

Theoretical Underpinnings of Rangeland Monitoring

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Monitoring of rangelands has evolved from traditional focus on plant communities and their successional status, taken from a few selected subsamples, to much broader perspectives. Rangelands, being complex biosocial systems, offer a near infinite array of possibilities for choice of variables and how to collect and interpret the data. Past monitoring approaches have inadequately considered objectives, critical definitions, and appropriate sequencing of steps taken. While management objectives should ideally have primacy in choice of variables used in inventory and monitoring, there are some countervailing advantages in employing some commonalities in monitoring protocols among tracts of rangelands. Inventories should come before monitoring. Assessment should follow collection of an adequately long time series of data which is the essence of monitoring. Trends involve judging whether the monitoring data show increases, decreases, or stable trajectories. Assessment involves an always at least partially subjective judgement of condition in relation to appropriate standards and objectives. We are no longer limited to just plant community data collected annually in a few conveniently and subjectively chosen quadrats. Geomatics (remote sensing, GIS, and GPS) opens the possibility of frequent, synoptic (everywhere, instantaneously) landscape coverage via satellite imagery. Indisputable evidence of cause(s) requires concurrent data on these influences along with similar trends from similar circumstances (replications) and controls [reference areas lacking the putative cause(s)]. Three alternatives that could replace plant succession as the underlying, dominant theory of rangeland monitoring are: risk assessment, sustainability, and desertification. Risk assessment is well proven where biophysical indicators can be employed. Politically neutral incorporation of socioeconomic considerations have yet to be demonstrated, however. Sustainability is such a broad and diffuse concept that anyone can read into it whatever he or she wishes. Desertification is the preferred macroconcept to guide us into the future, because its use can more objectively encompass both biophysical and socioeconomic features, at any scale in time and space.

Keywords inventory, survey, trend, condition, geomatics, risk assessment, sustainability, desertification, plant succession

The organizers of the workshop asked me to review the theoretical underpinnings of rangeland monitoring. I got this assignment probably because I have done similar

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reviews in the past (West, 1985; West, 1991; West et al., 1994; West & Smith, 1997; West, 1999) and have been actively involved in teaching and research efforts on the subject at-hand for several decades. I am pleased to take on the challenge of a written update of this topic again. However, I must warn the reader that the pace of change has picked up. Acceleration is occurring in both the underlying science and technology and in the social and economic urgency of reaching consensus on how monitoring can be best done on rangelands under all ownerships across the USA. This means that the amount of relevant literature to review is extensive. Thus, the following is not to be regarded as comprehensive, but only indicative of the literature that is available.

This article will focus on individuals and the influence of their ideas evolving from science and on capabilities emerging from technological advances. The companion paper (West, 2003) focuses on the history of institutional involvement and the social, economic, and political influences causing those institutions to propose particular approaches and then protect older or forward new approaches. In the interests of space available here, I will focus on approaches used in the Western U.S., although other developed nations are also experiencing similar increased attention to this topic. A few especially important citations from Canada, Australia, South Africa, and New Zealand will be included because these nations are ahead of us in development of some theory and technology applying to rangeland monitoring.

The single most important document driving these more recent monitoring concerns in the U.S. has been the National Research Council (1994) report and its conclusion that the conditions of our nation's rangelands in their entirety could not be ascertained at that time. The Heinz Center (2002) report on the current state of the nation's ecosystems reinforced the lack of credible nationwide information on the current states and trends of our "grasslands and shrublands" (the subcommittee responsible refused to use the term "rangelands"). These conclusions have apparently shocked enough influential people that there is finally probably sufficient momentum to see us through to an agreed upon strategy and tactics to answer reliably the questions of what are the overall conditions and trends of all of our rangelands. In answering this larger question, many think we will also automatically get answers to similar but smaller questions being asked for regions, states, ranger districts, allotments, ranches, pastures, site polygons, and stands. In the following, I will have to demonstrate that such an assumption does not hold. In other words, there are strong scale-dependent interactions between questions (objectives), variables, and methods in this topic (Figure 1).

Rangelands are such complex and heterogenous systems that they offer almost limitless possibilities of features to inventory and monitor. Economic and practical considerations, however, usually constrain our options. What should come first are written statements of the objectives of one's efforts. This is why objectives and the related terms, "goals" and "questions" are put at the top of Figure 1. This is regarded as crucial everywhere serious thinking on the topic has occurred (Aucamp et al., 1992; Allen, 1993; Friedel et al., 2000). If you do not spell out objectives (or questions for which you seek answers) for your activities, be they a national assessment or maintenance of appropriate features of a local site or landscape, the monitoring process will be successful only fortuitously. Because individual and societal objectives have changed and will do so over both space and time, choices of monitoring approaches have frequently differed.

Since each variable chosen for monitoring emphasizes a different aspect of the chosen system, these choices strongly determine the results. Trying to measure everything is not feasible. Thus, we will be forced to choose carefully what are tractable approaches, both nationally and locally, to meet the stated objective(s). Proxy variables, those easier and cheaper to monitor than the preferred but difficult and more expensive ones, may have to suffice. Let's first turn to some critical definitions before we proceed further.

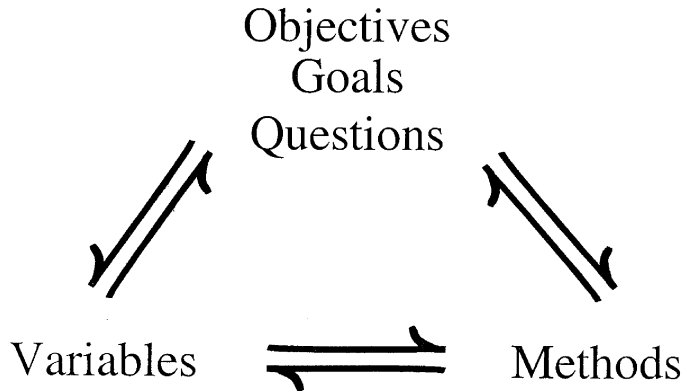


FIGURE 1 Interrelationships of objectives (goals or questions) with choice of variables and methods for scoring the variables.

Definitions

Ford (2000) stresses that if we fail to agree on assumptions and definitions, we have to expect interminable arguments on interpretations of science and technology-based information. Assumptions must also be clearly stated as axioms. Axioms state what is currently considered to be true. Questions must be formed as postulates. Postulates are statements that can be investigated and deemed true or false, or given a probability of falsehood. Ford (2000) also stresses that we need to start by writing down the question(s) to be asked, the theory relevant to each, the techniques to be employed, the measurements to be taken, and how inferences will be made.

These research-style procedures are relevant to monitoring because adaptive resource management (Bormann et al., 1999; Thomas & Birchfield, 2000) regards each action as a treatment whose results can be dealt with in a quasi-experimental mode. Feedback from these science-based tests are used to fine tune the management and put it on a more objective bases.

According to Ford (2000), a theory employs a logical construction, comprising propositions, some of which contain established information (axioms) while others define questions (postulates). Theories are neither completely speculative nor completely certain. A concept is any object or idea to which we can give a name and definition. The rangeland condition concept is merely a tool that should be isolated from ecological theories (Scarnecchia, 1995). Putting explicit time and spatial conditions on our chosen questions is a particularly important task in rangeland monitoring. These are known as “grain” and “extent” to ecologists (Allen & Hoekstra, 1992).

Inventories (surveys) are single time examinations of the resources available and attributes found across specified areas. Inventory data feed into development of management plans. Information is data organized in useful ways. Knowledge is understanding of a phenomenon well enough to predict outcomes in similar circumstances (Slobodkin, 1988). Monitoring involves tracking the changes in the selected resources, attributes, or their proxies over time. Monitoring is not necessarily repeated inventory, however, because different variables may be chosen to monitor (e.g., cheaper proxy or surrogate variables that are leading and thus provide early warning) and examined at usually lower levels of detail over time as well as space. Trend involves judging whether the time series of data show increasing, decreasing, or stable trajectories for features from the area under consideration. Friedel et al. (2000) emphasize that influences of the manager-applied treatments need to be separated from those not manipulated by the manager (e.g., climate,

insect herbivory). Because climatic effects are usually greater than those due to management actions, especially changes in livestock grazing, time series in excess of 20–25 years are necessary to separate trends from fluctuations and sampling error (random noise; Wilson, 1984). Trends of monitored variables guide revision of management plans. Indisputable evidence of cause(s) of observed changes requires simultaneous collection of data on the putative causes (Stow et al., 1998), along with similar trends from similar circumstances (replications) and controls (areas otherwise similar but lacking only the putative cause(s) (O'Neill et al., 1992).

Assessment involves taking inventory and monitoring information and interpreting it in the light of individual, institutional, national, or world-wide needs or goals (Malk, 1999). Assessment is a newer, more fashionable term. Inventory or survey are words not often invoked today because they admit that we do not always have the necessary primary data, something usually expected both internally or externally of an organization.

Condition, “health,” or integrity have been used more or less as synonyms by land managers. Scientists see distinctions between these terms (e.g., Karr, 2000, 1996; Kay et al., 1999). It will be important to have dialogue between scientists and managers to decide which term and associated concept to focus on while planning new monitoring efforts. Another required discussion will involve choice of variables. A third session needs to focus on whether the specified features (either individually or collectively) should be compared with the data with some real reference (baseline, initial value) or ideal expectation, either internal or external to the system. It is these choices of reference areas or benchmarks (West, 1991) that cannot entirely be objective and make the task of judging conditions (assessment) a mix of science, economic need, and morality. There are no intrinsic values, only the ones humans chose (Rolston, 1994).

Because environmental change and evolution create a constant stream of unique situations and biota, no single state can be “healthy” or “unhealthy” for everything. We have to express what aspects we consider are of greatest human interest. Values run the gamut from extractable resources of economic importance to individual humans, to ecological services to society at large (Balmford et al., 2002), to aesthetic and spiritual benefits to particular subcultures. Management toward sustainability of all these values involves a mixture of science and moral choices (Raven, 2002).

History of Theory Related to Rangeland Monitoring

Prior to development of science and technology, occupiers of rangelands evaluated their impacts not at all or casually and intuitively at best. Increased evidence is accumulating that the peoples using North American rangelands prior to the colonization by Europeans had far from benign influences (Flores, 2001). Because humans do not truly manage what they don't measure, or easily and objectively assess the lands impacted, some rangelands were permanently degraded. This has contributed to the collapse of some earlier civilizations (Diamond, 1997).

“The purpose of the scientific method is to replace the subjective process of developing new ideas into a logical framework of challenge and questioning to develop objective knowledge” (Ford, 2000). Ecology is the science that has provided the most important underpinnings to modern management of rangelands. Plant ecology, in particular, has made enormous contributions to traditional rangeland monitoring through the concept of plant succession. Nearly all plant ecologists once believed that the replacement of plants over time at a given spot on the land followed an orderly, slow, gradual, linear, deterministic, yet reversible pathway toward a single self-regenerating end point (equilibrium) of plant community composition called the “climax,” constrained mainly by climate (Clements, 1916). Some even believed that entire landscapes were covered by climax vegetation before Europeans came to North America.

The range profession, mainly through leadership of E. J. Dyksterhuis (1949) and the Soil Conservation Service [now the Natural Resources Conservation Service (NRCS)], developed condition classes based on departures from the one presumed monoclimate plant community expected to be associated with all concrete locations where a given ecological site [a category of land (Creque et al., 1999)] existed. Guides to the expected stages of plant succession in thousands of these differing kinds of rangelands (ecological sites) have accumulated over the past about 60 years. Managers of these rangelands, especially those under private ownership where the NRCS offers technical advice to managers, have depended on this information. Two developments have, however, put a cloud over this approach to assessing the condition of rangelands.

The first impact on the NRCS-led approach came from theoretical ecologists in academia. Clement's monoclimate theory was first replaced by the polyclimate theory, best demonstrated by Daubenmire (1940) in the West. Both models were, however, older mechanistic and equilibrium models stemming from the industrial age (Botkin, 1990) and were slowly replaced by nonequilibrium (Ellis et al., 1994) and chaotic (Abraham et al., 1997) ones.

The second influence for changing the older successional model came during the last half of the twentieth century, as time series of vegetation data from the field accumulated. These data were often not supportive of the Clementsian conceptual model (Smith, 1989). It was found that successional trajectories could not be reliably predicted because small undetectable differences in initial conditions frequently led to radically different and unpredictable results (the essence of chaos). The new models [in the NRCS's handbooks (Grazing 'Lands' Technology Institute, 1997)] now replacing the earlier single climax model display nongradual transitions with irreversible jumps forward, in reverse, and crossing over thresholds (points of no return) into new domains or alternative metastable states.

During the last half of the twentieth century, two subdisciplines of ecology—ecosystems ecology and systems ecology—developed and now have impacts on how we view rangelands (Lewis, 1969). The ecosystem concept is a synthetic and holistic notion that counters the excessive reductionism and overspecialization that developed in science following World War II (Wikstrom, 1989). Systems analysis began as a means of quantifying the needs for obtaining and supplying materials to the military forces during World War II. These principles have subsequently been applied to energy, material, and information flow in ecosystems (Kay et al., 1999). While vegetation is pervasive and forms the food base for herbivores, it is but one of many essential structural and functional components for ecosystems. Ecosystems comprise all biotic (including humans), abiotic, and mixed (e.g., soils) components interacting as a whole. Humans are dominant species often involved in keystone processes (e.g., fire prevention) influencing the state of each ecosystem.

With emergence of other interest groups besides graziers concerned with rangelands (Kennedy et al., 1995), range professionals are now forced to move beyond former exclusive focus on the portion of vegetation valuable as livestock forage. Any new monitoring scheme will have to pay attention to changes in the previously ignored biota [e.g., microphytic crusts (West, 1990)] plus other microbes and animals, as well as the abiotic environment (air, water, climate), soils, and ecosystem processes. Attention to patchiness and successional status of ecosystems across landscapes and regions is also now recommended (NRC, 2000; SAB, 2002). Landscapes are important because some problems develop slowly and subtly (e.g., declining sensitive species such as sagegrouse) and cannot be addressed without considering their various needs across a landscape during their entire life cycle. Thus, size, shape, and spatial contiguity of habitat patches may be crucial. Piecemeal, uncoordinated management of the various portions of landscape under different ownerships may result in alteration of only one critical piece of land. A larger perspective is thus often needed to analyze and correct or deflect the course of environmental change.

Inclusion of hierarchy theory into ecology (Allen & Hoekstra, 1992; Ahl & Allen, 1996) requires us to make better choices of variables and techniques, to quantify relationships at appropriate scales in time and space. For instance, if the question being asked is "What is the condition across an entire pasture (allotment, ranch, ranger district, or region)?", then measured changes in plant composition or coverage of the soils at a few selected one meter square plots will not suffice. Such limited, convenience or judgmental sampling will not (because of biases) adequately represent changes in the mosaic of polygons occupied by representatives of various ecological sites occupied by plant communities in various successional phases (stands) in an entire pasture to even larger spaces. The plot data show plant population and patch dynamics instead; phenomena that are inevitably more dynamic than those of vegetational and ground cover features emerging at larger spatial scales (Friedel, 1994). Another consideration is that management of livestock cannot control the utilization of individual plants on small plots because grazing decisions both by animals and humans inevitably focus on larger scales.

The set of relevant variables that can be reliably monitored at multiple scales is very limited (West, 1999). Most variables (e.g., plant community composition within quadrats) must be transformed into summarizable information for larger expanses in space and longer time intervals. For instance, Dyksterhuis (1949) transformed herbage weight data into "Excellent, Good, Fair, and Poor" categories based on their relationship to the one perceived climax vegetation thought possible for a given site. Excellent or near climax condition was assumed to have the highest available forage, protection of soils from erosion, wildlife habitat, and so on. This assumption failed for many situations, particularly for those beyond the tall grass prairies where the approach was pioneered. Use of the condition labels "excellent," "good," and so on, although a clear transgression from inventory to assessment (skipping the necessary intervener of monitoring), continues to the present time in parts of the world where food security dominates other issues [e.g., South Africa, (Snyman, 1998)]. However, in the USA where food and fiber production are taken for granted and environmental security and moralistic issues now dominate, different bases of judgement have come to be employed. For instance, NRC (1994) tried to switch the focus from forage production to ecosystem functioning through examination of evidence of soil stability, energy flow, and nutrient cycling. They suggested that the plot by plot data be assigned to the categories of "healthy," "at risk," or "unhealthy," without reference to ecological site guides. There are many problems with doing this. I will mention only two here. See Laycock (2003) for other relevant concerns.

The first problem with aggregating point or plot data upward is that of representativeness. Choosing one (e.g., key area) or a few samples to estimate the whole hinges on who is doing the selection. Biases toward either optimistic or pessimistic conclusions can be buried in this process. Adding the element of randomness required by conventional statistical inference greatly drives up the costs of such a subsampling approach. The sparser the vegetation, the more numerous random samples need to be to reach satisfactory levels of statistical confidence (Mayne & West, 2001; Sundt, 2002). Such intense subsampling is usually beyond economic reasonableness.

The second issue with the classical subsampling approach is that differing topographic positions and soils across pastures and allotments have different resistance, resilience, and potential for biotic communities, as well as different geologic rates of erosion and hydrologic regimes (the ecological site concept, see Creque et al., 1999). Unless the point or quadrat samples are correctly proportioned, the overall trends across a pasture or allotment will not be reliably reflected. It is also possible that the most important damage to a watershed, landscape, or animal's habitat is being done on a small unsampled area within or even adjacent to an area that is not within the purview of management because it was not sampled or could occur under a different ownership.

The range profession has put so much of its training efforts into identification of plant species, sampling within plots, and application of conventional statistical analysis that it hasn't had the background to examine other possible ways of answering the questions really being asked. West and Wu (2003) submit that we now have available other approaches that may better match the monitoring questions being asked. One alternative to the classical approach is employment of systematic sampling and geostatistical analysis (Goovaerts, 1999). For instance, Owens and Spalinger (2002) have recently shown how these principles could be applied to setting up a monitoring program on reindeer grazed tundras in Alaska.

Another promising alternative comes from landscape ecology theory (Turner et al., 2001) and geomatics [remote sensing geographic information systems (GIS) and global positioning systems (GPS) combined, Kavanagh, 2002]. The traditionalists' insistence on considering only species level information everywhere will have to be overcome, however, because a complete tally of all plants by species is and will probably remain impossible to do from remotely-sensed imagery. Nevertheless, from remote sensing, we now have huge archives of frequent synoptic (everywhere, instantaneous) data from which we can reconstruct time series of changes in total aboveground cover and productivity and changes in the sizes, shapes, and connectivities of patches dominated by various plant lifeforms and bare soil (Washington-Allen, 2003).

Numerous landscape metrics offer means to quantify changes on rangelands over both time and space (Gustafson, 1998). In addition, analysis of such data along grazing gradients (Pickup, 1996; Washington-Allen, 2003) allows for the changes due to climatic variation to be separated from those due to grazing. Effects of prescribed burning, and chemical and mechanical brush control are also easier to quantify over large areas by remote sensing. Complete census of all pixels, thus involving population statistics, not the traditional subsampling statistics, are involved in the border to border landscape approach. In order to build confidence in such approaches, however, we need additional ground-truthing and simultaneous comparisons to conventional monitoring efforts, including economic costs of the competing alternatives, before most will accept, even in part, a role for geomatics in rangeland monitoring.

The Future

Before we collectively choose modern, workable means of monitoring rangelands, either for the nation as a whole, for multistate regions, or individual ranches or allotments, we need to understand that these resources are no longer of interest to just graziers, miners, and energy providers. Thus, traditional interest groups are now being asked to prove that their actions do not endanger ecological security (West & Smith, 1997; Squires, 2000). Unless the fears of at least the moderate environmentalists are calmed, traditional resource managers will find their actions blocked, usually through procedures mandated by the National Environmental Policy Act or the Endangered Species Act. Thus, rangeland management must now be recognized as clearly operating between science and politics (Burnside & Rasmussen, 1997; Squires, 2000).

The broadened human interest in rangelands automatically means that there is now expanded scrutiny of how rangelands are monitored. This is more broadly demonstrated in my companion historical review focused on individuals and institutions (West, 2003). Traditional approaches of monitoring, where data collection obviously focused only on the utilitarian value of these lands for livestock grazing, must be augmented by a much more comprehensive approach, at least in the USA and other developed nations.

The more comprehensive U.S. approach to rangeland monitoring in the future will be built through collaborative efforts between resource users, scientists, and

representatives from interest and watchdog groups. Future monitoring will involve collection of numerous variables at multiple scales in time and space. Much more than biophysical data will be needed, since some of the interest will also be focused on social and economic indicators (West, 1999; Bartlett & Mitchell, 2002).

Because of distrust produced by the biases of land managers of the past, the monitoring protocol will have to have transparent, open source protocols. By this, I mean that any interested party can have access to the original data and will be able to independently analyze it to see if he or she reaches the same conclusion. This will put pressure on us to choose variables and means to quantify those variables in such a way that quibbling is minimized. An additional requirement will be that all scales in time and space over which rangelands can be viewed, be accommodated (Friedel, 1994).

The above is a tall order. Many more adequately trained and talented people and the fiscal resources to support them will be required to move rangeland monitoring forward. However, if monitoring is not more efficiently and reliably accomplished, adaptive resource management will never become commonplace (Friedel & Laycock, 1995; Moir & Block, 2001). Unless we become better stewards of our resources, our civilization could regress or fail.

In order to build modern, widely acceptable means to monitor and assess our stewardship efforts, we need new theoretical underpinnings for these efforts that will accommodate the expanded interest in rangeland at all scales in time and space. Three fresh concepts appearing to provide a theoretical thread through rangeland monitoring seem to be emerging: risk assessment, sustainability, and desertification. I will discuss the prospects for each of these concepts in gaining priority.

Risk Assessment

Each land use strategy is associated with a risk of the system (ecosystem, social system, etc.) going into an unacceptable condition (Cincotta & Perez-Trejo, 1990). Ecological risk assessment (ERA) produces statements of the magnitudes and probabilities of adverse effects, either anthropogenic or not, to our environment (Suter, 1993). ERA is a systematic and quantitative way of comparing and prioritizing risks. The ERA process helps ferret out probable causal links with inherent uncertainty, making the approach more credible than the deterministic models used in the past. Clear and consistent endpoints (variables) are defined. Land managers who use this approach can compare the implications of their assumptions and their data rather than relying just on intuition and political maneuvering. Washington-Allen (2003) has demonstrated use of ERA in modernizing rangeland monitoring of a part of a large ranch in Utah. The U.S. Environmental Protection Agency (SAB, 2002) suggests that ecological risk assessment be the framework for monitoring all kinds of American ecosystems in the future. However, some (Lackey, 1997; Evans, 1999) reject risk assessment as an undemocratic process because most people can't readily understand the terminology, data, calculations, or the basis for the risk assessors judgment.

Sustainability

Another popular thread in building new approaches to monitoring of many kinds, including rangelands, is the concept of sustainability (Chapin et al., 1996; Snyman, 1998). Sustainable land management is difficult to define tightly, however. In the rangeland context, it includes natural resources conservation, decreasing ecological risks, maintaining or enhancing biological diversity and productivity, economic viability, and social acceptability. Thus, everyone can grab hold of something of interest when sustainability is mentioned. The problem is that different societies and subcultures within those societies see the parts that they want and ignore the rest.

Sustainable development is a concept pushed most strongly by developed countries with stable governments, constant or declining human populations, strong economies, and increasing public awareness of the environment and biodiversity. To those nations caught up in a struggle for domestic food security, sustainability means an adequate diet for humans, whether environmental degradation occurs or not (Snyman, 1998). Even in developed nations where there are not certain immediate financial gains and long term benefits, few will opt for changed management unless bribed, especially for private lands (e.g., the Conservation Reserve Program, Ribaldo et al., 2001) or forced by administrative actions on public lands. Thus, another function of the proposed Agricultural Research Service (ARS) program (James et al., 2003) may need to provide demonstrations that monitoring does produce a sustainable operation and will indeed result in long term economic advantages that exceed those of operations ignoring conservation principles espoused by various individuals and institutions.

Desertification

The third option for a theoretical underpinning for new rangeland monitoring protocols is desertification. I agree with Arnalds and Archer (2000) that this is the most appropriate choice, at least for terrestrial ecosystems. Some (e.g., Mouat et al., 1997; De Soyza et al., 1998; Hoffman et al., 1999) have already made some progress in this direction.

Desertification has taken on many definitions, particularly following the United Nations Convention to Combat Desertification in 1994. The definition I prefer is my own (West, 1986), which stresses permanent reductions in the capacity of land for production [in complex joint production systems (Hoekstra, 2002), not the older one resource at a time utilitarian sense] that are due to human activities. It is admittedly sometimes difficult to separate the relative impacts of anthropogenic from non-anthropogenic influences. Nevertheless, grazing gradient-based methods have been developed to differentiate between climatic and grazing animal influences (Pickup, 1996; Washington-Allen, 2003).

One strong advantage of desertification as a basis for rangeland monitoring is that it is a macroconcept (Ford, 2000) that isn't limited to any particular scales in space or time (Safriel, 1999). The notion of a permanent reduction in the capacity of a terrestrial ecosystem to produce at primary, secondary, or tertiary levels can extend from a square meter, to stands, landscapes, regions, continents, or all the world's terrain above water. Furthermore, because aboveground net primary productivity (NAPP) can be remotely estimated and summarized at all of these spatial scales, this is one of the few variables that is not sensitive to choice of spatial scale to measure and summarize for (West, 1999).

NAPP can also be measured at multiple time scales. Choice of frequency to observe productivity is, however, very influential on the numbers produced. That is because the temporal importance of photosynthesis, respiration, growth, senescence, grazing, decomposition, and burning varies with the land use constraints annually occurring in various climatic regions. However, with remote sensing, we can now daily measure the net effects on areas from 1 km² upward. The details of what organisms are adding and what local influences (fire, grazing, tillage, etc.) are subtracting will have to be directly observed on the ground to make valid interpretations, however (Friedel et al., 2000). Thus, plant succession, the basis of the traditional means of monitoring rangelands, is still relevant as a needed piece of information. The times and places to do these observations most efficiently can be guided by remote sensing, however.

Another advantage of the desertification concept as the underlying theory to rangeland monitoring is that climatological, geological, hydrological, social, and economic understanding, as well as the traditional focus on vegetation and soils, all

contribute. Desertification may be regarded as a chronic “sickness” of the land that requires differing attention in time and space, depending on what are considered major causes contributing to the syndrome.

Desertification can be local and reversible with investments in knowledge and capital, especially if economics are ignored or subsidized (Milton et al., 1994; Whisenant, 1999). However, where desertification has been primarily caused by policies set at national levels, for example, sedentarization of nomads, the effects apply to large regions (Sneath, 1998). Production continues, but at levels below what occurred before (Snyman, 1998). Therefore, monitoring should also include social and economic indicators at property to national and even international levels (West, 1999; Rollings & Brunckhorst, 1999). Desertification is a macroconcept that will most easily accommodate the postnormal, inside-out-looking science likely to be applied to ecosocial systems of an increasingly human-dominated world (Waltner-Toews, et al., 2003). The Sustainable Rangelands Roundtable (Bartlett & Mitchell, 2002) is attempting to work toward a consensus on which variables to add, in integration with the more traditional aspects of a monitoring effort.

Global environmental change attributable to human activity could lead to desertification of some rangeland areas, but increases of some components in some regions. For instance, increases in perennial grasses in the formerly brush dominated Great Basin could materialize (Wagner et al., 2003) because of the expected doubling of rainfall and warmer temperatures. Some will view such trends positively whereas other segments (e.g., those favoring certain species, such as sharptail grouse or sagebrush voles over sagegrouse or pigmy rabbits) of society will view such events negatively. These are the reasons interpretation of conditions during assessment will always remain less than totally objective.

Conclusions

Basic science has produced a sequence of concepts. Technology has produced a progression of increasingly sophisticated tools scientists employ. Sometimes development of new tools (e.g., geomatics) has spurred theoretical advances in science (e.g., landscape ecology).

Availability of new ways to monitor eventually influences public policy because accumulating data and their analyses show unintended consequences of the previous policy. Assessments frequently include only those variables the authors feel people care about. People care about things they learn about, thus more important questions and new ways of answering them can escape scrutiny because of this circularity in thinking (SAB, 2002). In other words, it is imperative that we measure what we value and not value only that which we can currently measure. Further research and technological development, such as that proposed by the ARS (James et al., 2003), will help us overcome the latter.

Where reliable inventory and monitoring data do not exist, intuition and political expediency dominate during assessments, often to the disadvantage of the land and those people who depend on it (Gay, 1989). Science and technology should be steadily supported to develop better concepts, collection of greater amounts of more reliable data, and more efficient and effective means to analyze and summarize them in transparent ways. This will allow more objectivity to enter into the planning, assessment, and adjustment of management, via adaptive resource management. Every rational, well-fed human can endorse the goal of a persisting resource base providing options to future human generations.

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