African Journal of Range & Forage Science 2004, 21(2): 129–136
Printed in South Africa — All rights reserved

AFRICAN JOURNAL OF
RANGE & FORAGE SCIENCE
ISSN 1022–0119

The challenge of integrated rangeland monitoring: synthesis address

David Western

African Conservation Centre, PO Box 62844, Nairobi, Kenya
e-mail: dwestern@africaonline.co.ke

Received 29 March 2004, accepted 15 June 2004

The need to balance biodiversity conservation with sustainable development, though widely agreed upon, is elusive in practice. Human societies are increasingly disconnected from the ecosystems which support them. The loosening connection and growing scientific acceptance that ecosystems are complex, dynamic, non-linear systems pose new challenges for rangeland monitoring. Consequently, although conventional monitoring has contributed to better range practices, a far more integrated and multi-scale approach is required as human activity becomes more pervasive and dominant locally and globally. Integrated monitoring must track social and economic variables no less than ecosystem services in a reliable and affordable way. In addition, analysis and feedback involving the data collectors and land users should become an integral part of adaptive rangeland management more akin to business approaches than conventional science. As demanding as such an integrated approach may seem, much of the socio-economic data already exists and physical and biological data can increasingly be collected and collated by new imaging technologies. For monitoring to be locally and globally useful, it must provide information to local users in a timely and usable form and simultaneously provide data on which deleterious environmental impact can be assessed independently of the users. A set of guiding principles for setting up such programmes is discussed. The utility of monitoring and its guiding principles will only work effectively where good environmental governance is practiced by users and producers affecting rangeland ecosystems.

Keywords: adaptive management, complex, environmental governance, human impacts, multi-scale, socio-ecological

Introduction

At the Earth Summit of 1992 governments around the world reached a landmark consensus that biological diversity and the ecological processes that maintain it are crucial to human well-being and sustainable development (Holmberg *et al.* 1993). Translating political consensus into tangible improvements for society and the environment has proven far more elusive.

Many problems stand in the way of balancing economic exploitation with environmental health (Repetto 1986). These include burgeoning human population, rising per capita use of resources, fast-changing cultures and economies, discounting the future in economic cost-benefit analysis and the enormous political obstacles in moving from short-term profit maximising economies to sustainable development.

The challenge of living within the limits of available resources was problematic even for early subsistence economies living with the direct consequences of their action (Redman 1999). Globalisation has made sustainability all the harder to achieve by creating a free-market system in which the links between exploitation and its consequences are far more remote and diffuse (Stiglitz 2002). Relating action and consequence is also confounded by scientific models that do not accommodate complex, non-linear and threshold ecological effects operating across ecosystems and at a planetary scale (Levin 1999). Even the very concept of ecological limits and carrying capacity is complicated by economic subsidies, resource supplementation and human mobility.

The world's rangelands illustrate the challenge of monitoring better than any biome. Drylands make up 40 percent of the earth's land mass and support nearly 2 billion people (White *et al.* 2002). Despite low rainfall, drylands support the majority of the world's livestock and produce significant cereal, root and tuber crops (White *et al.* 2002). Drylands also include 23 percent of all terrestrial ecoregions, 47 percent of endemic bird areas, 17 percent of the centres of plant diversity (Sattersfield *et al.* 1998, Davis *et al.* 1995) and the largest wild herbivore populations on earth.

Monitoring was adopted as tool for measuring human impact on natural resources and adjusting offtakes to sustainable production in the rangelands as early as the 1920s (Friedel *et al*. 2004). These early efforts, rooted in the livestock and wildlife hunting industry, led to the establishment of public agencies responsible for the health of the land and its natural resources (Wilkinson 1992), thus anticipating sustainable development by more than 50 years.

Despite the tremendous diversification and intensification of human activity over the last few decades (Power and Barrett 2001) and the conceptual advances in ecosystem theory (Gunderson and Holling 2002), most rangeland monitoring is still narrowly focused on livestock production and wildlife utilisation. Few have yet adopted an integrated approach to data collection, analysis and application.

The lack of an integrated monitoring methodology points to an urgent need to reconsider the goals and methods of rangeland monitoring, given the pervasiveness of human impact. Put simply, the challenge is two-fold. First, to devise monitoring systems that transcend farm, ecosystem and global scales in order to track a wide variety of environmental and human variables and their interactions. Second, to create the social and institutional settings that ensure that information is widely and quickly enough disseminated to influence producer and consumer decisions, yet are cheap and robust enough to be widely adopted. Advances in technical capacity will be to no avail without the social networks and skills needed to absorb, negotiate and apply monitoring data.

In assessing the challenge of integrated monitoring, I first look at the diversification and intensification of rangeland use in recent decades, then at the implications for integrated monitoring and finally at the need to address environmental governance issues as a pivotal part of collecting and applying information to the sustainable use of the world's rangelands.

The Changing Rangelands

The world's rangelands were dominated and shaped by hunter-gathering societies during the Pleistocene (Martin and Klein 1984). During the Holocene, subsistence livestock economies displaced hunter-gatherers and reshaped the rangelands. In contrast to hunter-gathering societies, pastoralism supported high human and livestock densities based on seasonal migrations across a communally shared range and on specialised husbandry practices (Galaty and Johnson 1990). Most rangelands still bear the ecological imprint of such livestock use, settlement patterns, fire and water-harvesting (Harris 1980, Redman 1999). In recent decades, subsistence livestock economies have given way to sedentary commercial ranching over most of the rangelands. The transition has changed the relationship between people, land and resources, with profound implications for monitoring.

In traditional subsistence societies, the consumer is also the producer, creating a direct link between the herder's action and husbandry success. Adverse localised impact was mitigated by movement to some extent, but not with the liberty envisaged by Garret Hardin's 'The Tragedy of the Commons' (1968). Family, clan, tribe and ethnicity created a matrix of kinship and enmity that fostered local grazing alliances and orchestrated movements on the one hand (Galaty and Johnson 1990), but also restricted free movement on the other, thereby creating a feedback between herding practices and their impact. Individual herders were attuned to the costs and benefits of grazing strategies through the sensitive bioassay of milk and meat production (Western and Finch 1986).

The transition to commercial beef marketing meant curtailing mobility and raising stock for sales rather than consumption. In the US for example, homesteading and a boom in beef prices with the rush West led to overstocking, pasture destruction and heavy cattle mortality (Atherton 1961). Commercial sales to distant markets weakened the link between producer and consumer. The resulting destruction of the rangelands precipitated action by federal and state agencies intended to regulate the impact of livestock on public lands (Webb 1931, Voigt 1976).

Scientific rangeland monitoring in the US emerged as a tool to track the health of pastures and adjust stocking levels within carrying capacity, at least in principle (Dyksterhuis 1949). In practice, political votes from powerful corporations still carried more weight than the health of the public lands (Wilkinson 1992). The implicit assumption was that primary production governed livestock production and therefore the ranchers' economic output. Sustaining range productivity came down to tracking plant, animal, soil and nutrient status as key variables (Curtin *et al.* 2002). Much the same applied to game management, aimed at safe bag limits and fish and game agency revenues.

The origins of rangeland monitoring in North America grew directly from the need to track the variables that go into calculating maximum sustained yield of livestock, fish and game. This was a significant step towards national accountability for ecosystem health. For the first time it created a key role for transparent and repeatable scientific measurements as the basis for assessing and regulating the use of public lands (Webb 1931), a step that would gather momentum in rangelands around the world and anticipate the modern concept of sustainable development.

Over much of the world's rangelands, feedlots, water development and nutrient supplements have intensified livestock production. Such resource enrichment severs the link between livestock production and autochthonous energy and nutrient cycles. Calculations of carrying capacity become elusive when local enterprises are linked to a global economy. Industrialised farming, driven by new technology, infrastructure, commodity markets, outside investment and subsidies has boosted the economic output of the rangelands (Gardner 2002). In recent decades, rangeland use has diversified rapidly from traditional and commercial livestock economies. Industrialisation, urbanisation and ex-urban development, oil wells, mining, hydroelectric dams, wind and solar farms and so on have spawned new livelihoods. Tourism, recreation and protected areas have overtaken sport hunting as the main non-extractive uses of the drylands. Demographic changes, a steady decline in extractive industries and rise in the service sector have created a 'post-cowboy' economy over much of the rangelands (Power and Barrett 2001).

The transformation of the rangelands mirrors global change. The significance of human impact worldwide is captured in the inaugural publication of *Frontiers in Ecology and Environment* (Waltner-Toews *et al.* 2003):

> In the past, environmental managers could behave as if they were managing a 'natural' system to which they were external. With a few localized exceptions, this approach is no longer viable. Most ecosystems for which critical and urgent decisions need to be made are best seen as complex ecosocial systems… This view, which incorporates notions of multiple, interacting nested hierarchies, feedback loops across space and time,

and radical uncertainty with regard to prediction of systems behavior, requires rethinking. Post normal-science, complex systems theories and the creation of collective narratives offer the best hope for making progress in this field.

Ironically, the post-normal-science the authors envisage describes many features of traditional subsistence herding societies. How then, can we restructure rangeland monitoring for a complex ecosocial world? What should we monitor and to what ends? Who does the monitoring, and for whom? How can monitoring be made more relevant to human needs by ensuring the social and institutional dimensions of good governance are in place to tackle pressing problems? How can monitoring track human activity and steer it towards sustainability?

The Evolving Scope of Monitoring

Monitoring has evolved steadily in response to changing use of the rangelands and ecological ideas of how they function. An analysis of how monitoring has both tracked and influenced rangeland use and paradigms (Tobey 1981) would, in fact, offer an insight on the deepening interplay of science, technology, society and development. However, the accelerating pace of change in all spheres of human activity and the environment has so outstripped monitoring practices that a radical reframing of monitoring is called for.

Reframing entails upgrading rangeland monitoring to a predictive and applied science, rather than passively documenting events as they unfold. Climatology offers a good analogy for rangeland monitoring and shows how far it has to go to become a predictive science for guiding policy and practice. Climatology, rooted in simple measurements of rainfall and temperature in the 19th century, has evolved into an applied science capable of modeling and predicting human impact on global climate. As such, climatology has become a tool, not only for local and regional planning, but also for negotiating international agreements on curbing global warming and ozone thinning. A few examples illustrate the continuous and quickening evolution of rangeland monitoring and anticipate future developments.

- Monitoring practices originally arose as a response to overgrazing, over-hunting and the destruction of public lands and wildlife in late 19th and early 20th century. The primary interest groups were ranchers, hunters, conservationists and government agencies. Monitoring focused on tracking animal numbers and habitat conditions to calculate maximum sustained yield. Scientific models largely assumed ecosystems to be bounded, closed and at equilibrium. Stocking rates were assumed to be a linear and deterministic outcome of rainfall, plant production and soil nutrients. Livestock and wildlife sciences evolved as separate traditions.
- Beginning in the 1970s the environmental movement raised public awareness of the global scale of human impact. A direct outcome was concern over the degradation of rangelands, leading to the UN Desertification Conference of 1977 and the UN Convention to Combat Desertification (CCD) of 1999. National and global interest in the rangelands have grown with the recognition that land degradation affects not just indigenous and resident societies, but also has global ramifications, These include the influence of airborne dust from the Sahara on the US eastern seaboard's cloud cover, the contributions of fires and livestock methane production to global warming and the downstream effects of overgrazing on sedimentation in dams, power generation and freshwater and marine ecosystems. Similarly, the external work affects the rangelands more than ever before through physical, political and economic factors ranging from global warming to landuse policy, commodification of resources, trade agreements, technological developments, financial markets and demographic forces.
- Detailed ecological studies of rangeland ecosystems in the 1970s showed them to be open complex and adaptive systems (Gunderson and Holling 2002). Long-term Ecological Research Sites (LTERS) were established to track and monitor rangelands at a variety of locations. In Africa, many such sites explicitly included human activity as an integral part of ecology, recasting rangelands as a complex interplay of natural and human forces (Western 2003).
- The shift from preservation and utilisation of wildlife to biodiversity and landscape conservation in the 1980s had an equally profound outcome for rangelands. The shift, captured in the Convention on Biological Diversity (CBD), underscored the importance of diversity to genetic viability, species populations, ecosystems and the biosphere (Holmberg *et al.* 1993). The CBD also stressed the link between diversity, ecological process, sustainable development and equity in resource use.
- The twinning of biodiversity and sustainable development ushered in more holistic concepts of land management and conservation in the 1990s, most notably a recognition of human-dominated ecosystems and ecological services (Daily 1997). The resulting interest in full-cost accounting (Daly and Cobb 1989) effectively dissolved the boundaries between the natural and human realm, leading to the concept of panarchy-complex adaptive systems hierarchically linked across spatial scales that are continuously evolving (Gunderson and Holling 2002). Panarchy calls for an integrated approach to monitoring that transcends social, economic and natural systems.
- Over the last few decades technological innovations have also reshaped monitoring science. First aerial photography then satellite imagery changed monitoring from a toe-of-the-shoe assessment of plant abundance in a few meter-square sample plots (Tobey 1981) to a near-instantaneous and continuous assessment of a huge array of physical, biological and human variables worldwide (Kerr and Ostrovsky 2003). Today, multi-spectral, remote digital imaging, automated ground sensors and integrated, ecosystem-scale tracking programmes have created a flood of data that far outstrips user capacity.

The International Rangeland Congress papers testify to the enormous methodological and technological advances in monitoring over the last few years. Advances in scientific understanding and theory have been just as momentous. Such advances have led to a recognition that monitoring protocols should integrate physical, biological and human variables from local to ecosystem and planetary scales and, as in climatology, such measurements should be incorporated into models that anticipate deleterious human impact and foster more sustainable rangeland policies and practices.

Towards Comprehensive Integrated Monitoring

The challenge of shifting rangeland monitoring from its roots in animal production systems to an integrated approach capable of addressing the complex transformations in human and natural systems has been put succinctly by the International Rangeland Congress organisers (Biggs and Herrick 2003). I have abbreviated and slightly reworded the mission as follows:

> To monitor the capacity of healthy rangeland to support a broad suite of ecosystem services as well as social, economic and cultural needs, values and expectations for a wide range of stakeholders — in a fair, objective and representative way.

The organisers go on to say that monitoring should rest on biophysical technologies and approaches that underlie rangeland science — and on an understanding of scale effects across the rangelands. In applying the results, an adaptive framework based on hypothesis testing of management outcomes and making necessary adjustments should be used to bring about sustainable use (Walters 1986).

It is worth examining Biggs and Herrick's (2003) goals more closely to grasp the full implications for rangeland monitoring.

Integrated monitoring calls for a quantum leap in the number of variables measured. At a minimum, this means mapping and tracking all forms of land use and everything from minerals and key nutrients to water resources, fossil fuels, fertilisers, feed supplements and pollutants. It also means tracking the impact of each human activity on ecosystem functions such as diversity, productivity, albedo, nutrient and hydrological cycles, sediment transport and so on. Such monitoring should be sufficiently precise to track short and long-term changes over ecological time, in addition to human production cycles. By including biodiversity as an ecological service (Daily 1997), monitoring should also track habitat cover, patch dynamics and, directly or indirectly, ecosystem productivity, diversity, resilience and the processes that affect them.

So far, I have only touched on land use and ecological services. Integrated monitoring must also include all major forms of economic, social and cultural activity impinging on the rangelands, both *ex situ* as well as *in situ*. These activities span extractive and service industries, infrastructure, ex-urban development, recreation and so on. Each depends on ecological services and each has an impact on them. To understand, predict and influence human behaviour, we must, in addition, monitor the needs, values and expectations of a wide range of stakeholders. This means expanding conventional range monitoring to a wider and more representative constituency, including farmers, developers, home-owners, recreation users, energy producers and consumers, conservationists, scientists, government agencies, off-site communities affected by rangeland emissions and international agencies mandated to implement global agreements.

Such a comprehensive integrated monitoring programme would have to depend on stratified sampling procedures and contribute the relevant information for adjudication by the various constituents in a fair, objective and representative way. In other words, when it comes to human impact in the rangelands, monitoring must span the variety of uses and users, a point taken up under the section header 'Environmental Governance' below. To this gargantuan task must be added a welter of indices that allow us to track and monitor environmental health and all major human activities.

The expanded scope of a new integrated monitoring framework can only be realisable if rapid, cheap and reliable ways of tracking this plethora of verifiable data are available. Fortunately, remote satellite sensing, automated data collection and retrieval tools for measuring rangeland variables have advanced rapidly in recent years (Kerr and Ostrovsky 2003). Such advances are the reason we can even contemplate expanding the scope of rangeland monitoring and improving its application (Waltner-Toews *et al.* 2003). Further investments in research and development will increase the range of variables that can be collected remotely, as well as improve their resolution and application. I would add that such technological advances are the foundation of moving range science onto the predictive footing of climatology.

Beyond the collection of data lies the additional challenge of interpretation and application. This is no trivial challenge. Rangeland monitoring, like rangeland science, has rested on assumptions that livestock and wildlife production are linear processes within closed equilibrium ecosystems. Such assumptions made it relatively easy to calculate maximum sustained yield and carrying capacity, but have proved wholly inadequate for modeling rangeland ecosystems or arresting environmental degradation.

The development of complexity theory and the recognition of human-dominated ecosystems have changed the concepts of closed, steady-state ecosystems that dominated range management. The complexity and non-linearity of ecosystem dynamics means that, to be credible and useful, range science must make tentative predictions of human action and its consequences. Such predictions must be based on clear hypotheses, capable of being tested and adjusted according to outcome (Walters 1986). Simple prescriptions are reassuring, but run counter to the continual learning and adaptation process that underlies natural selection in real ecosystems. Adaptive management, in contrast, recreates the adaptive process by setting up feedback loops that, through monitoring, test the efficiency and sustainability of management alternatives (Walters 1986, Gunderson and Holling 2002).

Changing range science from prescription to hypothesis formulation, testing and continuous adaptation, will take a great deal of education and persuasion. Ironically again, the adaptive process will be more familiar to subsistence pastoralists than scientists, commercial ranchers and corporations weaned on linear programming. This means that there is a good deal scientists and range managers can learn from successful communities about the role social feedbacks play in assembling, verifying and debating knowledge and modifying practices accordingly.

Finally, the most profound challenge to range science comes in scaling context-specific findings to other levels and circumstances. The ranch may well remain a primary unit of production and decision, but it cannot be treated in isolation. A rancher is affected by globally transmitted diseases such as Foot and Mouth, by imported feeds, by water harvesting across the ecosystem, by global warming and myriad human remote activities. This means not only that we must monitor across all scales from farm to planet, but also measure the key variables and their interactions within and across scales. Such multi-scale monitoring must be capable of sensing pasture conditions relevant to the plans of a rancher and the sustainability of ecological services at all scales. Long-term ecological research sites will become especially important in studying such scale-dependant phenomena, figuring out the key processes affecting and sustaining ecological services and, finally, following the interconnecting threads in space and time.

Recognition of the need for comprehensive integrated monitoring amounts to a conceptual watershed. Yet the problem lies less in producing a common vision or even in technical or methodological limitations, than it does in embedding monitoring in the transactions of communities associated with the rangelands.

From Vision to Reality

To users, the comprehensive integrated monitoring protocol envisaged by Biggs and Herrick (2003) will appear overly ambitious and impractical, ignoring as it does the problems of cost, who collects the data, analysis, interpretation and application. They have a point, but before considering how to adapt a comprehensive protocol to individual users and specific problems, I want to point out two good reasons to aim for a comprehensive integrated monitoring protocol and draw attention to the vast untapped sources of data that makes the task more feasible than it would seem.

First, a comprehensive monitoring system sets targets for the ideal set of data to collect. Defining a comprehensive set also clarifies priority areas for research and development into better tools, methods and scientific paradigms for rangeland monitoring.

Second, whereas expanding monitoring to the welter of human activities affecting the rangelands is a seemingly futile task, in reality much of the information already exists. For example, reams of social, economic and attitudinal data are collected routinely in the course of local, national and global planning, forecasting and monitoring. In other words, the challenge is not so much a *de novo* monitoring system, but rather how to integrate the ecological and human domains that have been treated separately by scientists.

Despite the advantages of designing a comprehensive integrated monitoring protocol, it will be of little use if it ignores the most urgent threats and needs as seen by the people who use and affect the rangelands — or fails to tackle ecological sustainability (Margoulis and Salafsky 1998). In the last two decades, satellite imagery alone has piled up enormous archives of data, yet has contributed little to the sustainable development of rangelands. The delivery of information tends to be *post hoc* rather than predictive. Most data circulates among scientists, rather than freely in the public realm. The 'science-made' and 'science-delivered' approach to technological transfer also does little to foster understanding or a demand for information among potential users (Fischer 2000). The perceived lack of relevance that sophisticated remote monitoring programmes have to everyday problems limits the amount of funding available.

In short, a comprehensive integrated monitoring protocol runs the danger of stretching existing resources thinner and weakening data application by ignoring the constraints of collection, interpretation and utility.

How, then, can we make rangeland monitoring both more comprehensive and more usable?

Here again, the authors at this congress, particularly in this session, make many suggestions, ranging from simplification of data collection and localisation of application, to cost-effective measures and ways to get the information quickly to users and decision-makers. If there is one common message that emerges, it is that direct application is the best assurance for the growth and continuation of monitoring programmes.

The weakness of a case-by-case approach, however, is that without some overarching guidelines for adapting a comprehensive protocol to specific locations and needs, each set of users must learn afresh. Yet another shortcoming of monitoring driven entirely by contingency is that it thwarts comparative study and common lessons. It also ignores externalities and long-term effects — the impact of one community on another — and the slow-acting variables that undermine the sustainability of present action. This amounts to an abrogation of land custodianship that invites rangeland degradation. Clearly, we need a way to link the ideal to local self-interests and self-interests to public accountability for environmental impact. How can that be done?

Principles for Applied Monitoring

One way is to draw up a set of technical principles and practical guidelines to ensure that monitoring protocols meet specific needs while ensuring an adequate level of auditing to track environmental impact and ecological change (Margoulis and Salafsky 1998). A second related step is to apply filters that skim down a comprehensive protocol to meet both objectives — within the means available (Friedel *et al.* 2004). In illustrating the relevance of principles and filters, I draw heavily on presentations at the International Rangeland Congress.

Monitoring Principles

Principles to guide data collection should address the type of data to be collected, scale, methods and the collection and application of data. A few examples show how science can contribute to monitoring as both a specific and generic tool.

Data

The data collected should be appropriate to the scale of the problem and its application (Friedel *et al.* 2004). So, for example, data relevant to individuals or communities should include information that directly relates to their activity, whether ranching, farming, wildlife utilisation or other enterprise. Similarly, the frequency of monitoring should be adjusted to production cycles and rates of change in indicator variables in the economic, social and ecological domains. Some of the most successful protocols develop early-warnings of drought, over-consumption, insecurity and so on, directly used and often collected by local users and communities (Margoulis and Salafsky 1998).

At an ecosystem scale, data collection should focus on detecting large scale phenomena such as landuse patterns and trends, the level and type of human activity, indices of natural capital, biodiversity and ecological services, natural and human perturbations, stress indicators and measures of ecosystem function (Walker and Abel 2002). Frequency should be determined by the periodicity of significant changes in key variables measuring human and environmental change.

At regional and global scales, data collection should be broader still, based on measures of land cover types, biomass, human imprint, natural cover, habitat types, plant abundance and productivity, albedo, hydrological and sedimentary variables and so forth. Here again, frequency should be set by seasonal and long-term changes in key indicators of human and ecological variables.

Methods

Sampling method changes with scale. Plant structure, composition and nutrient quality can be measured on a meter square plot. Remote satellite probes give a more synoptic measure based on green biomass indices using NDVI and habitat-level features (Kerr and Ostrovsky 2003). One of the challenges in monitoring is to use statistical designs and monitoring protocols appropriate to the scale of interest, yet ensure that data collected at one level using the most cost-effective methods are compatible and interpretable across scales. The theory for cross-scale sampling using nested hierarchical sampling techniques is relatively well developed (Allen and Starr 1982) but poorly applied. A good deal more work is needed to put theory into practice. Long-term Ecological Research Sites in representative ecosystems are important, yet underused, laboratories for developing cost-effective measures and indices across scales from meter plots to satellite surveillance of landscapes.

Collection, analysis and application

Conventionally, the question of who collects data and how, and the analysis and application of the results, are treated separately. Generally, this is the Achilles Heel of monitoring (Margoulis and Salafsky 1998). Most successful monitoring programmes treat all aspects as an integrated set of activities organised within the community of users. If this is the case, then it suggests that the establishment of the user and interest group is the very foundation of data collection, analysis and application, not a *post hoc* consideration. I take up this point in more detail under 'Environmental Governance'.

The collection of data, how to simplify evaluation of key processes and variables using indicators, data storage and management, statistical analysis, technical interpretation of data and mode of presentation for consumers are all areas in which scientific design can guide monitoring using simplifying principles. The principles should also guide comparison and interpretation of data across scales.

Filters

Rendering down a comprehensive monitoring programme to meet the end-user's needs, while still retaining affordable and reliable indicators of overall ecosystem health, is, in my experience, the most challenging part of designing a protocol. This entails deciding on the minimum information needed to meet both objectives, the resources available in terms of remote imagery, vehicles, aircraft and ground support, the frequency and scale of data collection and the delivery schedule of the results to users. A good example of such an inventory of needs and means is given by Friedel *et al.* (2003) using examples in Namibia, Botswana and Australia. Certain data on, say, rangeland condition can be collected systematically and routinely. Other stochastic events such as fires and floods can be collected using an Event Book System. The advantage of such local participation is that data is cheaply collected, is relevant to immediate needs and can be applied by users based on their own experience and regular monitoring feedback. Minimum synoptic measures to track the state of rangelands at an ecosystem and regional scale should be subject to the same filtering processes and draw on a wider group representing public and government interests.

Environmental Governance

Rangeland monitoring has had some notable success in drawing attention to the degradation of the rangelands and over-hunting of wildlife, particularly in the western United States in the early 20th century (Tobey 1981, Dyksterhuis 1949). To a great extent, this success can be attributed to the applied origins of monitoring in maximising offtake while minimising damage to pasture, habitat and environment. Yet another important ingredient has been the definition of ownership and use rights and the role of the state in oversight and enforcement of regulations on government and often private land (Wilkinson 1992). However, as the uses of the rangelands diversify and intensify and the externalities become more important and far-reaching, the question of rights and responsibilities for individual property weighed against the health of the larger public commons are becoming more complex (Knight and Landres 1998). Poor livestock management affected few people outside the immediate owner's circle when populations were low and impacts localised. Now that human impact is so intense and universal, adverse human impacts such as erosion, sedimentation, nutrient and hormone leaching, fire and dust emissions affect millions of other people's lives locally and globally. The two-way impact can no longer be ignored when it affects the livelihoods, health and welfare of so many and the future of society.

Tracking such diverse activities and their impact on the sustainability of the rangelands cannot be done by conventional monitoring. It will take a broad integrated approach envisaged by Biggs and Herrick (2003) to work out how the disparate human activities and their impacts can be collected and applied to the sustainable use of the rangelands. However, how do we ensure that broader monitoring does not become irrelevant to users? How do we ensure that monitoring does increase knowledge and awareness of environmental impact and reach the users and relevant interest groups in usable form (Fischer 2000)? How do we ensure that the information leads to better accountability for human impact and more sustainable practices?

If integrated monitoring is to meet the challenges facing the rangelands, users and producers have to be linked by a common set of objectives in which monitoring becomes a vital tool in the quest for sustainability (Margoulis and Salafsky 1998). A good analogy is the role of market research in the design, development, marketing and delivery of commercial products. The various functions may be segmented within a corporation, but market success hinges on their integration.

An integrated systems approach is, therefore, not so much a technical hurdle as a problem of social networking. I have extracted a few salient points for how this can be done more effectively:

- Establish the network of interests before setting up an integrated monitoring programme. The interests should contribute to and drive data needs and their application.
- Create a producer-user association to institutionalise the collection, interpretation and application of data.
- Define the interests of participating groups and their respective roles.
- Establish pluralism-by-the-rules procedures for participants.
- Establish rights and responsibilities of participants.
- Set up clear guidelines for auditing and accounting for use and impact.
- Collect data as transparently as possible to ensure impartiality and verification.
- Create appropriate feedback mechanisms through which participants can adjust their activities and raise their performance based on verifiable results.
- Use the associations as learning institutions through which participants can improve their skills in working together and improve environmental responsibility and governance.

In other words, a blue-print for integrated monitoring cannot be drawn up by technical experts alone. Monitoring is an open-ended and adaptive process, responding continuously to new technology, scientific understanding, demand for information, environmental awareness and social responsibility. It must necessarily be the product of producer and consumer. The closer the two are brought together, the more effective monitoring will be.

In conclusion, the highest priority for integrated monitoring lies in creating user awareness of monitoring and demand for information and in establishing social networks and skills for trading off and applying the results so as to improve livelihoods and the state of the environment.

Acknowledgements — I am grateful to the Wildlife Conservation Society for financial support during the early part of this work and to the African Conservation Centre for support in the latter period. I also wish to thank Debbie Nightingale, Shirley Strum and the journal's referees for helpful comments and editorial suggestions.

References

Allen TFH and Starr TB 1982. Hierarchy: Perspectives for Ecological Complexity. University of Chicago Press, Chicago.

Atherton L 1961. The Cattle Kings. Indiana University Press, Bloomington, USA.

Biggs HC and Herrick J 2003. Management for sustainable use — rangeland auditing and monitoring. African Journal of Range and Forage Science 20: 117–130

Curtin CG, Sayer NF and Lane BD 2002. Transformation of the Chihuahuan Borderlands: grazing, fragmentation, and biodiversity conservation in desert grasslands. Environmental Science and Policy 5: 55–68.

Daily GC 1997. Nature's Services. Societal Dependence on Natural Ecosystems. Island Press, Washington, DC, USA.

Daly HE and Cobb J 1989. For the Common Good: Redirecting the Economy Toward Community, the Environment and a Sustainable Future. Beacon Press, Boston, USA.

Davis SD, Heywood VH and Hamilton AC 1995. Centres of Plant Diversity: A Guide and Strategy for their Conservation. Vol. 2 IUCN–World Conservation Union and World Wildlife Fund.

Dyksterhuis EJ 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management 2(3): 104–115.

Fischer F 2000. Citizens, Experts and the Environment. Duke University Press, Durham, NC, USA.

Friedel MH, Stuart-Hill GC, Walsh D (2004). What engages the interest of land managers in rangeland monitoring? African Journal of Range & Forage Science 21(2): 89–100.

Galaty JG and Johnson DL 1990. The World of Pastoralism. Herding Systems in Comparative Perspective. Guilford Press, New York, USA.

Gardner BL 2002. American Agriculture in the Twentieth Century. How it Flourished and What it Cost. Harvard University Press, Cambridge, Mass, USA.

Gunderson LH and Holling CS 2002. Panarchy. Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC, USA.

Hardin G 1968. The Tragedy of the Commons. Science 162(3859): 1243–1248.

Harris DR 1980. Human Ecology in Savanna Environments. Academic Press, London, UK.

Holmberg J, Thomson K and Timberlake L 1993. Facing the Future. Beyond the Earth Summit. Earthscan, London, UK.

Kerr JT and Ostrovsky M 2003. From space to species: ecological applications for remote sensing. Trends in Ecology and Evolution 18(6): 299–305.

Knight RL and Landres PB 1998. Stewardship Across Boundaries. Island Press, Washington, DC, USA.

Levin S 1999. Fragile Dominion. Complexity and the Commons. Perseus Publishing, Cambridge, Mass, USA.

Margoulis RM and Salafsky N 1998. Measures of Success. Designing, Managing and Monitoring Conservation and Development Projects. Island Press, Washington, DC, USA.

Martin PS and Klein RG 1984. Quaternary Extinctions. A Prehistoric Revolution. University of Arizona Press, Tucson, USA.

Power TM and Barrett RB 2001. Post-Cowboy Economics. Pay and Prosperity in the New American West. Island Press, Washington, DC, USA.

Redman CL 1999. Human Impact on Ancient Environments. University of Arizona Press, Tucson, USA.
Repetto R 1986. World Enough and Time. Successful Strategies for Resource Management. Yale University Press, New York, USA.
Stattersfield AJ, Crosby MJ, Long AJ and Wege DC 1998. Endemic Bird Areas of the World: Priorities for Biodiversity Conservation. BirdLife Conservation Series No. 7. BirdLife International, Cambridge, UK.
Stiglitz J 2002. Globalization and its Discontents. Penguin, London, UK.
Tobey RC 1981. Saving the Prairies. The Life Cycle of the Founding School of American Plant Ecology, 1955–1995. University of California Press, Berkeley, USA.
Voigt W 1976. Public Grazing Lands: Use and Misuse by Industry and Government. Rutgers University Press, New Brunswick, USA.
Walker B and Abel N 2002. Resilient rangelands-adaptation in complex systems. In: LH Gunderson and CS Holling (eds) Panarchy. Island Press, Washington, DC, USA.
Walters CJ 1986. Adaptive Management of Renewable Resources. Macmillan, New York, USA.
Waltner-Toews D, Kay JJ, Neudorffer C and Gitau T 2003. Perspective changes everything: managing ecosystems from the inside out. Frontiers in Ecology and the Environment 1(1): 23–30.
Webb WP 1931. The Great Plains. University of Nebraska Press, Lincoln, USA.
Western D 2003, Conservation science in Africa and the role of international collaboration. Conservation Biology 17(1): 1–10.
Western D and Finch VA 1986. Drought, cattle and pastoralism. Strategies for survival and production in arid lands. Human Ecology 14(1): 77–94.
White RP, Tunstall D and Henninger N 2002. An ecosystem approach to drylands. Building Support for new development policies. World Resources Institute. Information Policy Brief No. 1, pp 1–14.
Wilkinson CF 1992. Crossing the Next Meridian. Land, Water, and the Future of the West. Island Press, Washington, DC, USA.