability and ultimately , reconfiguration of ecosystems in less desirable states (Brown and Ash 1996) .

Understanding how disturbances change landscapes , either in a positive , stabilizing or negative direction is the challenge for scientists studying rangeland ecology . During the last 20 years , the development of non-equilibrium theory that defines plant succession over time as a series of multiple states that change (transition) in response to disturbance and may cross a threshold that represents irreversible change from a human timescale , has provided insight into the drivers , patterns , extent and limits of change observed over the past 50 to 100 years . While there are always exciting new techniques and methodologies for investigating the effects of disturbances on ecological processes , it is the context and interpretation of existing information and emerging tools for the use of that information that will determine our success in managing rangelands for human well-being .

**The ecological basis for rangeland management : tools to organize knowledge** While scientists would like to believe that their current experiments will dramatically alter the management of rangelands , the reality is that rangeland management for the next twenty years will most likely be a reflection of what is in the existing literature today . There are numerous examples throughout the history of ecology and rangeland science that support this assertion , and there is little evidence that any emerging idea or technology is going to dramatically shorten that time lag . So , our greatest challenge is how do we take what we already (think we) know and organize disparate , and sometimes conflicting , sources of information into a transparent , credible and flexible decision making framework .

Ecological Site Descriptions (ESDs) and their key component , State and Transition Models (STMs) are a relatively new technology for land management decision making (USDA NRCS 2003) . ESDs are composed of four main parts :

- Physical setting-the soils , landscapes and climatic conditions for each ESD . This section tells the user how to determine which ecological site they are on .
- State and Transition Model for soil and vegetation dynamics .
- Interpretations for specific land uses-this section describes the values associated with each state .
- Supporting information-contacts , literature , anecdotal observations , historical records , comment opportunity for on-line applications .

ESDs are based on soils , not on existing vegetation , and reflect the strengths and weaknesses of any given soil mapping protocol . Because any particular soil (however narrowly defined) includes an assumed distribution of properties that have important effects on vegetation behavior , a soil may be associated with a similar range of vegetation attributes . We know that the climatic , soil , vegetation and animal components of sites vary widely in their properties across their range of occurrence as individual attributes and have significant and complex interactions . These properties and interactions should be viewed as a distribution function rather than as an average. Regardless of the scale of mapping, soil map units are generally associations of distinct soils. Typically several soil mapping units are combined into a site assuming the climatic and soil properties and the vegetation behavior and animal impacts are similar. Vegetation assemblages on any particular soil also reflect disturbance and short term climatic fluctuations. Thus, however it is defined, a rangeland soil may be occupied by a relatively wide variety of vegetation communities and present managers a confusing array of choices. ESDs can be used to display and explain those dynamics within the context of management decisions. ESDs, due to the nature of rangeland ecosystems, must include a relatively wide range of variability in any given soil or vegetation property. While they lack the illusion of precision of narrowly defined mathematical models, they have the flexibility necessary to accommodate uncertainty associated with complex ecosystems and multiple land management objectives.

While ESDs have tremendous potential as a land management decision making tool, they are only as good as the information contained in them. The core component of an ESD is a State and Transition Model (STM) that describes soil/vegetation dynamics in response to climate and management (Figure 1). States are relatively broad groupings of plant communities possessing similar ecological function and structure. Transitions are the trajectories between states that contain a threshold. Generally, moving between states, whether by design or unintended consequence, requires a substantial event (drought, fire) that alters ecological processes and cannot be reversed by managerial responses once it is breached. Plant communities and pathways occur within any individual state and are generally regarded as being amenable to relatively common management actions or climatic fluctuations.

While they can accommodate information derived from virtually any theoretical or empirical interpretation of community scale change in rangeland ecosystems, they are most identified as a way to capture dynamics associated with rangelands not at equilibrium. As a nonequilibrium approach to vegetation dynamics supplanted the climax approach in the late 1980s, a new conceptual model for rangeland management applications was required (Westoby et al., 1989). STMs were first proposed in the late 1980s and have been extensively applied to rangeland situations throughout the world. In many ecosystems, vegetation dynamics do not follow a linear path following disturbance. This so-called classical succession model (e.g. disturbance>forbs >annual grasses>perennial grasses>shrubs>trees) may be partially adequate for some systems, but in many cases the varying nature of disturbance and recovery processes result in multiple stable states. In these systems, a transition between states is not an autogenic (self contained) process, but one which requires active management, such as mechanical or chemical inputs. Key elements in this approach are the concepts of resistance and resilience. In many arid land systems, STMs have been expanded to include soil/plant interactions that are central to the resistance and resilience characteristics of any ecological site.

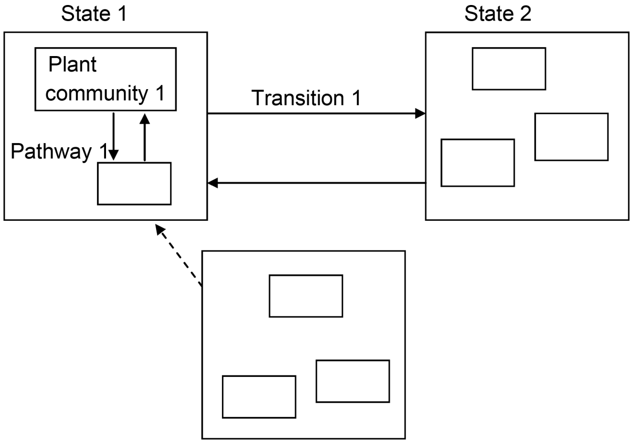

**Figure 1** *A generic state and transition model for a rangeland plant community showing the relationship among states, transitions, communities and pathways. Plant Communities and Pathways occur with States. States contain thresholds that are generally regarded as irreversible by standard management actions. Dotted line transitions have not been demonstrated to exist.*

Essentially, STMs regard anthropogenic disturbance and management responses as part of the system rather than as external to the system. States are used to describe the general configurations that a particular plant community may assume (i.e. short grass vs shrub-dominated) and the associated soil and vegetation attributes. Transitions describe the trajectories of change between states. These descriptions include climatic, natural disturbances and management associated with the change and the probabilities that each of these combinations may occur. Particularly useful is the identification of climatic events that may facilitate the successful application of a management response. Land management using STMs is a fairly logical process of inventory (what is the current state?), planning (what is the desired state?), implementation (applying management under appropriate circumstances) to achieve (or avoid) the change and monitoring (are the actions having the desired consequence ?) .

In early applications , STMs have greatly improved communications among land managers , scientists and the interested public . Scientists have used STMs to illustrate to land managers where research fits in the context of land management and the importance of understanding ecological processes . Land managers have used STMs to frame their problems for scientists and to better explain decisions to the interested public and funding bodies . Constructing STMs is an iterative process . By far the most important input is expertise , whether it is experimental or management based . Many ecosystems have been the subject of extensive and exhaustive investigation , but on-the-ground experience is critical for interpreting the information in management terms . There is no single mathematical model underlying STMs , but many STMs have been constructed based on model outputs , experimental results and observations . The definition of the poorly known is as important as the elucidation of the well-known (Bestelmeyer et al ., 2004) .

A challenge in developing , implementing and testing STMs is the availability of information . For the most part , rangeland ecosystems are well researched from a production standpoint , but poorly understood from an ecological dynamics perspective . Of even greater concern is the behavior of ecological systems in the face of novel climates , species introductions and uses . Obviously , it is impossible to have statistically valid experiments to support every state , transitions and pathway for every ESD that can predict outcomes of as yet unknown disturbance regimes . Thus , interactions and communications among researchers and users are critical in identifying key questions and conditions upon which to build a system of STMs and ESDs . Much effort has been expended , with much more likely to come in the definition of thresholds , a key point in the transition from one state to another (Briske et al 2005) . The tendency toward reductionism among scientists can be very misleading and counterproductive in this instance . A general description of an important threshold is completely adequate to provide managers with the information necessary to make critical decisions . The pursuit of precision in defining a threshold for a very narrow site and vegetation combination can waste limited time and resources and create a false sense of security among managers . The more the illusion of precision in the definition of a threshold , the more likely managers are to push the limits of resilience in rangeland ecosystems in the name of enhancing production efficiency .

**Conclusions** Ecology as a science is relevant to rangeland management only as it can be applied to the improvement of decision making and implementation . Resource professionals and the organizations they work for possess two kinds of information critical for making good resource management decisions : data and knowledge . Our challenge in the coming decade is to organize these sources of information and put them into a format that is accessible and interactive so that they can be used most effectively . We use knowledge to make decisions , including the design of experiments to generate new data . The difficulty comes when we attempt to use knowledge to fill in missing data without the benefit of scientific experiments and fail to identify it as such . We also have to seriously consider how we package" the knowledge . We often make assumptions , often without good understanding of the end user , who must also perform their own synthesis .

Another element in successful information management is making the information available to users . We have a variety of users ranging from people trying to make decisions about managing a particular piece of land to public interest groups trying to make inferences about the state of the land in general to scientists trying to determine what we know and how to generate new information to expand that understanding . While our information has always been available to anyone interested in it , the internet has dramatically changed accessibility . Before , people had to know enough to ask for a particular piece of information , now they need only know a few keywords to run a search engine and have the fortitude to find the relevant data within the often lengthy results of that search . It is not unusual for people to find information and not know how to use it (data without knowledge) . It is also common for people to find opinion (disguised as knowledge) and have no idea of the validity of the data that supports it .

ESD information can be very complex and , in many cases , difficult to understand . We cannot change that by dumbing it down . However , using a structured context for accessing that information and clearly defining what the information means and where it came from can increase its utility at all levels . In the end , ESDs have the potential to capture information applicable to all 3 of the critical themes of rangeland ecology . These descriptions reflect our understanding of the impacts of disturbances , they provide a basis for scaling our actions from a thorough understanding of a central scale , and they provide a framework for housing information that then can be accessed for a multitude of applications . In this fashion , we have a means where we can meld ecology and management , and actually practice resource conservation .

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