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Chapter 7: Grassland Sustainability

Introduction

In this chapter we discuss grassland sustainability in the Southwest, grassland management for sustainability, national and local criteria and indicators of sustainable grassland ecosystems, and monitoring for sustainability at various scales. Ecological sustainability is defined as:

> [T]he maintenance or restoration of the composition, structure, and processes of ecosystems over time and space. This includes the diversity of plant and animal communities, and the productive capacity of ecological systems and species diversity, ecosystem diversity, disturbance processes, soil productivity, water quality and quantity, and air quality. (USDA Forest Service 2000: Glossary)

Sustainability is measured over various spatial scales, often including a nested hierarchy of smaller and larger spatial scales. For example, if the habitat of a rare species was studied at only a fine spatial scale, the impact of disturbances and larger landscape patterns that affect species distribution and viability would not be considered.

Ecosystem integrity has been variously defined and incorporates the concepts of ecosystem functioning and resilience. Grumbine (1994) described five goals of ecosystem integrity:

- Maintaining viable populations (biodiversity)
- Ecosystem representation
- Maintaining ecological processes
- Protecting evolutionary potential
- Accommodating human use

Definitions and measures of integrity are discussed by De Leo and Levin (1997).

Nearly 75 percent of all threatened ecosystems in the United States are either grasslands or shrublands (Mitchell and Joyce 2000). Grasslands are home to more than 7,500 plant and animal species in the United States. Many grassland species are now either threatened or endangered, and more than 700 species are candidates for listing under the Endangered Species Act.

The majority of Southwestern rangelands are grasslands. Rangelands are defined as those areas where the potential natural vegetation predominately comprises grasses, grasslike plants, forbs, and shrubs, and where herbivory is an important ecological process (Anderson and others 1976, Frank and others 1998, Mitchell and Joyce 2000). Rangelands affect the quality of life of every person in the United States. This land accounts for approximately 706 million acres, or 40 percent of the lands in the United States, including grasslands, shrublands, tundra, alpine meadows, Southwestern deserts, and wetlands across the country (Colorado State University 2001). The U.S. Federal government manages over 21 million acres of prairie grasslands, including the shortgrass prairie of eastern New Mexico (National Wildlife Federation 2001).

We discuss grassland and rangeland management in terms of maintaining ecosystem processes, ecological integrity, and ecological sustainability. Sustainable rangeland management is defined as management of rangeland ecosystems to provide a desired mix of benefits to the present generation without compromising their ability to provide benefits for future generations (Colorado State University 2001). Managing grassland resources, including rangelands, for sustainability will help ensure that USDA Forest Service meets its stewardship responsibility of passing the nation's resources on to future generations in improved condition (Kaufmann and others 1994).

Without an effective way to accurately monitor social, ecological, and economic aspects of rangeland, and therefore grassland sustainability, it is difficult to measure progress toward sustainability. In recent years Federal land management agencies have been criticized for a lack of consistent, standardized indicators for reporting the status of rangelands. In response to this need, local, national, and international criteria for grassland sustainability are being developed. Efforts include the Sustainable Rangelands Roundtable (SRR), the Local Unit Criteria and Indicator Development (LUCID) project, and the Montreal Process. The purpose of grassland monitoring can vary, but an important aspect is to determine whether management activities have affected ecosystem sustainability and integrity.

Grassland Management for Sustainability

Southwestern grasslands are managed for a variety of uses, including livestock grazing, wildlife habitat, protecting water quality, and for recreation (National Research Council 1994, USDA Forest Service Kiowa and Rita Blanca National Grasslands 2001). Grasslands in the West and Southwest have been degraded by overgrazing and intensive use of riparian areas (USDA Forest Service Research and Development 2001). Forest Service research and management priorities have addressed stream bank erosion, sedimentation and erosion rates, restoring riparian vegetation, providing improved habitat for native species, and the cumulative impact of wildlife and livestock grazing.

Management actions must be consistent with Federal and State regulations, including the Clean Water Act, the Multiple Use and Sustained Yield Act of 1960, the Resources Planning Act of 1974, the National Forest Management Act of 1976, the Federal Land Policy and Management Act of 1976, and the Soil and Water Resources Conservation Act of 1977.

An important principle of all grassland management is to plan for drought conditions. Hydrological extremes are associated with climatological events, especially the El Niño Southern Oscillation (ENSO). The Southwestern United States has a strong teleconnection to the ENSO cycle. In general, El Niño brings periods of heavier winter precipitation in areas that are affected, while La Niña events are associated with drought. Depending on location, December through March precipitation in New Mexico is 138 to 214 percent that of average conditions in response to El Niño events (see National Weather Service map, NOAA 2001). February through April temperatures are lower in response to an El Niño event.

For management purposes, the frequency and severity of drought are more important than long-term average climate conditions. Too often land managers plan for average climate conditions, rather than the climatic extremes that can be expected. Drought conditions and low spring runoff occur in response to La Niña events at New Mexico sites (Dahm and Molles 1992, Molles and Dahm 1990, Molles and others 1992), while in response to an El Niño, winter/spring precipitation nearly equals summer precipitation. Drought conditions, including response to La Niña events, also correspond to an increase in fire frequency that is detectable in histories reconstructed from fire-scar data.

Grazing intensity can be reduced to prevent excessive vegetation and ecosystem damage during drought. In addition, grassbanks are being used in northern New Mexico and other areas as one part of a wider solution to address drought conditions. Grassbanks are rangeland management systems that provide alternative forage for livestock displaced from their regularly permitted allotments, which are undergoing restoration (USDA Forest Service Manual, Interim Directive 2001). Grassbanks can be useful during drought conditions to alleviate the stress on rangelands that do not have the capacity for higher grazing intensity due to climatic conditions. See chapter 8, "Tools for Grassland Management," for further discussion of grazing management.

Adaptive Ecosystem Management

Forests in the Southwestern Region utilize adaptive management, including management of grassland ecosystems (Kaufmann and others 1994). Adaptive management acknowledges the complexity of ecosystems and the uncertainty involved in predicting ecosystem responses to management actions. It ensures that land managers incrementally assess whether goals are met and whether interim results are acceptable. This means that decisions affecting ecosystem sustainability are incrementally reevaluated as monitoring data are collected, summarized, and evaluated. Therefore, adaptive management establishes a pathway to alter the course of management action as new knowledge is acquired.

A grassbank has been established in Chihuahuan Desert grassland on the Diamond A Ranch (Eastern Division) in southwestern New Mexico. (Photo by Charles Curtin)

For example, improvements in grazing management can result in reduced erosion and soil compaction, promote increased infiltration of precipitation into the soil (Roberson 1996), and increase biodiversity. When monitoring data show that resource conditions are below thresholds for ecological factors, then grazing management can be altered immediately or prior to the next grazing season. Steps can be taken to prevent overutilization of forage, provide rest to disturbed areas, alter the season of use, and improve overall management of livestock. Restoration programs to increase soil and streambank stability or to revegetate denuded areas are also part of adaptive management. To be effective, plans for adaptive management could include specific actions in response to observed or measured conditions, a timeline, and specific thresholds that trigger the management actions (Roberson 1996).

Criteria and Indicators for Sustainable Grassland Ecosystems

Developing indicators and monitoring them over time can help to determine whether problems are emerging, whether any action is desirable or necessary, what action might yield the best results, and how successful past actions have been. To develop and implement sound environmental policies, data are needed that capture the essence of the dynamics of environmental systems and changes in their functioning. These kinds of data then need to be incorporated into indicators (National Research Council 2000).

A criterion is a category of conditions or processes that is an explicit goal of sustainable development or by which sustainable development can be assessed. A criterion is too general in scope to monitor directly but can be characterized by a set of indicators that can be monitored over time. An indicator is a variable that can be assessed in relation to a criterion. It should describe attributes of the criterion in as objective, verifiable, and unambiguous manner as practicable, and it should be capable of being estimated periodically in order to detect trends (Colorado State University 2001). Indicators are designed to inform us quickly and easily about something of interest. They communicate information about conditions and, over time, about changes and trends. Like economic indicators, environmental indicators are needed

because it is not possible to measure everything (National Research Council 2000). For example, a criterion on the conservation of biological diversity includes indicators related to ecosystem diversity, species diversity, and genetic diversity (Colorado State University 2001).

National Indicators of Sustainability

One effort for identifying criteria and indicators (C&I) for the sustainable management of temperate and boreal forests at a national scale, the Montreal Process, has become widely recognized. Moreover, the concept of using C&I as factors for evaluating all facets of sustainability, including resource supplies, is receiving increasing acceptance (Corson 1996, Mitchell 2000). In 1995, the United States agreed to use the Montreal Process Criteria and Indicators to measure national progress in achieving the goals of sustainable forest management. This in turn generated the need for sustainability C&I for grass and shrubland ecosystems, as well as for energy and minerals (USDA Forest Service Inventory and Monitoring Institute 2001). There is a need for consistent, national baseline information to provide a common language and standards for assessment and planning that will lead to proper and effective decisionmaking. A comprehensive set of criteria and indicators should provide this tool (Colorado State University 2001).

The Montreal Process lists seven criteria and 67 indicators for the conservation and sustainable management of temperate and boreal forests. The C&I encompass a set of interrelated ecological, economic, social, and institutional factors. The seven criteria are:

- Conservation of biological diversity.
- Maintenance of productive capacity of forest ecosystems.
- Maintenance of forest ecosystem health and vitality.
- Conservation and maintenance of soil and water resources.
- Maintenance of forest contribution to global carbon cycles.
- Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies.
- Legal, institutional, and economic framework for forest conservation and sustainable management.

The first five of the seven criteria, along with 28 indicators, have been used to assess the applicability of Montreal Process biological and abiotic indicators to rangeland sustainability at a national scale (Mitchell and Joyce 2000). See *The International Journal of Sustainable Development and World Ecology*, volume 7 (2), June 2000, for a detailed analysis of the challenge and promise of developing C&I for rangelands, and for implementation at the national scale. So far 16 indicators have tentatively been identified for rangelands, including indicators for landscape diversity, community diversity, and population diversity. Genetic diversity has been particularly difficult to define due to a lack of baseline data. Some of the indicators lack standardized protocols. More work needs to be done on refining definitions, designing monitoring systems, and testing critical assumptions.

Other efforts to develop national sustainability indicators for rangelands include the formation of the Sustainable Rangelands Roundtable, which is sponsored by Colorado State University, the USDA Forest Service, USDI Bureau of Land Management, and USDA Agricultural Research Service. The roundtable includes representatives from nongovernmental organizations, public and private land management professionals, rangeland scientists, and university professionals (Colorado State University 2001). The roundtable will identify indicators of sustainability based on social, economic, and ecological factors, in the effort to provide a framework for national assessments of rangelands and rangeland use. For more information, access http://sustainablerangelands.cnr.colostate.edu/Roundtable_description.htm.

Local Indicators of Sustainability

Criteria and indicators for sustainability are being developed for specific scales. The intended scale for the Montreal Process was for all forests of a country, regardless of land ownership. The Local Unit Criteria and Indicator Development Project (LUCID) was initiated by the Inventory and Monitoring Institute to test criteria and indicators of sustainability at local levels. LUCID targets a local scale, such as the Tongass National Forest in Alaska or the Blue Mountain Province National Forests in Oregon. The local criteria and indicators should be revised periodically to incorporate new research results, technological advances, and new methods of measurement.

LUCID sites include forest, rangeland, and shrubland ecosystems. This process was developed to identify conditions that are needed to sustain ecological, economic, and social systems, and to determine the criteria and indicators for assessing how resource management influences sustainability. The Blue Mountains LUCID pilot test addressed C&I with verifiers (measurement protocols) and standards for shrublands and grasslands. The three Blue Mountains forests located in Oregon and Washington use the same ecological definitions, and the C&I are intended to apply to the entire province. Although it is too soon to

draw conclusions from C&I testing at Blue Mountains, future reports will address water quality, forest health, and community growth.

Here is an example of a local grassland criteria and indicator that is based on the LUCID criteria and indicators for maintenance of ecosystem integrity. The degree of fragmentation is an indicator of landscape structure (USDA Forest Service Inventory and Monitoring Institute 2001). Accelerated habitat fragmentation can be a detriment to species viability and adversely affect ecological patterns and processes such as disturbance (Forman 1995). One measure of fragmentation is the ratio of edge to interior habitat, with higher ratios indicating increasing fragmentation. Corresponding landscape metrics based on the LUCID criteria and indicators are shown in figure 7-1.

Maintenance of Ecosystem Integrity

Criteria:	landscape structure
Indicator:	fragmentation and connectedness
Verifier:	ratio of edge to interior habitat area

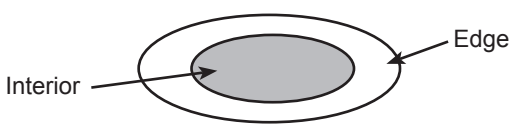

Figure 7-1. Criteria, indicator, and verifier for fragmentation: a sample metric for monitoring sustainability at landscape scale that is based on the LUCID criteria and indicators for maintenance of ecosystem integrity (USDA Forest Service Inventory and Monitoring Institute 2001). An edge is the boundary between habitats that protects the core. Higher ratios of edge to interior habitat area indicate increasing landscape fragmentation (Forman 1995, Prendergast 2000). Note that verifiers should have specific target values.

Monitoring for Sustainability in Grasslands

Monitoring is a step-wise process that involves: framing a question(s) and developing a study plan to address the question(s) using a standard protocol; collecting data according to the monitoring plan; storing the data for retrieval, and evaluating the results. Monitoring should include goals, thresholds for change, and remedial actions that occur when thresholds are met or exceeded. An ecological systems approach to monitoring ensures a strong foundation in ecological theory, adequate consideration and understanding of cause-and-effect relationships, and a systematic approach to select and evaluate parameters that are monitored (Sieg 1999). Furthermore, the questions should focus on key ecological processes and interactions, rather than individual parts of the system.

Conversely, *inventory* involves gathering data that are needed to analyze and evaluate the status or condition of resources (Powell 2000). Examples include the Forest Service programs entitled Terrestrial Ecological Unit Inventory (TEUI), Biological Forest Resource Inventory, Rangeland Resource Inventory, Wildlife Habitat Inventory, Threatened and Endangered Species Habitat Inventory, and the Human Dimension Heritage Inventory. Corporate strategies, goals and approaches for integrated natural resource inventories were developed for national (strategic), forest (tactical), and project (operational) scales (USDA Forest Service 1999).

The Forest Service recognizes three types of monitoring related to Land Management Planning: implementation, effectiveness, and validation monitoring. *Implementation monitoring* tracks compliance with Forest Plan standards and guidelines and helps determine whether planned management activities were completed. *Effectiveness monitoring* helps determine whether desired outcomes were achieved by management actions. *Validation monitoring* tests the assumptions and models of Forest Plan implementation. In addition, monitoring associated with applied research can supply critical information for decisionmaking. The scope of *ecological monitoring* needs to include programmatic monitoring that tracks and evaluates trends of ecological, social, or economic outcomes (Powell 2000).

Despite the development of protocols and indicators for sustainability, the criteria of sustainable grasslands are not easily measured. Some helpful references for grassland monitoring include Elzinga and others (1998), Gibbs and others (1998), and Munn (1988). Examples of existing grassland monitoring programs can be found in Wondzell and Ludwig (1995). A successful monitoring program for grasslands could include the following considerations.

- A description of each step of the monitoring system and the quality assurance/quality control protocol (Bormann and others1994, Everett and others 1994, Moir and Block 2001).
- The statistical parameters to be measured.
- Trend detection.
- A funding commitment from management, including maintenance of field equipment or repeated remote-sensing applications.
- Early determination of who monitors and a commitment of adequate human resources to accomplish the tasks over time.
- Public stakeholders' involvement in the monitoring program (Cortner and Moore 1999).

Monitoring for grassland sustainability should address current practices for managing grazing animals and grazing herds, especially conservative stocking rates. A summary of grazing systems is beyond the scope of this chapter. However, an analysis of the importance of grazing intensity versus grazing system is provided by Holechek and others (1999).

Forest Monitoring Reports

According to Land and Resource Management Plan monitoring reports for U.S. Federal government fiscal years 1998 and 1999, most National Forest monitoring in the Southwestern Region was implementation monitoring—that is, 65 percent. (Data are only available through the USDA Forest Service Intranet site.) About 32 percent of the reported monitoring was evaluation monitoring, and the remaining 3 percent was validation monitoring. The information is not detailed enough to know whether grassland monitoring followed this general trend.

Study Design

Successful monitoring programs should have the following characteristics (Powell 2000, 2001):

- Be purposeful and conducted to answer specific questions.
- Be done at the appropriate spatial and temporal scale to answer the question.
- Be done in collaboration with others (for example, agencies, interested publics, researchers, and nongovernmental organizations). Collaboration results in sharing the workload (including obtaining data from other sources), gaining expertise, and building credibility and trust.
- Use the best available science and established protocols to collect and evaluate the data.
- Use modern information management techniques and tools.
- Apply stringent selection criteria so that a monitoring activity is only conducted if it is feasible, realistic, and affordable.
- Emphasize evaluation as much as the collection of the data.

The established protocol identified in a monitoring plan should include standard sampling and analytical methods that determine the precision and accuracy of measurements. These are the procedures for quality assurance and quality control. Accuracy refers to the degree of agreement between a calculated or measured quantity and the true value of the parameter. Precision refers to the degree of agreement between replicate measurements of the same parameter, and includes the concepts of duplicability, repeatability, and reproducibility. For example, in the USDA Forest Service Global Change Research Program, quality management establishes programwide policies and procedures that ensure adequate documentation and data quality for all field, analytical, and modeling activities. Quality assurance implements these policies by establishing and monitoring quality control (QC) procedures including the identification of variability and followup control recommendations to improve the accuracy and precision of measurements. QC procedures are implemented by scientists within each project and are designed to produce a sustained reduction of error and document systematic error within statistically defined limits (USDA Forest Service Global Change Research Program 2001).

Proper training and supervision of field and laboratory staff is necessary to ensure adherence to the protocol and the success of the monitoring program.

Scale

The temporal and spatial scales chosen depend on the question or problem that monitoring will address. Spatial scales for assessing sustainability can be viewed, for example, as ecological units (Bailey 1995); a nested watershed hierarchy; or other appropriate units such as community, ecosystem, and landscape scales. Temporal scales can range from the time it takes bacteria to reproduce or molecular processes to occur through evolutionary and geological time scales.

It is necessary to conduct ecological studies at the appropriate temporal and spatial scales because changes occur at many scales at the same time, and different processes are likely to be important at different scales. Depending on the scale chosen, two species can appear to be highly interrelated or completely independent. For example, Levin (1992), when considering the reasons for shrimp distribution in the ocean, found that krill distribution at small spatial scale was a function of the behavior of individuals. However, at large scale, krill distribution was a function of oceanographic processes. Thus, the conclusions about the factors that affect the distribution of these organisms varied according to the scale where measurements were made.

Processes and functions that are appropriate to monitor at watershed scale include succession, biogeochemical cycles, energy transfer through the food web, disturbance, and competition.

Because studies at fine spatial resolution have greater detail, the study results can detect heterogeneity and other ecological patterns. However, those same study results also have a low potential for

Table 7-1. Criteria and indicator linkage between Montreal Process and Local Unit Criteria and Indicator Development (LUCID). Reproduced from LUCID homepage, http://www.fs.fed.us/institute/lucid/.

MONTREAL PROCESS CRITERIA (1-7)
LUCID Indicators

1. CONSERVATION OF BIOLOGICAL DIVERSITY
I.2.2.1 Vegetation types and structural classes
I.2.4.5 Ecologically sensitive areas, e.g., riparian areas are retained
I.2.5.1 Populations of indigenous species
I.2.6.1 Exotic species
I.2.6.2 Community guild structure
I.2.6.3 Species at risk
I.2.7.1 Gene frequencies change

2. MAINTENANCE OF PRODUCTIVE CAPACITY OF FOREST ECOSYSTEMS
I.2.2.3 Fragmentation and connectedness
I.2.2.2 Linear features
I.2.3.2 Primary productivity
I.3.1.2 Land base available for production

3. MAINTENANCE OF FOREST ECOSYSTEM HEALTH AND VITALITY
I.2.1.2 Disturbance processes

4.CONSERVATION AND MAINTENANCE OF SOIL AND WATER RESOURCES
I.2.1.1 Hydrologic condition
I.2.4.1 Pollutants
I.2.4.2 Soil quality e.g., soil compaction, displacement, erosion, puddling, loss of organic material
I.2.4.3 Soil nutrients
I.2.2.5 Water quality e.g., dissolved oxygen, suspended sediments and water nutrients
I.2.4.6 Morphology and function of stream channels

5. MAINTENANCE OF FOREST CONTRIBUTION TO GLOBAL CARBON CYCLES
I.2.3.1 Nutrient cycling
I.2.4.4 Ecological legacies and structural elements

6. MAINTENANCE AND ENHANCEMENT OF LONG-TERM MULTIPLE SOCIO-ECONOMIC BENEFITS TO MEET THE NEEDS OF SOCIETIES
1.1.1 Wilderness
1.1.2 Aboriginal and non-Aboriginal cultural, spiritual, social sites/values
1.2.1 Scenery
1.3.1 Recreational, tourism and education opportunities (by activity)
1.4.1 Access to forest resources
1.6.1 Worker health and safety
1.6.2 Public health and safety
1.7.1 Subsistence and non-subsistence gathering
I.3.1.1 Community economic trade balance (imports and exports)
I.3.2.1 Annual and periodic removals of products (timber and non-timber)
I.3.2.3 Money spent by visitors in local communities (by activity)
I.3.2.4 Value to products including value-added through downstream processing
I.3.2.5 Resource production component of economy
I.3.2.6 Income from National Forest activities
I.3.2.7 Employment of local population in resource management
I.3.3.1 Rent capture
I.3.3.3 Community economic diversity

7. LEGAL, INSTITUTIONAL AND ECONOMIC FRAMEWORK FOR FOREST CONSERVATION AND SUSTAINABLE MANAGEMENT
1.4.2 Ownership and use rights
1.5.1 Participation/involvement in decision-making
I.3.3.2 Mechanisms for economic benefits sharing

making generalizations. Studies at broad scale show the dynamics of a system, detect slower rates of process or system change, and have a high potential to derive generalizations. Studies at multiple or nested scales can be used to aggregate and extrapolate fine-scale results to larger scales. Examples of how to identify questions at the appropriate scale are provided by Powell (2001).

Criteria and Indicators for Monitoring

For each question that is raised, criteria and indicators to answer that question should be identified and monitored. Because an essential goal of ecosystem management is ecosystem sustainability (Funston 1995, Rauscher 1999), questions associated with ecological monitoring might address whether ecosystem conditions, or management activities affecting ecosystem conditions, are sustainable. The international Montreal Process was developed to identify criteria and indicators for forest sustainability at a national scale. Subsequently, the applicability of the criteria and indicators from the Montreal Process to grasslands has been assessed (Flather and Sieg 2000, Joyce 2000, Joyce and others 2000, McArthur and others 2000, Neary and others 2000). The Local Unit Criteria and Indicator Development (LUCID) Project addressed sustainability at a forest management scale. Monitoring for these criteria and indicators will help determine whether ecological conditions are sustainable (table 7-1).

Tools

There is no standard "tool kit" for ecological monitoring in grasslands. The scientific methods and processes used to answer ecological questions are the monitoring tools. The methods and processes chosen will depend on the question(s), the ecological indicators that are selected, temporal and spatial scales of concern, degree of detail, precision and accuracy that is required, and financial budget. Therefore, the concept of monitoring tools is a broad one that can include:

- Methods for framing your questions and multiple working hypotheses.
- Instrumentation for quantitative or qualitative measurements.
- Analytical tools to detect patterns and change across time and space (such as GIS, remote sensing, fractal analysis).
- Other methods for data analysis such as statistics, conceptual and mathematical models, fuzzy logic.
- Decision-support systems or other expert systems.

Vegetation sampling methods for rangelands are discussed by Stohlgren and others (1998). Other grassland monitoring methods are discussed in Jacobsen and others (1998).

Evaluating and Interpreting Results

Much of the Forest Service monitoring data are being stored in a corporate database, the Natural Resource Information System. These data require scientific evaluation considering current scientific knowledge and research results. One step in evaluating monitoring data includes a comparison to critical values for "keystone" indicators of change. When critical values are approached or exceeded, then further actions are likely warranted to ensure sustainability. For example, the Air Resource Management Program has identified wilderness values that can be affected by air pollution, and their associated sensitive receptors and concern thresholds. These indicators and thresholds reflect pollution transport and interactions between the atmosphere, geosphere, and biosphere, and these are contained in the Natural Resource Information System, NRIS-Air module. They provide management guidelines for protecting Air Quality Related Values in Class I Wilderness Areas.

Evaluation also includes summarizing data in statistical and graphical formats and identifying changes or trends. A variety of methods exist for detecting ecosystem changes and trends including statistical methods (analysis of variance, cluster analysis, and so forth), comparisons of current conditions with past reconstructions (dendrochronology, paleolimnology, pack-rat middens, and so forth), modeling, and spatial analysis using GIS, satellite imagery, and remote sensing. A common approach for trend detection is analyzing data from repeat sampling over time, including data from long-term monitoring networks. In some cases, a qualitative assessment and professional judgment may be adequate evaluation tools.

Condition Classes

One way to assess and categorize monitoring data is according to condition classes. A good example is the Soil Condition Rating Guide to determine whether soil quality objectives are met (table 7-2). The guide incorporates multiple indicators for three soil ecosystem functions—hydrologic function, stability, and nutrient cycling—into ratings of either satisfactory, impaired, or unsatisfactory.

Other monitoring systems that use multiple indicators and classification include Thalweg-Watershed

Table 7-2. Soil Condition Rating Criteria. Reproduced from FSH 2509.19, Soil Management Handbook, R3 supplement 2509.18-99-1, effective 10/20/1999. Also see Doran and others (1994).

SOIL CONDITION RATING GUIDE

Function	Indicator	CONDITION CATEGORY		
		Satisfactory	Impaired	Unsatisfactory
HYDROLOGIC	Surface Structure [1]	Moderate/strong granular or single grained.	Sub-angular blocky or weak granular.	Massive or platy.
	Surface Pore Space [1]	Many/common tubular pores, high vertical continuity.	Common/few tubular pores.	Few tubular pores, low vertical continuity.
	Rupture Resistance [1]	Loose to slightly hard (dry) Loose to friable (moist).	----	Very hard to very rigid (dry), Extr. firm to very rigid (moist).
	Near Surface Subzones [1]	No surface crusting or subsurface compaction.	Water compacted or non-biotic surface crust present.	Mechanically compacted.
	Bulk Density	Bulk density not increased.	Moderate bulk density increases (5-15%). (>15%).	Significant increase in bulk density
	Infiltration	No decrease in infiltration.	Moderate decrease in infiltration. (10-50%).(>50%).	Significant decrease in infiltration
	Penetration Resistance	No increase in resistance.	Moderate increase in resistance (10-50%).(>50%).	Significant increase in resistance
STABILITY	Modeled Soil Loss	Current soil loss ≤ tolerance.	Current soil loss > tolerance.	
	Visible Sheet Rill & Gully Erosion	Sheets/rills/gullies not evident.	Rills/gullies are small, discontinuous, poorly defined & not connected into any pattern.	Rills/gullies actively expanding, well-defined, continuous & connected into a definite pattern.
	Pedestaling	No/slight pedestaling of plant, litter and rocks. No evidence of exposed roots.	Grasses, forbs and rock fragments are pedestaled. Small, fibrous root strands of forbs & grasses are exposed on the soil surface.	Trees and shrubs are pedestaled and may be hummocked. Shallow, lateral roots of trees and shrubs are exposed.
	Erosion Pavement [2]	None to slight. If erosion pavement exists it is discontinuous or localized.	Erosion pavement is continuous or exists in interspaces between canopy cover of trees & shrubs.	
	Soil Deposition	Not unusual or excessive.	Soil and/or litter deposition is present. Fine litter may be patterned as small debris accumulations.	Soil and/or litter is deposited on the uphill side of logs, brushpiles, etc. Soil may be moving offsite.
	Surface (“A”) Horizon	“A” horizon is present, well distributed, not fragmented.	“A” horizon is present, but not evenly distributed. Changes in physical properties exist.	“A” horizon is absent or present in association with prominent plants. Properties are similar to those of the underlying subsoil.
NUTRIENT CYCLING	Vegetative Community Composition	Distribution of desirable, perennial plants reflects species by vegetative layer (i.e. trees, shrubs, forbs and graminoids) as identified in the potential plant community.	Changes in vegetation composition indicate a shift towards a drier, less productive plant community. There may also be an increase in annual plants, shallow-rooted grasses, taprooted woody perennials or invasive plants.	The perennial forb and/or graminoid vegetative layers are absent or sparse.
	Litter	Litter is distributed evenly across the soil surface and is associated with all vegetative layers	-----	Litter is either absent or is associated only with prominent plants and not evenly distributed across the soil surface.
	Coarse Woody Material	Pipos/Quga-----5-10 t/ac. Pipos/Fear2-----7-14 t/ac. Abco/Fear2-----8-16 t/ac.	-----	Pipos/Quga-----<5 t/ac. Pipos/Fear2-----<7 t/ac. Abco/Fear2-----<8 t/ac.
	Root Distribution[1]	Many/common roots in surface horizons.	Moderately few roots in surface horizons.	Few/very few roots in surface horizons.

1/ Categories and/or descriptions defined in USDA Handbook No. 18, Soil Survey Manual, October, 1993.
2/ Certain soils within desert ecosystems inherently contain erosion pavement (desert pavement) surfaces. Desert pavements are not used to indicate soil condition.

Link (T-Walk) and Proper Functioning Condition (PFC) for riparian areas. T-Walk classifies stream conditions as either robust, adequate, diminished, impaired, precarious, or catastrophic (Ohlander 1998). PFC protocol uses the categories Proper Functioning Condition, Functional - At Risk, and Nonfunctional to describe riparian conditions (USDI Bureau of Land Management 1993). Further examples of rangeland classification are provided by the National Academy of Sciences (National Research Council 1994).

BLM has also recently developed procedures for rangeland health assessment (Pellant and others 2000). These are based on three attributes of rangeland health: soil/site stability, hydrologic function, and integrity of the biotic community. The procedures use 17 indicators that focus on vegetation or soil stability to assess the function of the three attributes of rangeland health. The indicators are:

- Rills
- Water flow patterns
- Pedestals and/or terracettes
- Bare ground
- Gullies
- Wind-scoured, blowouts, and/or deposition areas
- Litter movement
- Surface soil resistance to erosion
- Soil surface loss or degradation
- Plant community composition and distribution relative to infiltration and runoff
- Compaction layer
- Functional/structural groups
- Plant mortality/decadence
- Litter amount
- Annual production
- Invasive plants
- Reproductive capability of perennial plants

There are also additional optional indicators.

Attributes are rated qualitatively according to condition classes that compare current conditions to departure from reference areas or ecological site description. Condition classes include extreme departure, moderate to extreme, slight to moderate, and none to slight.

Modeling

State-of-the-art modeling tools can be used to examine changes in grassland processes. For example, the Century Model simulates the dynamics of carbon, nitrogen, phosphorus, and sulfur over time. It can be used as a tool for ecosystem analysis, to evaluate the effects of management changes, and to analyze changes in the biogeochemistry of grasslands (Parton and others 1996). The model is based on net primary productivity as a function of water availability, nitrogen availability, and temperature; and soil carbon and nitrogen pools that are active, slow, or passive in their turnover times. Century includes a grassland/crop submodel that is linked to a soil organic submodel simulating the flow of nutrients through plant litter and soil. The model has recently been used to assess the response of temperate and tropical grasslands to climate change (Pace and Groffman 1998).

HilleRisLambers and others (2001) used mathematical modeling to interpret vegetation patterns (patches of vegetation and bare soil) in semiarid grazing systems. They noted that there is a prevalent, positive relationship between plant density and water infiltration that results in formation of vegetation patterns in semiarid areas throughout the world. Modeling results showed that other factors such as herbivory (grazing) are not as important in generating the patterns. Where plant dispersal is low, increased herbivory is predicted to lead to a transition from closed vegetation cover to spatial patterns in vegetation to bare soil. This same transition is not likely to occur, however, where plant dispersal is high. The model also predicts that vegetation changes are reversible if grazing is reduced.

Summary

Grasslands in the Southwest have a semiarid to arid climate and a patchy distribution of precipitation. However, land managers often plan for average climate conditions and distribution, rather than the extremes that can be expected. For management purposes, the frequency, severity and distribution of drought are more important than long-term average climate conditions.

The USDA Forest Service continues to address various management concerns in grasslands including streambank erosion, sedimentation and erosion rates, restoring riparian vegetation, providing improved habitat for native species, and the cumulative impact of wildlife and livestock grazing. It is important to determine whether management activities impact ecosystem integrity and sustainability. Ecological sustainability can be defined as “the maintenance or restoration of the composition, structure, and processes of ecosystems over time and space.” One way to measure sustainability is using criteria and indicators of sustainability at local levels; an example is the Forest Service’s LUCID program, which was designed to test appropriate monitoring parameters at the local level. While there is no standard “tool kit” for assessing ecological sustainability, a variety of useful tools are available, including the Forest Service’s Soil Condition Rating Guide and modeling tools such as the Century model.

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