International Grassland Congress Proceedings

21st International Grassland Congress / 8th International Rangeland Congress

Information Technologies for Rangeland Monitoring: What Do They Need to Address?

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The 21st International Grassland Congress / 8th International Rangeland Congress took place in Hohhot, China from June 29 through July 5, 2008.

Proceedings edited by Organizing Committee of 2008 IGC/IRC Conference

Published by Guangdong People's Publishing House

Information technologies for rangeland monitoring : what do they need to address ?

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Key points : We advocate that the success of rangeland monitoring can be enhanced with the development of a more encompassing conceptual framework , in addition to greater technological capacity . Important conceptual constraints include ambiguous monitoring goals , minimal integration of scientific , professional and local knowledge , the inability to address multiple ecological scales , and the absence of comprehensive monitoring-management-policy networks . Ecological resilience is proposed as a platform to integrate the complexity of social and biophysical systems and to link local , professional and scientific knowledge sources . We outline the components of a comprehensive monitoring framework that is based on a mutual commitment to collaborative learning and action among multiple stakeholders to promote social-ecological resilience .

Key words : ecological resilience , knowledge sources , rangeland management , social-ecological systems

Introduction

Global rangelands are characterized by diverse ecosystems that represent 40% of Earth's land area . The extent and diversity of global rangelands provide numerous ecosystem services to human societies (e .g . , climate regulation , biodiversity , as well as food , fiber and water) (Havstad et al . , 2007) . Therefore , the sustainability and continued provisioning of these services in response to natural and anthropogenic disturbances is of major concern . Monitoring is required to document and anticipate ecosystem responses to various disturbances , direct management actions , and promote wise stewardship . The ability to anticipate pending ecosystem change provides the greatest opportunity for adaptive management to direct and manage change , rather than merely respond to it (Folke 2006) . Although the importance of monitoring is widely recognized and numerous protocols exist , the rangeland profession is currently in the process of designing and implementing a modified set of monitoring protocols to provide broader ecosystem assessments and more directly address the contemporary needs and expectations of society .

The major components of effective rangeland monitoring have been well defined and they include the following (Western 2003) .

1 . Possess the capacity to scale from local to landscape and regional levels to encompass the complexity of human-dominated systems .
2 . Expand beyond conventional measures of vegetation composition and soil surface characteristics to more comprehensive assessments of ecosystem services and human activities .
3 . Continue to refine models of ecosystem function to encompass the realities of complex , open and adaptive systems dominated by human activity .
4 . Recognize and address multiple stakeholder groups , including cultural , socio-economic and governance considerations .

Even though there is wide recognition and general support for the inclusion of these monitoring components , implementation is complex and variously constrained by numerous issues including , land ownership and use patterns , ineffective assessments of monitoring success , and limited stakeholder participation . Taken to its logical conclusion , the recommended components of effective monitoring encompasses an unique approach to rangeland management that represents a radical departure from the prevailing command and control structure that has dominated natural resource management since the middle of the last century (Holling 1996 ; Reynolds et al . , 2007) .

Our approach to this pivotal , but daunting challenge is to provide a broad conceptual framework for organizing and implementing the recognized components of effective rangeland monitoring . This approach is based on the premise that the limited success of previous monitoring protocols has been a consequence of inadequate conceptual constructs , in addition to insufficient technical capacity . The most important conceptual constraints include broad and ambiguous monitoring goals , minimal integration of scientific , professional and local knowledge , the inability to address multiple ecological scales , and the absence of comprehensive monitoring-management-policy networks . The paper concludes with a brief conceptual framework describing how these critical monitoring components can be organized and implemented to assess the resilience of social-ecological systems .

Significance of Monitoring Goals and Protocols

Monitoring protocols are required to define the status or condition of specific biotic groups or entire ecosystems in response to stresses and disturbances (Dale and Beyeler 2001) . Ecological indicators represent key variables that are assumed or have been demonstrated to provide information about ecosystem attributes and processes that are relevant to managers , but that are difficult to assess directly .

Attributes of effective ecological indicators for inclusion in monitoring protocols include :

1 .Easily implemented , cost-effective and provide relevant information to various stakeholders .
2 .Provide anticipatory information about ecological processes that can inform management actions .
3 .Predictable and responsive to single or multiple stresses and disturbances placed on ecosystems .
4 .Applicable or adaptable to a broad range of climatic , soil and vegetation variation and over a wide range of ecological scales (Dale and Beyeler 2001) .

However , monitoring is often implemented with ambiguous goals that make little provision for scale of assessment and mutiple stakeholder interests (e .g . management unit , regional and national assessments) . This makes it difficult to address specific stakeholder concerns , determine monitoring success , and modify protocols to more effectively address various objectives . The development of explicit monitoring goals should begin with a rigorous , objective reevaluation of current goals with the best local , professional , and scientific knowledge available . Even well-designed and implemented monitoring protocols will not contribute to effective rangeland stewardship if they are not focused on the appropriate goals or issues . This reevaluation of monitoring goals has been prompted by both an advance in ecological knowledge and a modification of societal expectations of the services derived from rangelands . The implementation of ambiguous monitoring protocols produces a high probability of failure because of a potential mismatch between monitoring goals and the specific assessments employed . We argue that additional integration of multiple knowledge sources and greater participation of various stakeholder groups will enhance both the relevance and success of rangeland monitoring .

Multiple Knowledge Sources

Previous monitoring efforts have been constrained by not only the complexity of biophysical systems and diverse stakeholder groups , but also by multiple knowledge sources that influence management decisions (Burns et al ., 2006) . We recognize three broad knowledge sources that influence decision making on rangelands . First , local knowledge refers to experiential knowledge that is developed from direct interaction with the land , often to provide a source of livelihood , that is transferred between generations and among members of a community . Second , professional (i .e ., expert) knowledge represents the conventional wisdom collectively held by formally trained rangeland professionals that has become institutionalized across multiple generations . Third , scientific knowledge is acquired by a systematic process of data collection , statistical analyses , hypothesis testing , and peer review . Professional knowledge is perhaps the most complex because it includes aspects of both experiential and scientific knowledge in varying combinations that have been organized to address various management goals .

Multiple knowledge sources provide a wealth of rangeland information , but they often function in parallel because few mechanisms exist for information exchange among them . Consequently , the convening of multiple stakeholders who hold diverse knowledge sources often produces competing goals , misunderstanding , and occasionally antagonism among groups that hinders the development , implementation , and interpretation of monitoring protocols . We consider effective information exchange among the various knowledge sources to be as great a challenge as that of technical capacity for effective rangeland monitoring (Burns et al ., 2006) . In cases where various knowledge sources conflict , there may be an opportunity to test hypotheses through monitoring by using adaptive management . In cases where scientific knowledge is absent or inconclusive , local knowledge may be a valuable information source to construct a more robust understanding of ecosystem dynamics . In other instances where scientific information is conclusive , it can be used to validate or modify local and professional knowledge . The rangeland profession desperately requires a mechanism to facilitate communication and foster participation among these various knowledge sources to promote more effective monitoring of global rangelands .

Toward a Comprehensive Monitoring Framework

We perceive the major challenge to the development of effective monitoring to reside in the identification of a framework that can accommodate the biophysical complexity of rangeland ecosystems , multiple sources of knowledge , and the human dimensions of these social-ecological systems (Reynolds et al . 2007 ; Stafford Smith et al ., 2007) . We advocate that this framework must have a strong underpinning in ecological theory to accurately represent the biophysical structure and dynamics of rangeland ecosystems . However , it must also explicitly incorporate local and professional knowledge because reductionist science can not answer all ecosystem scale questions relevant to ecosystem management (Herrick et al ., 2006) .

Ecological resilience as a central tenant of rangeland monitoring

Ecological resilience describes the amount of change or disruption that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures (Peterson et al ., 1998) . This interpretation of resilience assumes that ecosystems can be expressed as two or more alternative stable states and emphasizes the potential occurrence of state transitions or thresholds between stable states . Thresholds represent the conditions in which the limits of ecosystem resilience have been exceeded and alternative states form (Figure 1) . These concepts are commonly presented as state-and-transition models (STMs) that include identification of potential alternative stable states that may exist on a site and the natural and anthropogenic mechanisms that force states across thresholds to alternative states

(Briske et al ., 2005) .

We advocate that greater attention be directed toward resilience-based monitoring because it emphasizes the conditions and dynamics that influence state proximity and vulnerability to potential thresholds , in addition to identification of the thresholds themselves (Briske et al ., 2008) . Greater knowledge of resilience improves the ability to manage ecosystem change , rather than merely react to it , by providing opportunities to incorporate adaptive management (Folke 2006) . Ecological resilience of desirable states can be reduced by improper land use practices (e .g ., fire suppression , overgrazing) and extreme environmental conditions (e .g ., multi-year drought , intense storm events) , both independently and in combination . The loss of resilience may often be expressed as a slow imperceptible decline over periods of years and decades that increases the probability of threshold occurrence and the formation of alternative stable states (Scheffer and Carpenter 2003) . Alternatively , the loss of resilience may result from an abrupt change in ecosystem pattern and process induced by severe episodic events such as 500 year storms or multi-year droughts that act on low resilience systems (Walker et al ., 2004) . We envision this robust ecological concept to lend itself to monitoring application with various levels of sophistication and at various ecological scales .

The key to successful implementation of resilience-based monitoring is the development of a suite of effect indicators linking ecosystem structure and function . Process is often inferred from structural variables and patterns because it is often impossible or impractical to directly measure process rates given the expanse and complexity of rangeland ecosystems . Recognizable indicators and benchmark conditions can identify when states are approaching thresholds as well as how far states have moved beyond thresholds after they have been crossed (Briske et al ., 2008) . Indicators of decreasing state resilience (e .g ., increasing size and connectivity of bare patches) forewarn managers that actions must be taken to stabilize resilience and minimize the likelihood of crossing a threshold . Similarly , indicators of alternative state resilience (e .g ., height and density of encroaching shrubs) after thresholds have been crossed will provide information concerning both the probability and appropriate prescriptions for implementation of successful restoration procedures to recover former states .

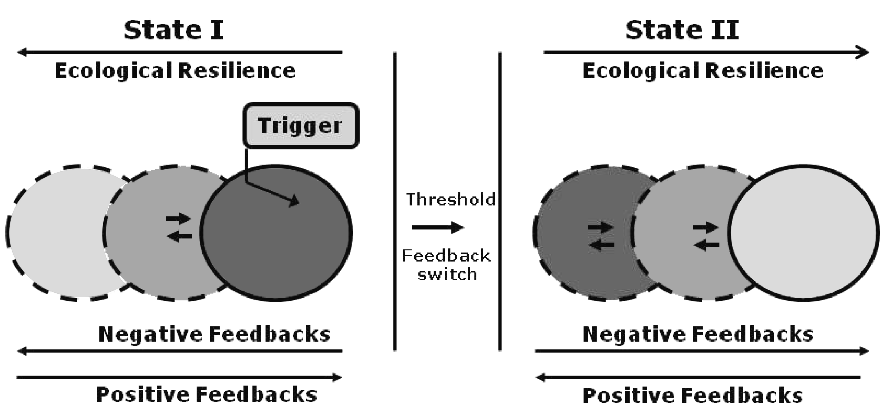

Figure 1 *Ecological resilience can be envisioned as state movement toward or away from potential thresholds . Circles within states correspond to community phases that possess varying degrees of resilience based on their proximity to potential thresholds . An increase in negative feedbacks enhances resilience and moves states away from thresholds , while an increase in positive feedbacks diminishes resilience and moves states toward thresholds . Triggers represent events that immediately induce states to exceed their resilience limits and cross thresholds to alternative stable states .*

Monitoring across ecological scales

Monitoring protocols must be able to assess processes that drive ecosystem change among various scales of organization (Bestelmeyer et al ., 2006) . Key patterns and processes at fine scales include , individual plant growth and reproduction , small patch development and distribution , and plant or patch grazing . Intermediate scales are represented by variously arranged larger patches of self-organized plant groups that affect levels of resource availability by capturing overland water flow and soil deposition . At the broadest scales , the geographic distribution of plant communities and ecosystem resilience is influenced by patterns of geomorphology and climate , and the history and pattern of land use may feedback to affect climate and geomorphic change (Scheffer and Carpenter 2003 ; Reynolds et al ., 2007) .

These scale-dependent processes further interact to form cross-scale interactions within landscapes and regions (Peters et al ., 2004) . For example , impacts on individual plants at fine scales collectively affect larger patch structure and thus broader-scale processes such as erosion . Changes in regional ground cover and land use patterns may further influence climate by modifying atmospheric chemistry , dust emissions , and albedo . Regional climate processes , in turn , determine how local-scale disturbance regimes translate into changes in local patch development and distribution . Broad-scale socio-political processes further interact with biophysical processes when changes in national land-use policies drive changes in local land-use decisions . Monitoring failures can often be attributed to a mismatch between the scale of dominant processes and the scale of assessment . For example , fine-scale monitoring of vegetation transects may not provide an indication of patterns that could be detected by remote sensing of larger scales , such as the acceleration of gully formation and runoff that eventually alters water availability in upland portions of the system (Pringle et al ., 2006) .

Traditionally , monitoring protocols have focused exclusively on indicators of fine-scale and fast variables such as plant cover and production that are measured at a few discrete locations and points in time (Reynolds et al ., 2007) . These variables are important for short-term tactical decisions , but they may not necessarily be correlated with long-term ecosystem change . Slow variables represent less dynamic , broad-scale responses (e .g ., nutrient redistribution , functional group replacement) that underlie long-term ecosystem change that in turn may feedback to influence subsequent fine-scale change and the response of fast variables . Techniques that assess the spatial pattern of patches , and long-term changes among them , across continuous areas and how fine-scale processes produce contagious effects over long time frames require greater development and implementation (Bestelmeyer et al . 2006 ; Pringle et al ., 2006) .

Organization of monitoring-management-policy networks

Monitoring and adaptive management represent mechanisms by which learning and collaborative management actions can be structured to maintain ecosystem resilience and the social systems that depend upon them (Figure 2) . The development of more inclusive and effective monitoring protocols requires that rangeland ecosystems be viewed as integrally linked social-ecological systems (Walker et al ., 2004 ; Stafford Smith et al ., 2007) . Knowledge of ecosystem pattern and process , human and natural impacts upon on them , and feedbacks between ecological and social systems , is critical to determining future management actions (Berkes et al ., 2003) . In this context , monitoring is the nexus of social-ecological systems because monitoring information provides the foundation for collaborative learning and management action which is critical to ecosystem resilience .

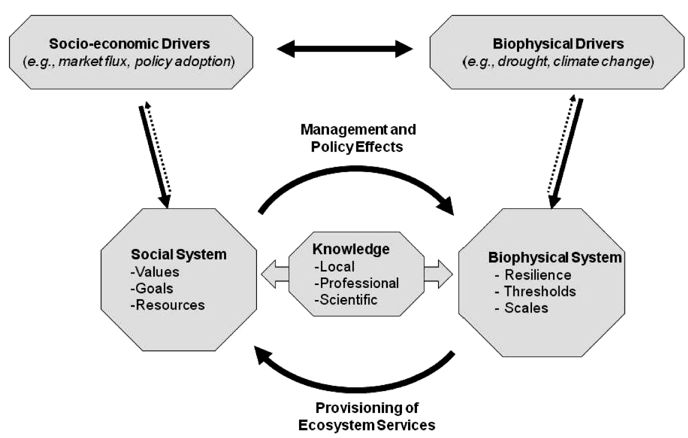

Figure 2 *A conceptual monitoring framework designed to capture critical information describing interactions of social-ecological rangelands systems . Complexities of the biophysical system are rivaled by those of social systems and several knowledge sources exist to interpret interactions among them . Emphasis on biophysical drivers must be paralleled by emphasis on social drivers because their interactions influence monitoring outcomes (modified from Stafford Smith et al . 2007) .*

Stakeholder involvement is important because they represent the individuals and groups that are affected by or are likely to affect a proposed management action , and thus will influence the acceptance and application of monitoring outcomes . In addition , if social learning is a goal of monitoring , it can only be achieved by involving multiple stakeholders in the monitoring process , especially the design and interpretation phases . At its best , collaborative , adaptive ecosystem management leads to multiple-loop social learning ; that is , learning that transcends new information about cause and effect relationships or management effectiveness and inspires participants to question underlying ecological or social assumptions , and the values , norms and governing institutions that support them (Keen et al ., 2005 , Fernandez-Gimenez et al ., *In Review*) . This type of learning has the potential to profoundly influence human behavior and social relationships and it may very likely be required to modify current resource use patterns that threaten ecosystem resilience .

Recommendations for an Integrative Monitoring Framework

How do we reconcile our commitment to science-based monitoring with the need for greater stakeholder involvement and increasing integration of local , professional , and scientific knowledge ? The answer partially resides in a mutual commitment to collaborative learning and action by managers, scientists and other stakeholders to promote social-ecological resilience (Walker et al., 2004; Reynolds et al., 2007). Participants must collectively identify the proper scales and assessment procedures that provide information concerning the sustainability of ecological resilience and ecosystem services. In addition, participants must effectively incorporate social complexity into current models focused on the biophysical complexity of rangeland ecosystems. Monitoring must be understood as one critical element in the larger cycle of collaborative adaptive management (Figure 2). In this process multiple stakeholders, including land owners, ecosystem managers and scientists, work to define and assess the system of interest, establish management goals, identify alternative strategies for achieving goals, and design a management strategy and associated monitoring approach that will determine whether goals are being met and decrease uncertainty about the system's behavior and responses to management. Monitoring information can then be collected, analyzed, interpreted and applied to future decision-making. Monitoring critical linkages within social-ecological systems will provide more robust information to inform management recommendations and policy decisions than focusing on biophysical systems alone.

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